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# THE BEKENU NIAH - SUAI AREA SARAWAK, MALAYSIA.

THE ANALYSIS OF THE ENVIRONMENT,  
A DETAILED APPRAISAL OF THE SOILS  
AND THE TECHNIQUE OF SOIL MAPPING,  
AND AN ASSESMENT OF THE  
AGRICULTURAL POTENTIAL.

By  
J. R. D. WALL

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SOIL SURVEYOR  
GOVERNMENT OF SARAWAK  
APRIL, 1966.

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J.R.D. WALL

SOIL SURVEYOR, GOVERNMENT OF SARAWAK.

APRIL, 1966.

(i)

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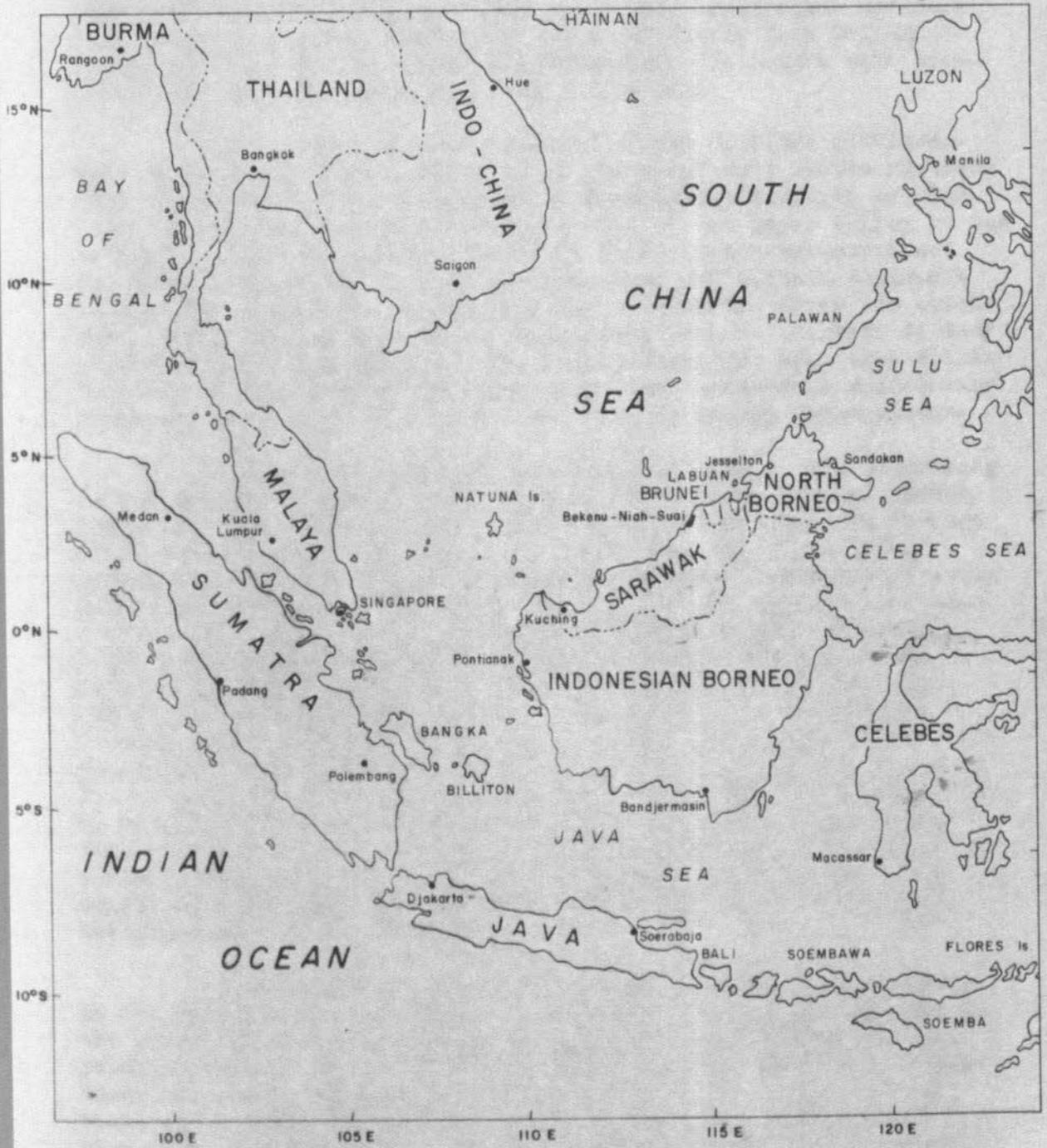
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PART ONE

INTRODUCTION - PHYSICAL AND ECONOMIC

GEOGRAPHY OF SARAWAK.

Figure 1. The position of the Bekenu-Niah-Suai area within Sarawak, and the setting of Sarawak within South-East Asia.



Sarawak forms a crescent-shaped portion of the northern part of the island of Borneo. It lies between  $0^{\circ} 50' N$  and  $5^{\circ} N$ , and between  $109^{\circ} 25' E$  and  $115^{\circ} 45' E$ , and covers about 48,300 square miles. The area studied occupies 1,300 square miles on the north-western seaboard of the state (Fig. 1).

### PHYSICAL GEOGRAPHY

The climate of Sarawak is typically Equatorial Monsoonal and owes its characteristics to its proximity to the equator where seasonal variations are ill-defined. There is a weak temperature and rainfall pattern, however, consisting of a wet season from October to January and a slightly warmer and moderately wet season with occasional dry periods during the rest of the year.

Geologically Sarawak consists of two distinct provinces. West of the Lupar Valley (Fig. 2) is the relatively stable northern part of the Sunda Shield composed of Palaeozoic, Mesozoic and Tertiary igneous and sedimentary rocks; East of the Lupar Valley to the northern tip of the country spreads a broad, southwest-northeast trending arcuate belt of thick geosynclinal and deltaic sediments, ranging from Upper Cretaceous to recent. Finally, there are extensive, young coastal and inland sedimentary plains, overlain in many places by organic sediments. The Bekenu-Niah-Suai area lies within the belt of Middle Tertiary argillaceous and arenaceous sedimentary rocks and includes both coastal and riverine swampy flood-plains.

Sarawak's topography is strongly related to the underlying lithology and structure of its rocks. Thus batholiths and stocks, common in West Sarawak, have formed large isolated massifs through differential weathering, rising by 2,000 feet above low-lying peneplained areas underlain by sedimentary rocks. Similarly, young extrusive lavas and pyroclastic rocks in Central Sarawak form high plateaux at 3,000 feet and prominent mountain ranges at 6,000 - 7,000 feet respectively. The sedimentary rocks throughout the country weather to give distinctive land forms. The older, and generally more competent, sandstones and shales have weathered forming linear patterns of high ridges and narrow valleys following the strike of the country. These are especially well developed in the interior watershed areas. Younger sedimentary rocks appear to be generally less resistant to erosion; the shales in particular weather rapidly into systems of small, low hills and ridges, which resemble ripple patterns on air photographs. Some of the young sandstone beds, however, are thick and hard and weather to well-developed cuestas and plateaux.

Plio-Pleistocene fluctuations of sea level have resulted in the production of terraces and distinct low erosion surfaces on the hills behind the coastal swamps, particularly in the softer, younger sedimentary rocks of North Sarawak, such as in the Bekenu-Niah-Suai area. Weathering and dissection is so rapid, however, that even amongst the recently produced landforms the belts of shale have already been lowered substantially more than adjacent sandstones. Limestone throughout Sarawak produces highly distinctive karst morphology, typified by that at Subis in the Niah River basin.

Recent deposits are widespread and form extensive alluvial basins both along the coast and for considerable distances up the main rivers. In many places they are covered by peat to depths of at least thirty or forty feet. The growth of these has probably been stimulated by a recent slight rise in sea level which intensified already impeded drainage conditions. Thus, in coastal areas, such as between the Sibuti and Nyalau Rivers in the area studied, there has been widespread sediment accretion and infilling of lower river courses behind the offshore sand-bars that developed from sandstone headlands. Peat has subsequently accumulated on the wide estuarine flats between the main rivers.

Sarawak's vegetation is tropical evergreen and predominantly broad-leaved. There are marked contrasts in physiognomy and composition, however, which can be related to ecological habitats, and in particular to soil distribution. In the Bekenu-Niah-Suai area eight lowland forest communities are present. The hills are occupied by Lowland Dipterocarp Forest containing in places valuable stands of timber. Secondary forest of this area, as elsewhere in Sarawak, is due almost entirely to shifting hill rice cultivation.

The hot, wet, Equatorial Monsoonal climate throughout Sarawak results in a predominance of the podsolization process in almost all but the most poorly drained soils. The differences between the soils primarily reflect differences in lithology, mineralogy, and topography. The few areas of lateritic soils are found only on rocks rich in ferro-magnesian minerals; while podsoles are found only on parent materials consisting almost entirely of silica (as quartz) and with almost no iron or aluminium. Topography directly affects the distribution of Skeletal soils, which occur predominantly on steep hills, and is responsible for the poor drainage conditions in which Saline Gley, Gley and Peat soils develop. The precipitous slopes of the karst country underlain by massive and pure limestone support distinctive Calcic Organic soils.

With the exception of Lateritic and Groundwater Laterite soils all the Great Soil Groups recognised in Sarawak are present in the Bekenu-Niah-Suai area.

## POPULATION AND ECONOMY

### POPULATION

The national census of 1960 (Jones, 1962) revealed that Sarawak roughly the same area as England, had a population of only 745,000. The average rate of growth between 1947 and 1960 was 2.5%, since when improved health programmes are thought to have helped raised the rate to about 3% by 1965. The population density in the Bekenu-Niah-Suai area is about 17/square mile, the same as that for Sarawak as a whole. The population distribution is closely related to land productivity and accessibility.

The population of Sarawak consists essentially of Chinese (31%), Malays (17%) and native races (51%) with well-defined distributions and distinct economies. The Chinese are mainly engaged in commerce and in intensive cash crop cultivation near main settlements, such as at Bekenu and Niah. The Malays principally occupy lower river and coastal fishing villages, and the suburbs of large

Population and Economy

towns where many are employed by the Government: rice, coconut and rubber cultivation are important occupations of Malays in the more rural areas. The indigenous races are restricted to well-defined, largely inland parts of the country. They are strongly tied to a subsistence economy, based mainly on rice production and supported by cash crops, such as rubber, in some accessible areas.

ECONOMY

The gross domestic product per capita in 1961 was about £72. The current (1955-1961) rate of increase of an estimated 3.4% (Government of Sarawak, 1963) is barely sufficient to keep ahead of the rate of population increase and to maintain a slow rise in the standard of living. Unpublished Government Statistics indicate that the gross national product per capita in 1965 will probably exceed £80, and that the average gross national product per capita increase between 1961 and the end of 1965 is 4.0 percent. The country's economy relies heavily on the export of primary or processed primary forest and agricultural products, namely timber, rubber and pepper. This reliance on agriculture is likely to continue in the future since the once rich source of bauxite in West Sarawak is practically exhausted and oil production from the Miri field is decreasing, although results of recent offshore exploration nearby are promising. It is probable that coking coal, fireclay and cement will become useful items in the future economy of the country, but never to the extent of superseding in importance the agricultural products.

Agriculture together with forestry provides employment for four fifths of Sarawak's labour force, yields 45% of the gross domestic product (£53 million, 1961) and produces 85% of the exports by value. The obvious importance of agricultural products in the economy is reflected in the attention and money being spent on improving crop production and acreage, and particularly in the search for good agricultural land. Government subsidized rubber and coconut planting schemes were introduced in 1956 and 1959 respectively, prior to which agriculture was wholly unaided. Agriculture is almost entirely in the form of smallholdings, since commercial estate agriculture has not been encouraged to the extent it has in Malaya and Sabah. Forest exploitation has been handled by private enterprise, almost entirely with Chinese capital.

In recent years the Government has actively stimulated agricultural production by the introduction of planting schemes for rice, pepper and fruit, in addition to coconut and rubber, and subsidized livestock schemes. Advice, demonstration and help on production, processing, and marketing has similarly increased productivity and brought an awareness of what can be done with new methods and correct techniques.

The lack of communications has been a severe handicap to agricultural development (Fisher, p.675). Immediately after the Second World War there were less than 50 miles of all-weather, metalled roads in the country (excepting Kuching town roads) and probably less than 100 miles of rough jeep tracks.

Most cultivated land was alongside navigable rivers and streams. Land more than about 2 hours walk from a navigable stream was left under primary forest as, for example, in the area studied. The Development Plan for 1964-68 includes an approved road-building programme of some 280 miles of trunk and feeder roads (excluding urban and minor roads) which are intended first to link the most important urban and agricultural areas, and then to tap potentially good agricultural land, such as that in the Sibuti, Niah, and Suai river basins. It is the physical background, particularly the soils, of this potentially important part of the country that forms the main topic of this thesis.



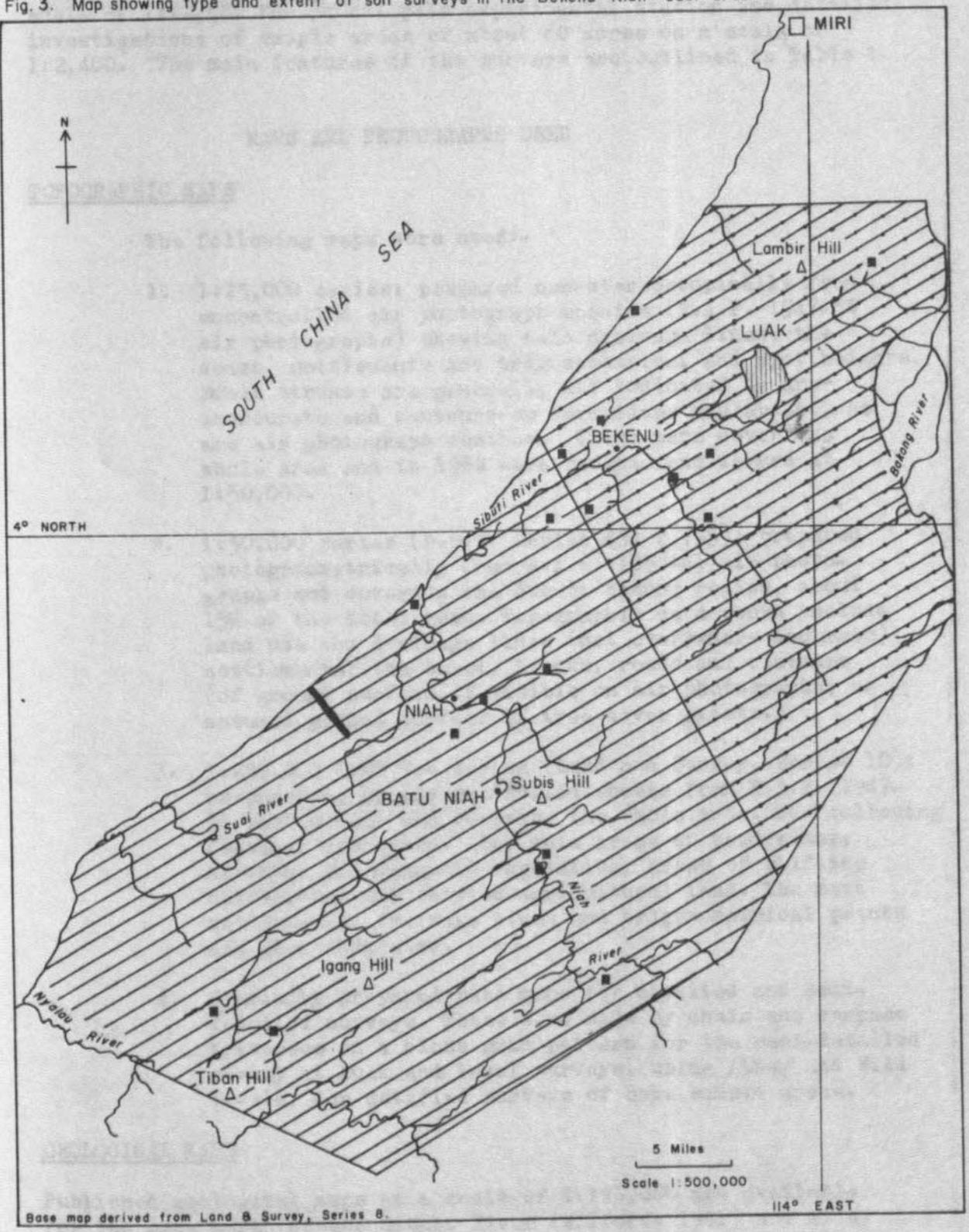
Table 1. Time taken, approximate cost, and work involved in different types of survey used in Bekenu-Niah-Suai area.

Type and name of survey	Area (sq. miles)	Working man days		Working man days - Lab.	Expenditure (nearest £10)		Miles cut per lines, paths followed	No. of soil samples
		field	Surveyor Staff		Salaries, Labour allowances	Field Exp. Travel		
1. AIR PHOTO RECONNAISSANCE Lambir-Bakong	484	-	-	2	2	10	-	.02
2. RECONNAISSANCE Bekenu-Niah-Suai	597	35	140	420	70	80	260	70
3. RECONNAISSANCE Coastal Reconnaissance	383	50	200	650	70	70	410	20
4. RECONNAISSANCE Batu Niah	46	10	40	120	25	15	80	40
5. SEMI-DETAILED Luak Experimental Station	2	21	68	248	22	30	200	60
6. DETAILED Sample Area (one)	60 acres	10	39	35	11	18	20	40
							20	2688
							4.0	66

\* Excludes depreciation on equipment, cost of air photographs (on loan from Lands and Surveys Department and cost of soil analyses (about £3 to £5 per sample for determinations requested.)

Surveys 2, 3 and 4 together cover the area described in this thesis.

Fig. 3. Map showing type and extent of soil surveys in the Bekenu-Niah-Suai area.



Base map derived from Land & Survey, Series 8.

-  Air photograph reconnaissance  
(1:250,000)
-  Reconnaissance  
(1:100,000)

-  Semi-detailed  
(1:12,500)
-  Detailed (shown schematically)  
(1:2,400)

### Maps and Photographs used

The types of surveys made in the area (fig. 3) have varied from a reconnaissance of the whole area at a scale of 1:100,000 and an air photograph reconnaissance of part of the area on a scale of 1:250,000 to a semi-detailed investigation of 1,400 acres on a scale of 1:12,500 for an oil palm experimental station and detailed investigations of sample areas of about 60 acres on a scale of 1:2,400. The main features of the surveys are outlined in Table 1.

### MAPS AND PHOTOGRAPHS USED

#### TOPOGRAPHIC MAPS

The following maps were used:-

1. 1:25,000 series: prepared non-stereoscopically from uncontrolled air photograph mosaics (R.A.F. 1947-54 air photographs) showing main drainage lines, the coast, settlements and trigonometrical and spot heights. Small streams are generally not indicated or are inaccurate and contours or form lines are absent, as are air photograph centres. These maps cover the whole area and in 1962 were reduced and issued at 1:50,000.
2. 1:50,000 series (D.O.S. Series 434 T 735); prepared photogrammetrically from R.A.F. 1958-61 air photographs and covering the Sibuti-Bakong region, about 15% of the total area. Topographic data shown include land use and drainage lines (not everywhere accurate) settlements, the coast, tracks, roads and contours (of ground surface if visible on air photographs, or assumed ground surface if tree cover exists.)
3. 1:250,000 Land Use series (Land and Survey, Series 10); prepared as partly controlled sheets from R.A.F. 1947-54 photography and covering the whole area. The following features are shown: the main areas of peat swamp, kerangas and mangrove vegetation, areas of shifting cultivation and settled agricultural land. The main settlements, drainage lines and trigonometrical points are also indicated.
4. Specially prepared base maps for detailed and semi-detailed surveys. These were made by chain and compass traverses on a close grid pattern for the semi-detailed survey at Luak and level surveys, using Abney and Wild levels, for detailed surveys of some sample areas.

#### GEOLOGICAL MAPS

Published geological maps at a scale of 1:125,000 are available for the area north of the Sibuti River (Wilford, 1961) and at a scale of 1:250,000 (Haile, 1962) for the area south of the Sibuti River. A compilation geological map at a scale of 1:500,000 covers the whole area (Liechti, 1960).

Maps and Photographs Used

AIR PHOTOGRAPHS

A complete coverage of vertical air photographs was available before 1963 at scale 1:20,000 - 1:30,000 (R.A.F. 1947-50), but the quality was highly variable. For survey work since 1963 generally better quality air photographs have been available for the whole area taken by the Lands and Surveys Department at 1:25,000 scale.

SOIL SURVEY METHODS

The methods used in the reconnaissance soil surveys are described first, followed by those used in the semi-detailed and detailed surveys.

RECONNAISSANCE METHODS

The aim of the reconnaissance survey was to provide rapidly general information on soil distribution and properties and this was achieved by:-

1. Initial air photograph analysis.
2. Field investigation to verify or amend the initial air photograph analysis and to collect samples.
3. Final air photograph analysis.
4. Preparation of soil map and report.

1. INITIAL AIR PHOTOGRAPH ANALYSIS

The initial air photograph analysis provided a general impression of the area, enabled the mapping of features known to be indicators of soil boundaries and allowed the selection of suitable lines of access, points of examination and sample areas for field-work. Features on air photographs known by experience to be good indicators of soil distribution in Sarawak are topography and vegetation (c.f. the closely similar method of land system surveys by C.S.I.R.O. Australia; Haantjens, p.13).

TOPOGRAPHY was found to be the most useful indicator of soils in the Bekenu-Niah-Suai area because properties of soil parent materials could be deduced by the presence of distinctive land forms. Important elements of topography analysed were slope, which by its shape, steepness and length points to the probable hardness and structure of the soil parent material and to the soil depth, texture and drainage. The amplitude of relief was found to be a guide to the rate and intensity of erosion and hence to the age, maturity and depth of the soil. Gullies and landslides indicated by their density, shape, size and position on the slope the probable soil stability, texture and possible need for soil conservation.

One of the main boundaries drawn during initial air photograph analysis was that separating flat land with alluvial or organic soils from hilly land with residual soils. This was straightforward except in areas where low relief was obscured by differences in vegetation heights, particularly under secondary forest of different ages. Small height differences in cleared alluvial land are indicative of important soil differences and these could be gauged on the photographs in places by tonal changes. Light-toned ground generally indicates higher land and hence well-drained soil compared to the darker-toned land of generally poorly drained lowlying parts.

Soil Survey Methods

The drainage patterns are controlled to a greater or lesser degree by rock structure and reflect erosional and sedimentation processes, both of which significantly affect the soil distribution. Thus the parallel stream pattern in flat land near the coast pointed to a sandbar-lagoon topography while rectangular or trellis systems in inland parts indicated alternations of hard and soft sedimentary rocks. The stream density per unit area indicated the degree of surface water run-off, a factor directly related to soil type. Ridge and spur analysis aided the detection of minor streams and rock structure, which in turn helped to complete the picture of stream and lithological patterns.

VEGETATION was a particularly important soil type indicator in areas of low relief and where drainage patterns are poorly defined or sparse. Small differences in soil drainage, nutrient availability and rooting depth are reflected by major changes in vegetation. Differences of as little as one or two feet in relief divided entirely different vegetation communities in many lowlying areas. Almost all forest communities reflected detectable changes in soil type; in many places it was possible to recognise individual tree types on the photographs that are known to be related to specific soil conditions. For example Casuarina equisetifolia only grows on recent, well-drained beach sand; Nipa fruticans and various mangrove (Rhizophora) species indicate saline clays; Oncosperma filamentosa prefers partly saline soils; Shorea albida grows on deep peat and a number of unidentified but distinctively crowned trees were used as indicators of different types of hill soil.

The analysis of cultivated land from air photographs was found to be useful since the crops grown reflect soil agricultural suitability to a great extent. Although it was found that rubber is grown on a great variety of soils in the Bekenu-Niah-Suai area, as elsewhere in the country, the gardens extending from hills onto flatter land had a dividing line of light tone against dark tone which was taken to be the boundary between poorly drained alluvium and better-drained hill soils. Rice fields, coconuts, fruit and pepper gardens are grown on certain ranges of soils and these crops could be identified on the better quality air photographs.

Generally, permanently cultivated land is the best land within easy reach of the nearest village, say less than one hour's travel by foot or river. Unused land within this distance can be inferred as being probably unsuitable for cultivation due to excessively steep slopes, bouldery land, infertile soil or to the presence of peat and mangrove swamps, since local farmers invariably choose the best soils for hill rice cultivation. Similarly, the most distant fields from centres of habitation are likely to be on the best soils in that neighbourhood.

Land used for shifting cultivation was difficult to analyse since the different heights of the regrowth commonly obscured a subdued topographic pattern and the regrowth gave little indication of soil agricultural suitability.

PHOTO-ASSOCIATIONS. Reconnaissance soil surveys elsewhere in Sarawak have shown that certain types of topography identified on air photographs consistently have associated morphologically similar vegetation communities. Subsequent field-work has also shown that soil and soil parent material patterns can be identified with these topography and vegetation patterns. The patterns are in effect ecological units in which microclimate, topography, lithology, vegetation and fauna are all complexly inter-related and, to a large degree, interdependent. Such units are commonly termed ecosystems (Ovington, p.105) and to a large extent these are the features mapped during initial air photograph analysis, and described in Part Three. It is invalid to term the patterns ecosystems, however, in the absence of verifying field data. Also, it is shown by fieldwork that although the boundaries drawn are almost all those of ecosystems, the units themselves range from the truly uniform ecosystem of the estuarine lands to complex mosaics or associations of ecosystems, such as in the dissected terrace landscape. In this study, therefore, the term photo-association is coined for the concept of a distinct topography-vegetation unit identified on air photographs. Land system mapping in Australia is effected also by interpreting whole photo patterns (Haantjens, p.15) rather than by mapping separate photo elements (Vink, p.22; Frost, p.347; Buringh, p.646).

Soil is an integral link in an ecosystem and thus the mapping of photo-associations is the mapping of specific groups of soil almost certainly related genetically through having evolved under the same environment. Readily recognisable photo-associations in which the type and range of soils can be expected to be fairly consistent comprise about three quarters of the Bekenu-Niah-Suai area, the remaining land consisting of indeterminate, intermediate or mixed types where it was assumed that the soils would be equally varied.

The ten photo-associations recognised in the area are described in tabular form in Part Three before the full descriptions of the soil-forming factors and the descriptions of the soils.

## 2. FIELD INVESTIGATIONS

Field examinations of soils were made along traverses aligned mainly across the grain of the photo-associations so as to examine as many potentially different areas of soils as possible in the shortest time. In settled areas paths and tracks were used, but in uninhabited areas access lines were cut on compass bearings from points recognised on air photographs and maps at a rate of between a half and two and a half miles per day depending on the nature of the forest and terrain. The soils were examined along about 260 miles of cut tracks and paths during the reconnaissance survey (Map 1), or about one mile of track per five square miles.

Each photo-association was examined in many places, particular attention being paid to those photo-association thought to be of agricultural value. Some watershed areas could not have been reached by less than about three days cutting. In such areas data was used from the same photo-association in more accessible areas using the extrapolation process.

Soil Survey Methods

Soils were examined with an Edelman auger which can recover cores from all but the most stony, sandy, and peaty soils. Where peat was deeper than the length of the auger (48 inches) a long sapling was cut, notched at one foot intervals, and pushed in to determine the depth. When withdrawn the material caught in the notches was identified to determine at what depth peat gave way to clay or other material. Auger examination sites were usually selected on a variety of different topographic positions along access lines ensuring that as complete a representation of soil types as possible was investigated. Descriptions at each site included information on soil depth, thickness of horizons, colour, texture and stoniness; information on topography, rock outcrops, signs of erosion, flooding and agricultural usage were also included as sketches or notes.

Soil pits were dug at several places representative of the main soil types. The profiles were described including both the basic data described for augerings and other details such as structure, rooting depth, clay movement, pore space, animal activity and drainage. The sites were also described in terms of topography (slope length, shape, steepness), vegetation (density of canopy, age, species, community) past and present land use, parent material and recent weather. More than 300 samples were collected from genetic horizons for subsequent laboratory analysis (Map 1).

Four trained Agricultural Assistants capable of leading a cutting party and describing the main soil features assisted the writer on the reconnaissance surveys.

Fieldwork for reconnaissance surveys in the area in 1961 and 1962 required about 16 weeks, the time being more or less equally divided among the river basins. A further two weeks were spent in the Bakong Valley in 1965 by two Agricultural Assistants.

### 3. FINAL AIR PHOTOGRAPH ANALYSIS

A final detailed examination of air photographs was made on returning from the field following the same principles as that of the first interpretation but using the field information to revise and draw more accurately the soil boundaries.

The field data showed:-

1. the type and range of soils in each photo-association;
2. the relationship between air photograph characteristics and soil patterns;
3. whether the same soils occur consistently in the same photo-association.

The field information thus enabled the accuracy and reliability of the initial photo-interpretation to be improved. Where the same soils occurred consistently in a photo-association that had a wide distribution the basis of that unit was considered sound for the purpose of reconnaissance soil mapping. The mapping units used in the final soil map were soil associations.

#### 4. PREPARATION OF SOIL MAP AND REPORT

The final air photograph analytical data at scale 1:25,000 was transferred to a prepared base map at scale 1:50,000 using a Stereosketch, a machine combining a stereoscope and map table that can be raised or lowered to alter scale. The map and the photographs (as stereo pairs) can be seen simultaneously. A photographic reduction was made of this map to scale 1:100,000 in order to reduce drawing errors.

The report contained in addition a land capability map at scale 1:100,000 showing the best areas for agricultural development and suggested routes for roads to tap these areas.

#### AIR PHOTOGRAPH RECONNAISSANCE METHODS

The area shown in Figure 3 as being completed by air photograph reconnaissance was effected before the main reconnaissance survey, solely by the methods of air photograph analysis described above with no fieldwork. This type of survey was used primarily to determine rapidly the broad agricultural potential of the Lambir-Sibuti-Bakong area. No actual information on soils could be given, but land unsuitable for agriculture due to high steep slopes, peat swamps and estuarine swamps and terraces was delimited accurately and a recommendation given that a reconnaissance survey be made of the Sibuti basin extending southwards.

#### SEMI-DETAILED METHODS

Steps used in the survey work were:-

1. Base map preparation
2. Fieldwork
3. Final map compilation.

#### 1. BASE MAP PREPARATION

For the semi-detailed survey on a scale of 1:12,500 at the proposed site of the Luak Experiment Station (Fig. 3) a 1:12,500 scale map was prepared from air photographs supplemented by chain and compass ground traverses. From air photographs the streams, rivers, tracks, vegetation boundaries and pronounced ridges were plotted. There was slight scale distortion due to lack of ground control.

#### 2. FIELDWORK

Soil auger observations were made at least every 500 feet along parallel cut lines spaced 500 feet apart, from which a provisional field soil map was compiled; soil boundaries were checked between cut lines. From soil pits dug in sites representative of the soil series, profile samples were collected for laboratory analysis. Surface soil samples of the main soil series were also collected for agronomy analysis, 8 - 10 samples being taken from a 1/10th acre site. From the Luak area 63 profile and 130 agronomy samples were collected, and the length of the cut lines totalled 29 miles.

### 3. FINAL MAP COMPILATION

After completion of soil analyses, which are used to confirm the soil series classification, the final soil map was prepared. Vegetation and topography maps were also compiled at the same scale as the soil maps for comparative purposes.

The information obtained from the semi-detailed survey was used, with reservations, as a detailed example of larger areas known to be similar from reconnaissance surveys.

#### DETAILED METHODS

Fourteen small sample areas (Fig. 3) were studied in detail, varying from a single hillside with a complex soil pattern to a large area of uniform alluvium, and varying in size from about one acre to a quarter mile. Information from these areas, selected to be typical of a particular photo-association, was extrapolated to similar land in the same photo-association.

Sketch maps were made in the field and boundaries of soil series and soil phases drawn from a close augering pattern: the distance between examined sites varied from a few feet to about 200 feet. Each area was examined in one day by two persons.

Similarly detailed studies were made of five large photo-association sample areas of about 60 acres (Fig. 3) in 1965, in which contoured base maps were prepared by level survey and in which soil, topography and vegetation maps were made at a scale of 1:2,400. Ground observations were made at 100 feet intervals on a parallel grid 200 feet apart. Each area was studied over a period of about one week. From these five areas 101 soil profile samples were taken for chemical analysis and thin section study.

The photo-associations recognized from the field work are interpreted in the following manner and are described in the following paragraphs.

PHOTO-ASSOCIATION (Type I)

This photo-association is a very common one and is found in the lower part of the river in the lower part of the valley.

The photo-association is a very common one and is found in the lower part of the river in the lower part of the valley. It is characterized by a very low level of water and a very high level of sediment.

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PHOTO-ASSOCIATION

The photo-association is a very common one and is found in the lower part of the river in the lower part of the valley.

PART THREE

PHOTO-ASSOCIATIONS.

The photo-association is a very common one and is found in the lower part of the river in the lower part of the valley.

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The photo-association is a very common one and is found in the lower part of the river in the lower part of the valley. It is characterized by a very low level of water and a very high level of sediment.

PHOTO-ASSOCIATION (Type II)

This photo-association is a very common one and is found in the lower part of the river in the lower part of the valley. It is characterized by a very low level of water and a very high level of sediment.

PHOTO-ASSOCIATION

The photo-association is a very common one and is found in the lower part of the river in the lower part of the valley.

The photo-associations recognised from air photograph interpretation in the reconnaissance surveys are described in tabulated form below and shown on Map 2.

## 1. BEACH PHOTO-ASSOCIATION (Plate 1)

Distribution: in a predominantly narrow coastal belt between Cape Bungai in the north and the Nyalau River in the south. Occupies less than 2% of the whole area.

Topography: long, linear, low undulations almost parallel to the present shore except near river mouths; shown by a pattern of light- and dark-toned strips in cleared land. Height differences could not be detected between the high beach lines and lower swales; the gentle tonal change indicates gentle slopes and no gullying is visible. High, light-toned lines are generally less than 100 feet wide; lower, dark-toned swales are in places 300-400 feet wide.

Drainage pattern: parallel, and particularly well developed between the Suai and Niah rivers. Streams rather than rivers predominate, their meander belts being confined sharply by old beach lines and their sources lying in the swamps immediately inland of this photo-association.

### Vegetation:

a) primary vegetation is confined to those parts more than two to three miles from main river mouths. The main species detected are Casuarina equisetifolia, known to colonize sandy beaches and here recognised by its tall, emergent pointed crowns. Low, dark-toned, even, feathery-crowned Nypa fruticans and Oncosperma filamentosa in some of the swales indicate saline, probably sandy clay soils (properly part of the Estuary Photo-association).

Their absence in other swales indicates freshwater conditions.

b) cleared land occurs close to main rivers where villages are sited. Coconut palms can be detected and the low, light-toned, even cover of grassland is distinctive. Much land is under scrubby, young to old secondary growth.

Boundaries: well-defined except in a few places bordering the Peat Photo-association.

Soil features deduced from air photograph analysis: the coastal distribution and topography indicate an alluvial (marine) origin, predominantly sandy texture and an internal drainage ranging from poorly to well- or excessively drained; the vegetation of swales is halophytic in places. Elsewhere in Sarawak such soils are known to be quartzose, weakly to strongly podsollic and nutrient deficient.

## 2. ESTUARY PHOTO-ASSOCIATION (Plate 1)

Distribution: confined to river mouths, inner meander bends of lower river courses and strips alongside a few of the larger lagoons penetrating the Beach Photo-association. Occupies less than 1% of the whole area.

Topography: flat.

Drainage pattern: meandering main river courses and anastomosing creeks.

Photo-association

Vegetation: primary and dominated by mangrove and Nypa fruticans.

The Nypa is gregarious and has a close, even, dark-toned, feathery canopy; mangrove formed lighter-toned clusters of emergent bushy crowns. Near the inner margins tall, grey, fine-crowned, feathery emergents of Oncosperma filamentosa are commonly visible also the emergent, large-crowned and dark-toned Heritiera globosa.

Boundaries: clear except in a few places such as in part of the lower Niah River where the transitional belt to freshwater conditions is wide.

Soil features deduced from air photograph analysis: The river mouth distribution and flat topography indicate an alluvial (estuarine) origin and poorly drained soils. The vegetation is known to favour brackish to saline edaphic conditions. Elsewhere in Sarawak these features occur with poorly drained clayey or sandy clay soils.

3. PEAT PHOTO-ASSOCIATION (Plates 2, 3 and 4)

Distribution: extensive in coastal areas between the lower reaches of the main rivers and in the area drained by the Bakong River in the northeast, small patches also occur in the upper Sibuti and Suai valleys. Occupies about 15% of the whole area.

Topography: flat or slightly domed (see drainage pattern).

Drainage pattern: the small swamps have no apparent surface drainage; the larger swamps are crossed by a few, large, dark-coloured streams with fairly straight courses and are drained at their margins by very small dark-coloured meandering streams whose weak radial pattern implies a slightly raised central area.

Vegetation: two vegetation types are developed on the peat ecosystem:

- a) Mixed Swamp Forest characterised by an irregular canopy with variable crown size and tone which is dominant on swamp margins.
- b) 'Alan' Forest characterised by gregarious 'alan bunga' (Shorea albida) with an even canopy of light-toned, large to fine, closely knit crowns. This forest occurs in swamp centres, mainly in the larger coastal swamp, and also in the upper Sibuti and in the Bakong valleys (Plate 3).

Boundaries: The boundaries are commonly indistinct, particularly where bordering the Flood-plain Photo-association.

Soil features deduced from air photograph analysis: The distribution in the lowlands and the flat or almost flat topography indicate poor soil drainage. The 'Alan' Forest and Mixed Swamp Forest are indicative of deep, acid peat elsewhere in Sarawak: the dark coloured stream water is generally associated with peaty soil.

4. FLOOD-PLAIN PHOTO-ASSOCIATION (Plates 2, 3, 4 and 5)

Distribution: widespread, mainly as long, winding belts adjacent to main rivers and in many small irregular, connected pockets among the hills. Occupies about 12% of the whole area.

Photo-associations

Topography: flat, with the exception of river levees which are recognisable in cleared land by their light tone. There is an abrupt break in slope against hills.

Drainage pattern: common small meandering streams originating from other photo-associations cross the flood-plains to join main rivers. This is particularly noticeable in land cleared for rice cultivation.

Vegetation: areas of primary forest remained in the remote upriver parts, where in places the varied crown size, height and tone contrast with forest on adjacent hill land; elsewhere it is difficult to distinguish between land that is flat and alluvial, and gently sloping low hills such as those in the upper Sawai, Mulis, and Lamaos valleys (Plate 5).

Most cultivated flat land is placed provisionally in this photo-association since it is usually impossible to differentiate on air photographs between rice and rubber cultivated on poorly drained alluvial soils of this photo-association and the same crops cultivated on the Peat Photo-association. Helpful indications however are that if peat swamp vegetation occurs nearby the crops are probably on peat, while if they lie close to a river and are bounded inland by Mixed Swamp Forest the crops are probably on alluvium. If streams are common and light-toned the land is also likely to be alluvial, as near Cape Bungai, or if streams are few and dark-toned the land is more likely to be peat swamp. Rice fields are uniformly light-toned and contained drain networks, such as near Sibuti, and it is inferred that land has been cultivated for rice where secondary growth exists in flat land. Rubber has a uniform, close knit canopy of mottled light and dark tones and occurs mainly around Sibuti.

Boundaries: less clear than most photo-associations in the area in low lying land but generally distinct among the hills.

Soil features deduced from air photograph analysis: from the distribution and topography the soil is inferred to be of an alluvial (riverine) origin with peat in places and largely poorly drained. From surveys of similar land elsewhere in Sarawak the textures are known to be variable.

5. TERRACE PHOTO-ASSOCIATION (Plate 6)

Distribution: a belt along the coastal margin of the hills, chiefly northeast of Cape Batu and between the Nyalau and Suai rivers. The terraces are less than a half square mile in area. Terraces occupy less than 1% of the whole area.

Topography: flat or, in a few places such as near Batu Niah, gently sloping. Near Cape Batu a faint, parallel, linear system of alternating dark and light tones resembling that in the Beach Photo-association probably indicates a gently undulating surface: this also could be interpreted as outcrops of bedrock where terrace materials have been stripped. Terrace heights as measured from the air photographs are less than 100 feet above sea level near Cape Batu, and elsewhere less than 50 feet above local base level.

Photo-associations

Terrace flanks are steep. The landward side of the terraces northeast of Cape Batu is formed by a continuous line of steep-sided hills, more or less following the junction of the Lam-bir and Miri Formation rocks. This feature is interpreted as an old shore-line, although it could also have been a fault line scarp, or a line of differential erosion between adjacent rock formations.

Drainage system: not visible on air photographs.

Vegetation: primary vegetation known as 'kerangas' is predominant. The canopy is uniform with fine, close-set, medium-toned crowns. Near Cape Batu the terraces are partly used for hill rice.

Boundaries: clearly defined by both vegetation and topography.

Soil features deduced from air photograph analysis: the coastal distribution and topography indicate an alluvial (marine) origin; the vegetation on similar terraces to the north was known to be indicative of humus podsoils developed in quartz sand.

6. DISSECTED TERRACE PHOTO-ASSOCIATION (Plates 6 and 7)

Distribution: patches north of the Nyalau River, in the upper Suai valley, close to Batu Niah and in a wide coastal belt northeast of Cape Batu. Occupies about 2% of the whole area.

Topography: landscapes consisting predominantly of terraces too small to be mapped as the Terrace Photo-association together with low hills having summits at the same height or lower than nearby terraces, that is with an amplitude of less than 100 feet, and more commonly less than 50 feet. Hill slopes are largely in the range of 15° - 30°; ridges are rare and alluvial areas in valleys are mostly too small to be included in the Flood-plain Photo-association.

Drainage pattern: moderately fine meandering systems with little apparent structural control.

Vegetation: primary forest is most common, generally 'kerangas' on the terraces remnants and Lowland Dipterocarp Forest on the hills. In places near the Nyalau River peat swamp vegetation fills narrow valleys among the hills too small to map separately in the Peat Photo-association. The land is cultivated patchily for hill rice in the more accessible places.

Boundaries: generally clear with the Flood-plain and Peat Photo-associations and with those consisting of high hills. The boundaries are partly arbitrary between this photo-association and the Terrace and Low Hill photo-associations.

Soil features deduced from air photograph analysis: the terraces can be expected to have soil features similar to those in the Terrace photo-association except that some in this unit probably have a riverine origin. The hill soils overlying arenaceous formations can be expected to be more sandy and podsolised than those on argillaceous rocks. The predominant rock types are known from geological maps.

7. LOW HILL PHOTO-ASSOCIATION (Plates 2, 4, 5 and 7)

Distribution: large areas coincident mainly with the distribution of argillaceous rocks (Map 3). Occupies about 50% of the whole area.

Photo-associations

Topography: under primary forest the canopy gives an impression of only slightly dissected relief, but where the vegetation is cleared, the land can be seen to be moderately to strongly dissected with numerous valleys. The amplitude of relief ranges from 100 to less than 20 feet, detectable only in cleared land. Slopes appear to range between 15° and 30° except in some belts, such as in the Sawai, Lamaos and Mulis valleys, where low hills with gentle slopes are dominant. Long ridges are less common than groups of small hills. Landslides are not apparent.

Drainage pattern: main elements are subangular, tending to a trellis pattern, and draining the low hills along the regional geological strike, southeast to northwest. Smaller streams where visible appear to reflect little structural control.

Vegetation: primary forest is widespread in watershed areas and consists mainly of Lowland Dipterocarp forest, characterised on air photographs by an uneven canopy with varied crown size, height and tone. Areas north of the Niah River contain many large, distinctive, light-toned, emergents of unknown identity, largely coincident with the distribution of calcareous rock formations. Narrow valleys on the coastal margin of this photo-association in places contain peat swamp vegetation of the Peat Photo-association.

Cleared land is used for a variety of crops including rubber, hill rice, pepper and vegetables. The last two crops can be identified mainly near Bekenu, Sibuti, Niah and Batu Niah (Plate 8); pepper occurs in small plots as a pattern of dense black dots, rubber is grown extensively near Sibuti. Hill rice and secondary growth resulting from hill rice cultivation, occurs in a wide belt in all main river and middle river valleys.

Boundaries: defined mainly by topography. They are arbitrary between the Dissected Terrace Photo-association and this unit.

Soil features deduced from air photograph analysis: the topography indicates soils of residual origin, and from their distribution where argillaceous rocks are dominant the soils are thought to be weakly podsolised and clayey, as they are known to be in adjacent areas. Some soils north of the Niah River are probably calcareous.

8. RIDGE PHOTO-ASSOCIATION (Plates 6, 9, 10-12)

Distribution: coincident mainly with arenaceous rock formations in well-defined belts and occupying about 20% of the area.

Topography: ridges with narrow summits, extending for as much as two to three miles in places, but mostly less than half a mile. The ridges occur in parallel groups, most rising to about 300 feet above sea level, except in the western Lambir Hills where some exceed 500 feet in height. The amplitude of relief is estimated to be 100 - 300 feet over most of the area, and as much as 400 feet in the western Lambir Hills. Most slopes range from 20° to 35°; some scarp slopes are cliffed where landslides have occurred. Valleys are long and narrow.

Drainage pattern: the main streams form an angular pattern, in places trellis-like, in others parallel, but all are clearly influenced by the prevailing regional strike, northeast-southwest. The upper Sibuti River tributaries tend to form an arcuate trellis pattern following the trend of the Belait Formation outcrops (Map 3).

Photo-associations

Vegetation: primary forest is dominant and consists of Lowland Dipterocarp forest with fewer large emergents and generally darker tones than that of the Low Hill Photo-association; the general impression being of a less luxurious growth. Cleared land is used almost exclusively for hill rice.

Boundaries: largely clear as determined by topography and to a lesser extent vegetation.

Soil features deduced from air photograph analysis: the topography indicates that the soils are of residual origin and the similar distribution to that of arenaceous rocks points to podsolised sandy soils, like those that are dominant in similar land north and south of this area.

9. CUESTA PHOTO-ASSOCIATION (Plates 9 and 11)

Distribution: limited to outcrops of parts of the Lambir, Belait and Nyalau formations in the Lambir Hills, the headwaters of the Sibuti, Niah and Bakong rivers, the Igang Hills and to patches between the Nyalau and Suai rivers. Altogether about 4% of the whole area.

Topography: principally cuestas, the highest of which rise to about 1,500 feet in the Lambir Hills and 700 feet in the Igang Hills. The general amplitude of relief in these higher hills exceeds about 300 feet: the dip slopes are moderately steep and the scarps are commonly cliffed and marked by landslides. Elsewhere the heights of the hills are estimated to be less than 400-500 feet and the amplitude 100-300 feet. The lower cuestas have long gentle dip-slopes with steep scarps; their width is generally greater than those of the steeper cuestas.

Drainage pattern: largely coarse and angular; only well developed in the higher land.

Vegetation: two distinct types can be differentiated; one on the scarps and the other on the dip slopes. Scarp slope forest resembles the Dipterocarp forest of the Ridge Photo-association while dip slope forest in all localities is closely similar to the 'kerangas' forest of the Terrace Photo-association. The land has nowhere been used for cultivation.

Boundaries: mainly clearly defined by topography and vegetation.

Soil features deduced from air photograph analysis: the topography, the same distribution as that of massive sandstone, and the specialised vegetation indicate impoverished, strongly podsolised sandy soil on dip slopes and shallow sandy soils on scarp slopes.

10. KARST PHOTO-ASSOCIATION (Plate 13)

Distribution: about seven square miles of country close to Batu Niah.

Topography: a compact group of cliffed hills rising 800 to 1,000 feet above surrounding alluvium. The hills are traversed by a three-directional pattern of long, deep, linear corridors; in the southeast these have developed at the expense of intervening limestone which is left as tall, pointed pinnacles.

Drainage pattern: none visible, although streams on surrounding alluvial land flow close to the foothills.

Photo-associations

Vegetation: two main types are visible; that on the lower foot-slopes and in corridors, and that clothing the summits. The former type has an irregular canopy with a wide variation in crown size and tone, while the latter is lower, thinner and more light-toned. Bare white rock protrudes through the summits in places and forms the marginal cliffs.

Boundary: clearly defined by topography.

Soil features deduced from air photograph analysis: This type of topography and vegetation coincides with the distribution of limestone rock. This combination elsewhere in Sarawak is known to indicate thin scattered organic soils and possible inorganic soils broken by much bare limestone rock.

PART FOUR

SOIL FORMING FACTORS

PART FOUR

SOIL FORMING FACTORS.



Figure 5. Mean monthly temperatures at Miri and Bintulu, 1951-1963

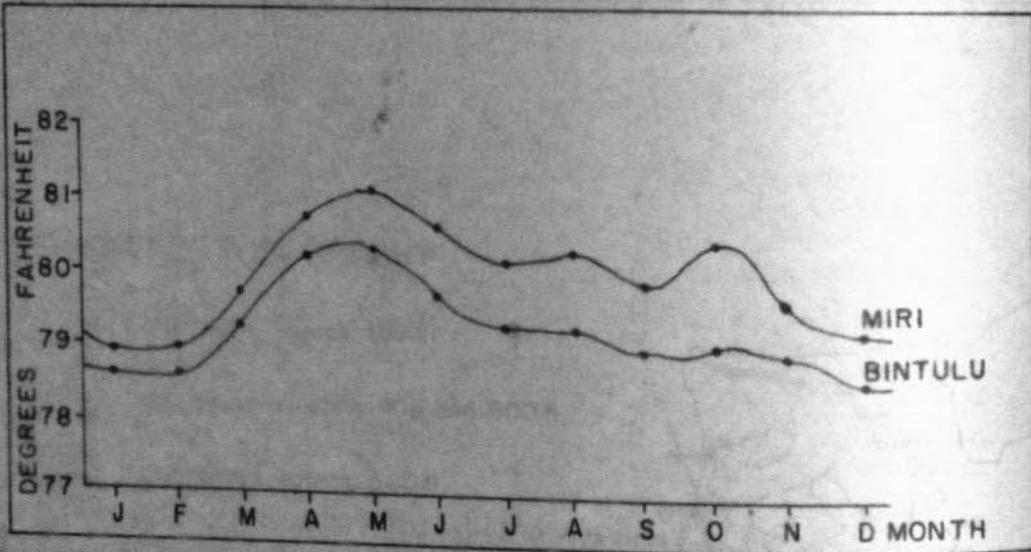
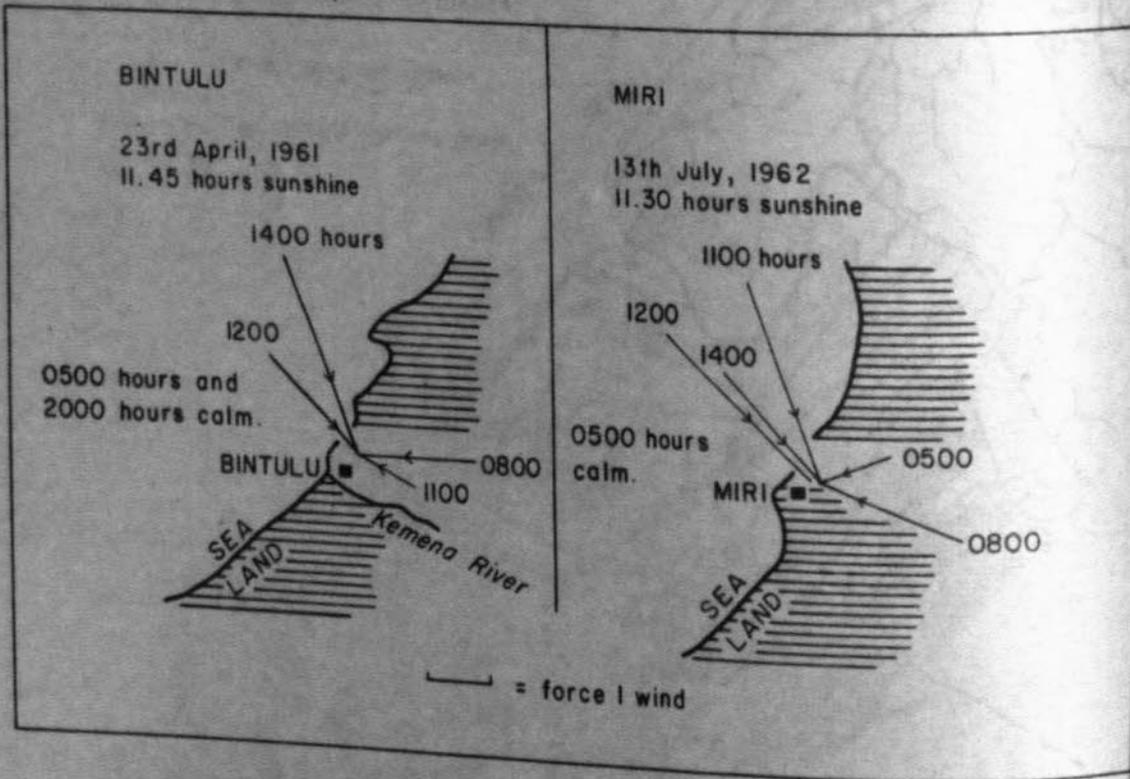


Figure 6. Wind roses for Bintulu and Miri showing development of land and sea breezes on a cloudless day.



## CLIMATE

Climate is responsible for the development of important characteristics of most of the residual soils in the Bekenu-Niah-Suai area. Temperature, rainfall, and evaporation are the most important elements of climate in soil genesis and are described under separate headings below.

Broadly, the air temperature is characterised by a uniformly high daily and monthly mean with the diurnal range far exceeding the mean monthly range. Mean soil temperatures are higher than mean air temperatures and are more uniform. The rainfall is characterised by a high annual mean with monthly means varying from about eight inches in the drier season from March to September to about 13 inches in the wetter part of the year. Percentage variations from the mean are great, due to erratic and prolonged convectional rain. It is rare for the monthly rainfall to be less than 2.5 inches. Monthly evaporation, however, is constantly high and because of this it is likely in many years that in one or more months of the drier season the incoming rainfall is exceeded by evaporation; this, combined with surface water run off and other water losses, leads to an occasional deficit of soil water.

### TEMPERATURE

Temperature records, although not available from within the area, have been recorded at Bintulu and Miri from 1950 and 1951 respectively. Both meteorological stations are situated on the coast with low hills and swamps lying immediately behind (Fig. 4) and should be representative of most of the Sibuti, Niah and Suai river basins, at least in the broader aspects.

The monthly temperature regime (Fig. 5) shows that the mean monthly means range from a low of about 79°F from November to February to a peak of about 81°F in April and May. There is, therefore, a slight seasonal change. Extreme monthly means vary between limits of about 77° - 83°F; monthly means differ from mean monthly means by less than 2°F.

The daily temperature variation is marked and regular. Provided heavy cloud, wind (Fig. 6) or rain does not occur there is a steady rise during the morning reaching a peak shortly after midday of 87° - 90°F (Fig. 7). Subsequently there is a gradual drop to a minimum of 75° - 68°F just before sunrise. It is normal for cloud to build up during the morning and afternoon, however, and cloud and wind combined can lower the maximum by 8° - 10°F while prolonged heavy rain may lower the maximum by as such as 15°F (Fig. 8). The mean diurnal range of 11° - 15°F (Fig. 9) therefore greatly exceeds both the mean monthly and mean annual range. Figure 5 shows a trend to a slightly cooler season from November to February. The absolute maximum temperature at Miri and Bintulu is 95.4°F and 94.8°F respectively, the minimum 67.0°F and 66.5°F respectively.

The two stations from which the figures are taken are thought to be typical of the coastal land in the Sibuti, Niah and Suai river basins. It is unlikely, however, that temperatures will differ significantly either in the most inland parts of the area surveyed (25 miles from the sea) or in the most hilly parts reaching a maximum of about 1,500 feet in the Lambir Hills.

Figure 7. Diurnal shade temperature regime at Bintulu.

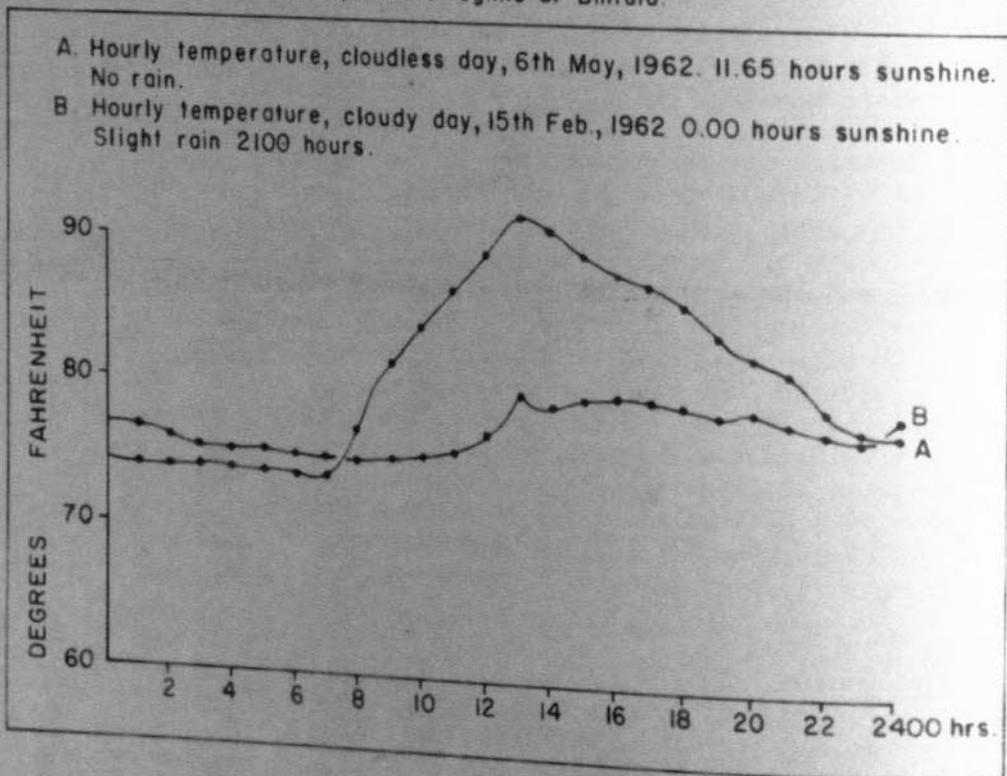


Figure 9 Mean diurnal range of temperature at Miri and Bintulu 1951-1963

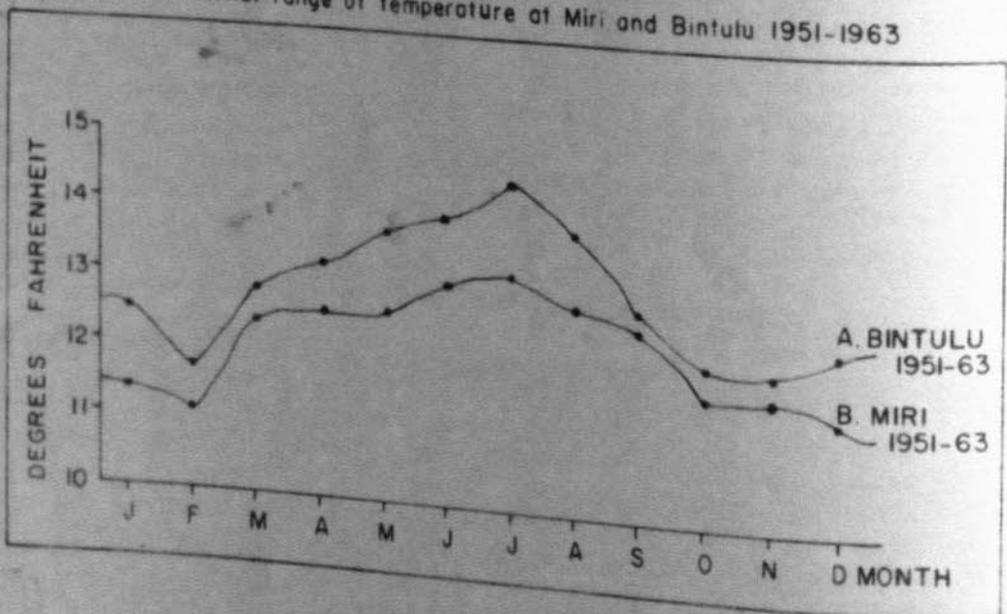
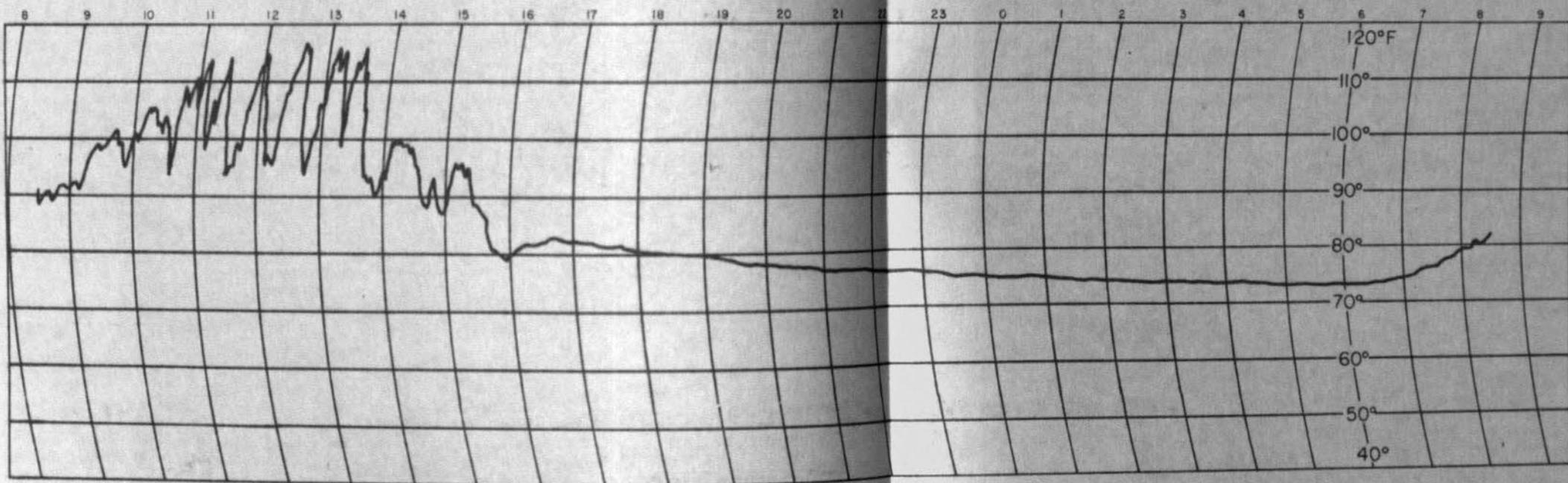


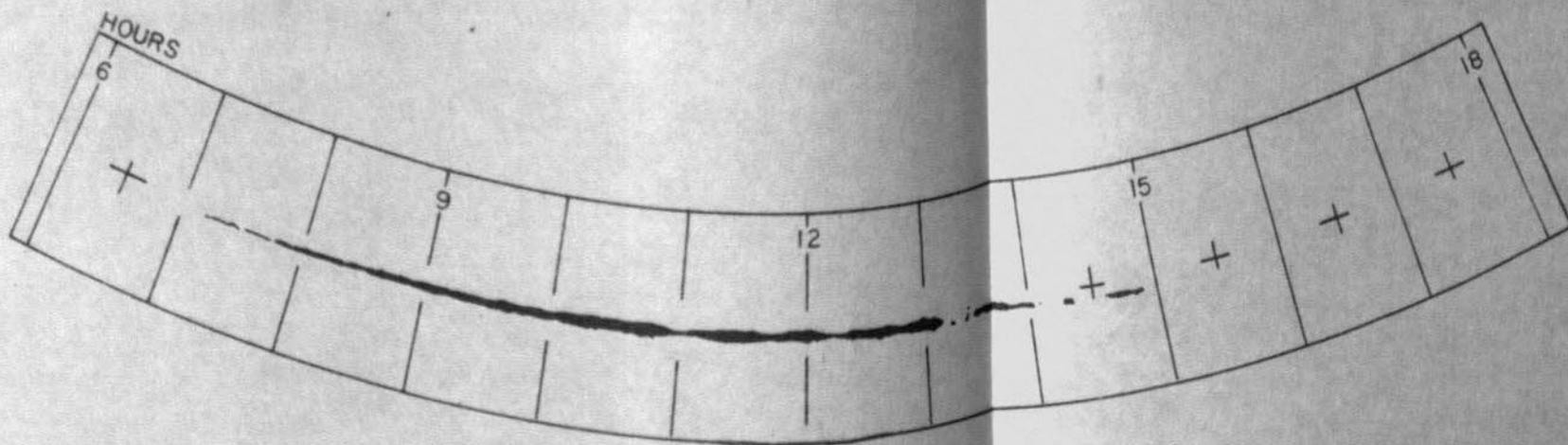
Figure 8 A. Thermograph recording of direct radiation received at ground level.

B. Continuous sunshine recording.

A. Station: KUCHING Height: 89 feet above sea level. Oct., 1962. Time on: 26th, 0830 hrs. Time off: 27th, 0830 hrs.



B. Oct. 26th, 1962



Soil Forming Factors

Climate

Assuming a standard drop in temperature of  $1^{\circ}\text{F}/300$  feet increase in altitude the highest point of the Lambir Hills at 1,528 feet can be expected to have a mean daily temperature differing by only  $5^{\circ}\text{F}$  from that of adjacent lowlands.

The figures of atmospheric shade temperatures quoted above are presumed to approximate to the air temperature under tall forest with a fairly free air movement. Thicker vegetation, particularly secondary growth between about three and fifteen years old, has much more restricted ventilation and always appears hotter, probably due in part to a high humidity.

Air temperatures at or close to the ground generally are known to differ markedly from screen temperatures and to vary strongly with the amount and kind of vegetation present, the water content of the soil, soil colour and air movement (Mohr, Van Baren, pp. 22-29). Extreme surface temperatures prevail where there is no vegetation, where the soil is dark and dry, and where there is no air movement. Conditions approximating to these occur in land burned for the planting of hill rice, which is common in the main valleys of this area, to a lesser degree where young rubber is planted on terraces and on the closely grazed scrubland of the beaches. Temperatures (of incoming radiation) recorded at Kuching airport by a thermograph placed just above a dark brown surface soil so that the metallic temperature-sensitive device was fully exposed to sunshine, are shown in Figures 8 and 10. Kuching airport being 12 miles from the coast and 87 feet above sea level probably has a similar temperature regime to that of the Bekenu-Niah-Suai area. Figure 10 shows that the highest figure of incoming radiation on a cloud-free day was about  $117^{\circ}\text{F}$ , a figure reached on several occasions over a period of eight weeks. The surface soil temperature exceeds incoming radiation at ground level by as much as  $75^{\circ}\text{F}$  in temperature latitudes (Penman, in Russell, p.328). Assuming a similar relationship exists in Sarawak and considering the much stronger radiation, the bare soil temperature can be expected to reach an estimated maximum of about  $195^{\circ}\text{F}$ . The incidence of cloud and rain has a marked effect on surface temperatures. The most rapid changes in temperature occur during periods when clear skies at midday alternate with heavy cloud or thunderstorms leading to drops of  $14^{\circ} - 30^{\circ}\text{F}$  within 15 minutes, as shown in Figure 8.

The presence of vegetation reduces surface diurnal ranges considerably due to absorption of both incident and direct radiant heat during both the day and night. The more complete the shade and the thicker the cover the more efficient this moderating effect will be.

From the soil surface heat is conducted down the profile, but with an increasing retardation of temperature maxima with increasing depth. The data at Bintulu and Miri indicate that the temperatures in grass-covered sandy soils are higher and more uniform than air temperatures to depths of at least 48 inches, and that the temperature in the soil becomes more uniform with increasing depth.

The mean monthly soil temperature at 12 inches depth is generally  $5^{\circ}\text{F}$  higher and, during the hotter months, as much as  $7.5^{\circ}\text{F}$  higher than the mean monthly air temperature (Figures 11 and 12). The soil temperature regime resembles that of the air temperature

Figure 10 A. Thermograph recording of direct radiation on a day with little cloud. B. Thermograph recording of shade temperature on the same day.

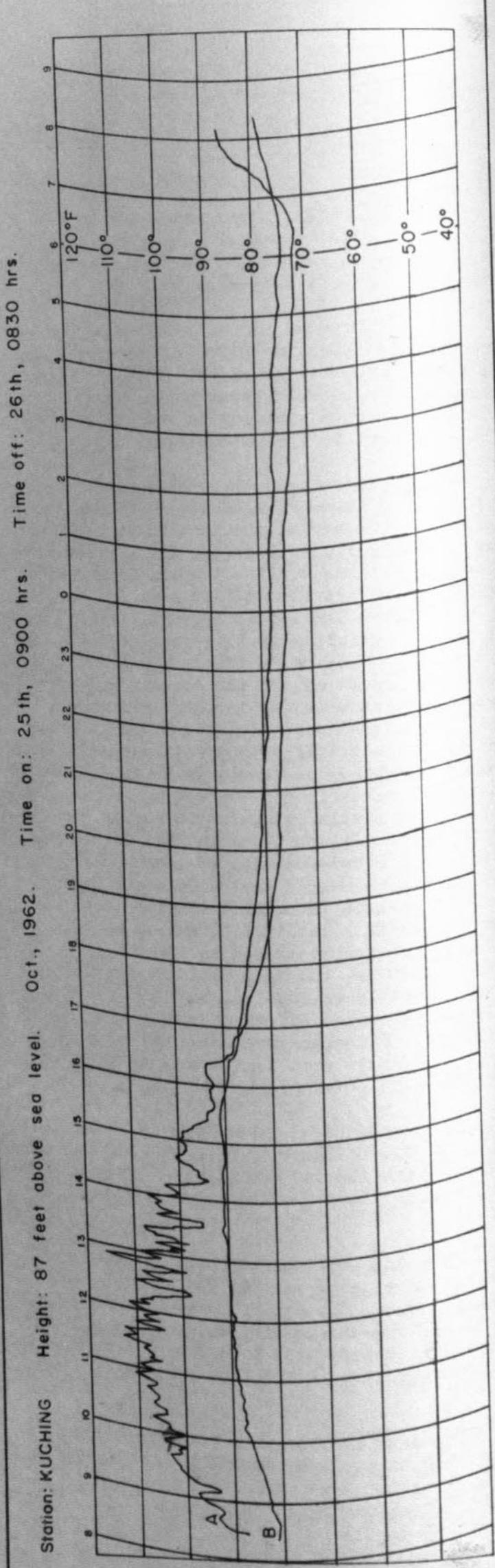


Figure 11. Mean monthly mean shade and soil temperatures at Bintulu 1961-1962

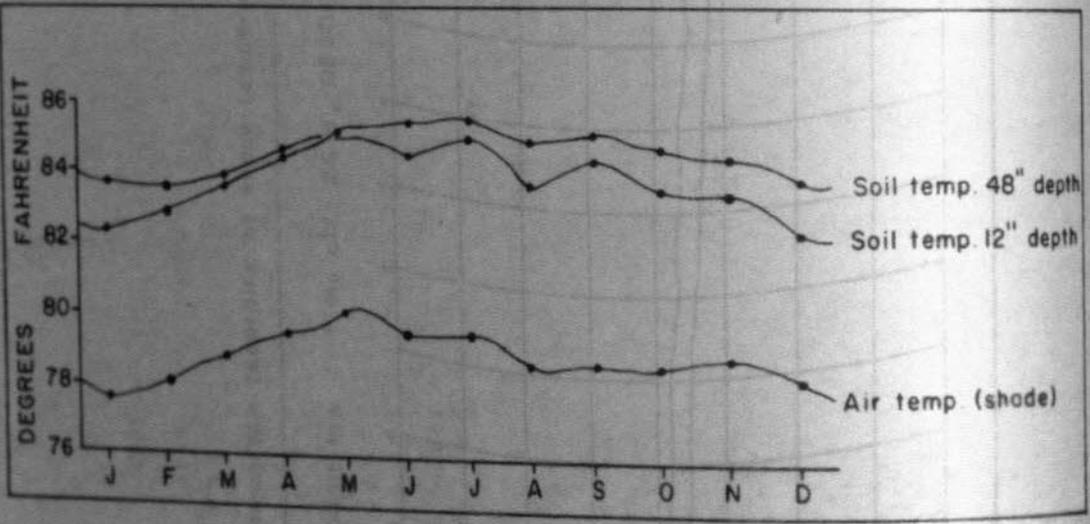


Figure 12. Mean monthly mean shade and soil temperatures at Miri 1950-1956

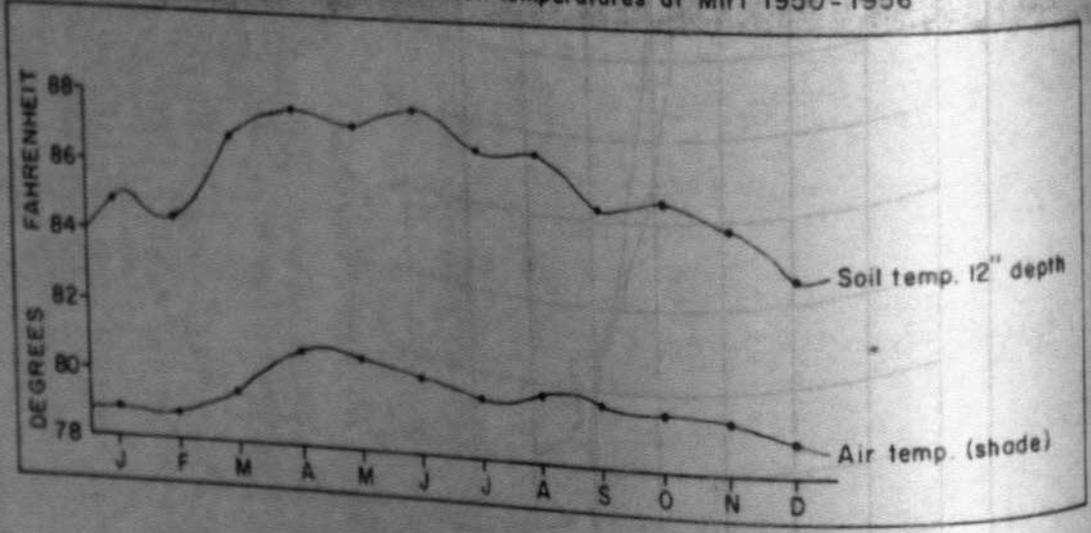


Figure 13. Block diagrams of mean monthly rainfall in the coastal region of Fourth Division.

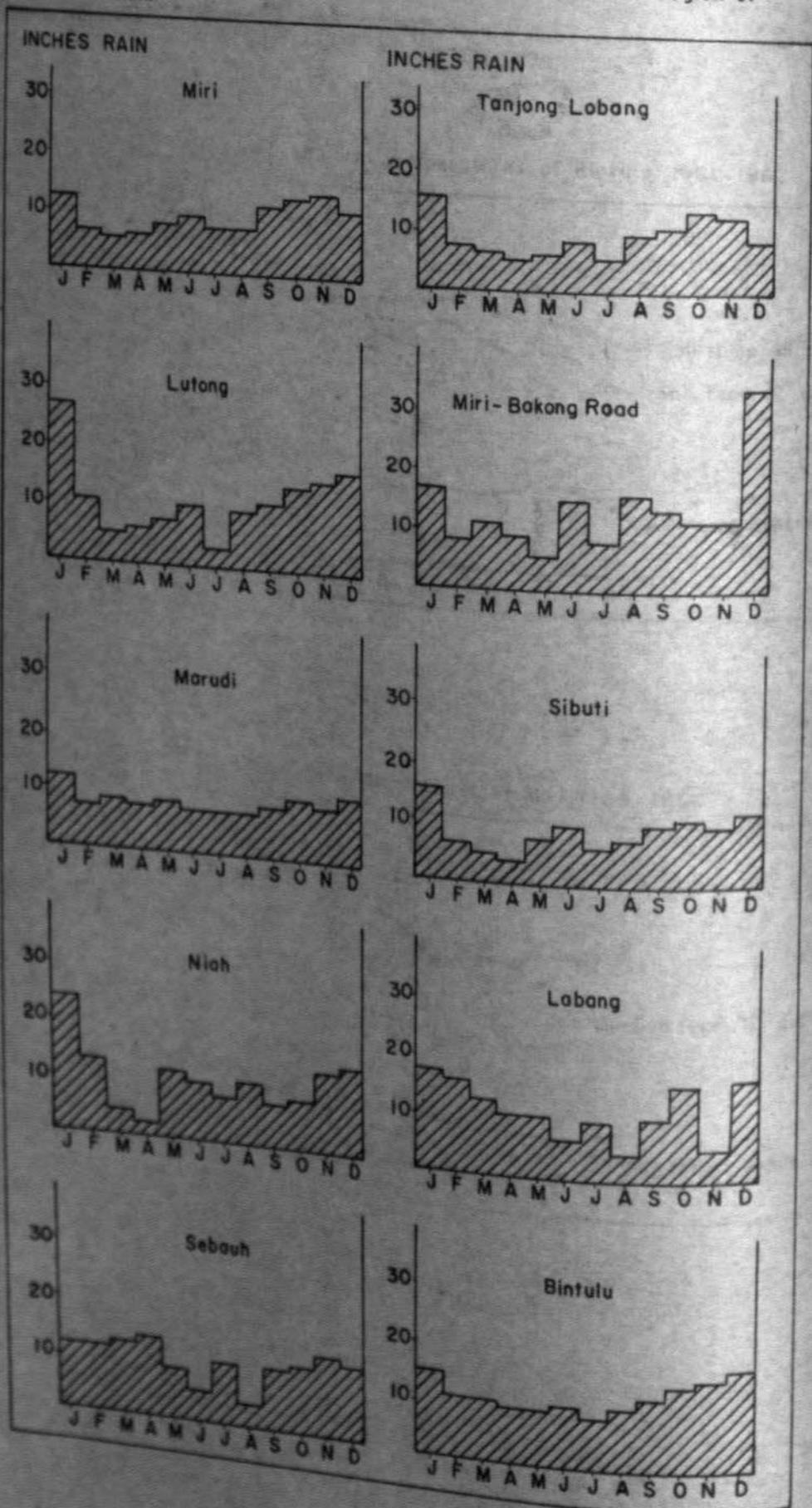
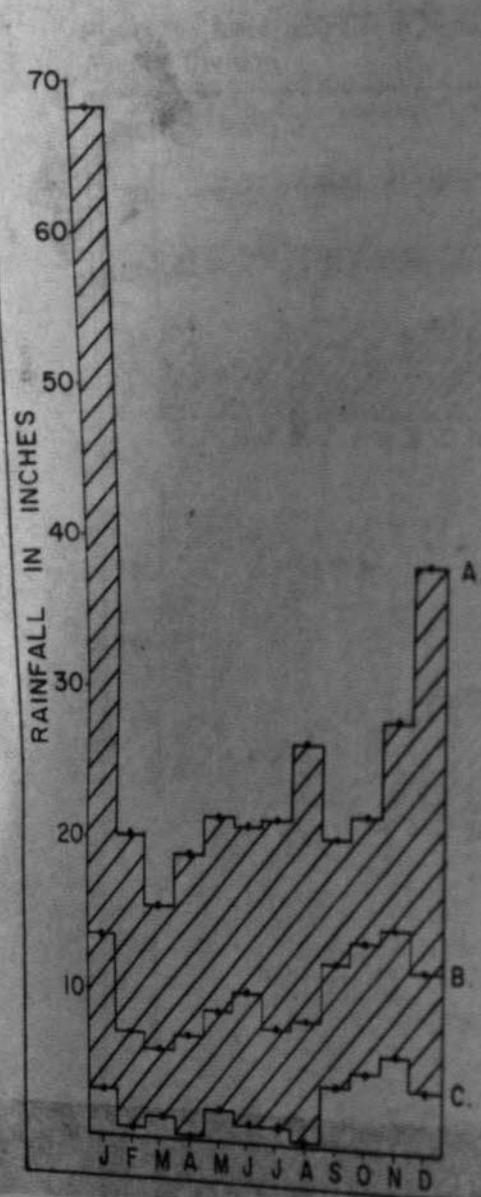
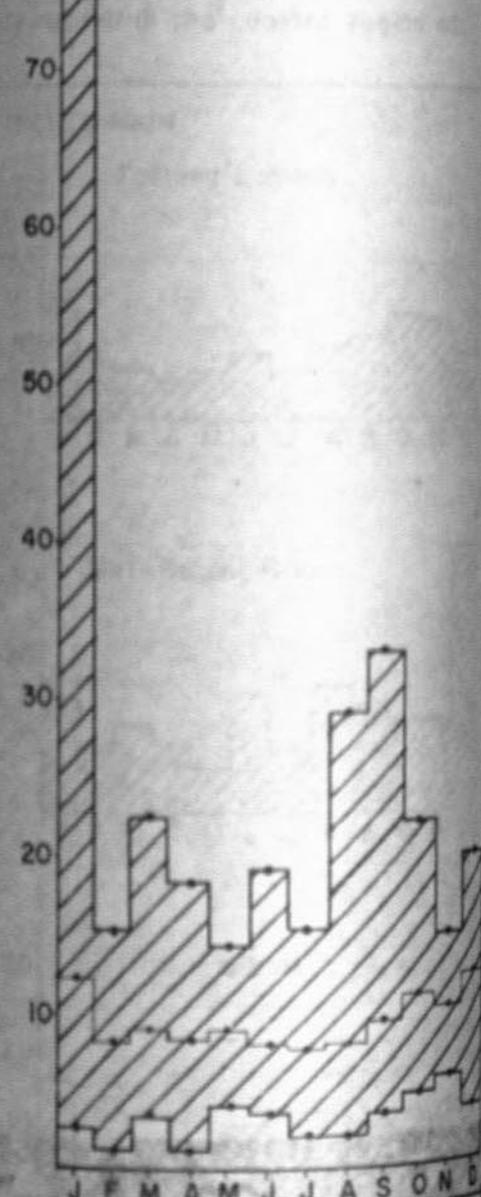


Figure 14 A. Absolute monthly maximum rainfall. B. Mean monthly mean rainfall. C. Absolute monthly minimum rainfall at Miri, Marudi, Bintulu and Long Akoh.

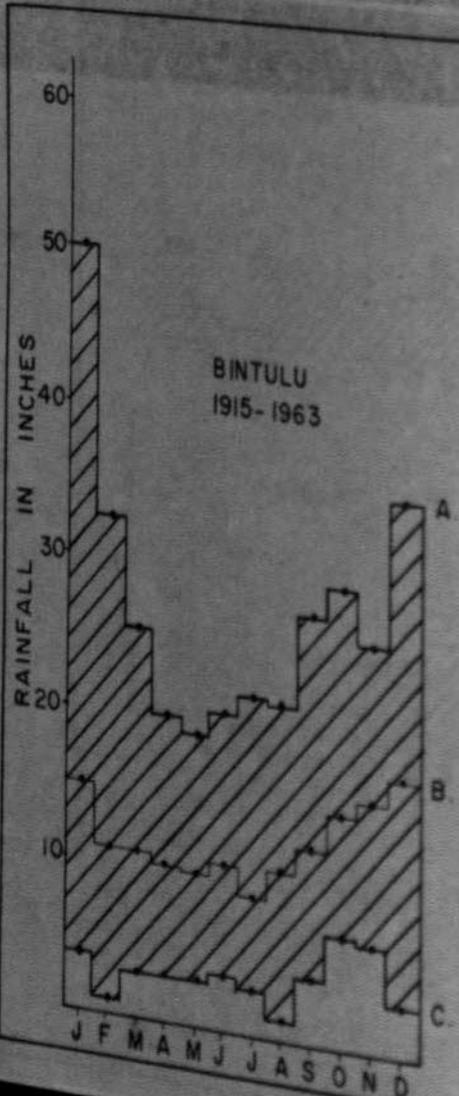
MIRI 1917-63



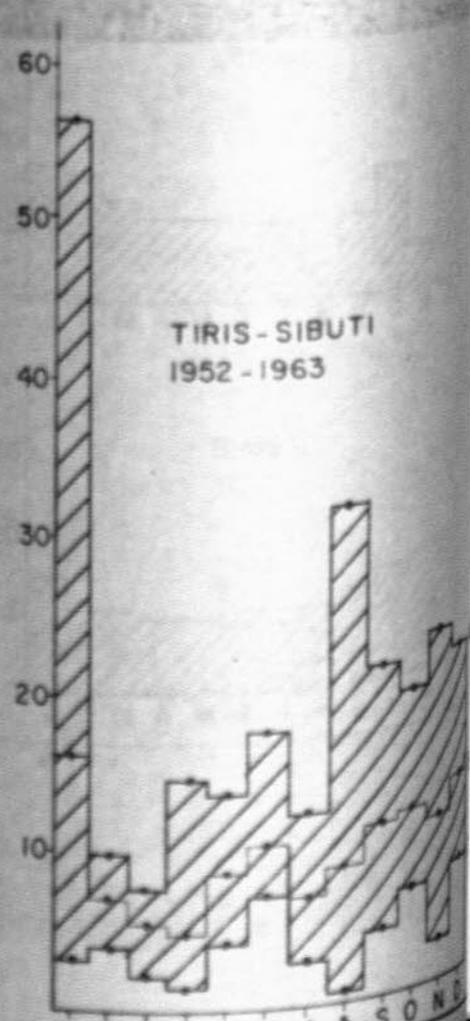
MARUDI 1912-63



BINTULU 1915-1963



TIRIS-SIBUTI 1952-1963



Soil Forming Factors  
Climate

throughout the year, the peaks and lows being exaggerated slightly at 12 inches. At a depth of 48 inches the mean monthly soil temperatures exceed those in the air by from  $5^{\circ}$  -  $6.5^{\circ}$ F, the peaks lagging behind by one or two months and the amplitude between mean maxima and minima being reduced to  $2^{\circ}$ F.

Under forest the soil temperatures are probably lower but still slightly higher than equivalent air temperatures. The range between maxima and minima is probably narrower than under soil with no vegetation cover.

RAINFALL

Incomplete long term rainfall data is available for Bintulu and Miri from 1915 and 1917 respectively and rain gauges have been maintained within the area studied at Tiris (Bekenu) since 1952, and outside the area at Marudi since 1912. The terrain at Marudi closely resembles that in the Bekenu-Niah-Suai area. Since 1962 gauges have been established at Niah, Tanjong Lobang and the Miri-Bakong road within the area, and at Sebauh, Labang and Nyalau to the southwest (Fig. 4) all situated in low to medium height hilly terrain, not exceeding 200 feet.

As long-term means cannot be compiled for the newer stations their short-term monthly records are compared with those of the nearest long established station over the same period, and then adjusted by the same amount that the older records of the older station differ from the more recent short-term means. By this method approximate, calculated annual means (Fig. 13) are obtained from which isohyets (Fig. 4) have been compiled.

The annual regime of the three long term stations, Miri, Bintulu and Marudi, is similar, as shown in Figure 13. February to August is the driest part of the year with a slight rise in precipitation in May and June. This is due to the northward shift of the tropical rainbelt during these months. From September to January is the wettest part of the year, a season known as the 'landas' throughout Sarawak. The heavier precipitation during these months is largely a result of the southward drift of the tropical rainbelt causing the fringes of the northeast monsoon to move over Sarawak.

The mean monthly rainfall figures mask a great variation (Fig. 14). At Marudi the range for January is from 20% to slightly more than 600% of the mean, the high variation being due to an exceptional period in January, 1963, which had four consecutive days with more than six inches of rain, totalling 46.3 inches, and with one day yielding 22.1 inches. This was the equivalent of 320 million gallons of water per square mile per 24 hours. (Jeeps and Gates, p.61).

The mean number of rain days per month for Bintulu and Miri is shown in Figures 15 and 16 combined with the mean number of days per month in which rainfall exceeds two inches and four inches. Figure 17 shows the calculated mean rain intensity per rain day for these two stations. In both places there is a clear increase in the number of rainfall days during the 'landas' from September to January. This trend is paralleled, but in a more subdued manner, by the graphs (Figs. 15 and 16) showing the frequency of heavy rains of more than two inches per month, with the exception of secondary peaks which are particularly common in June.

Figure 16. Showing frequency of raindays and days with heavy rainfall at Bintulu.

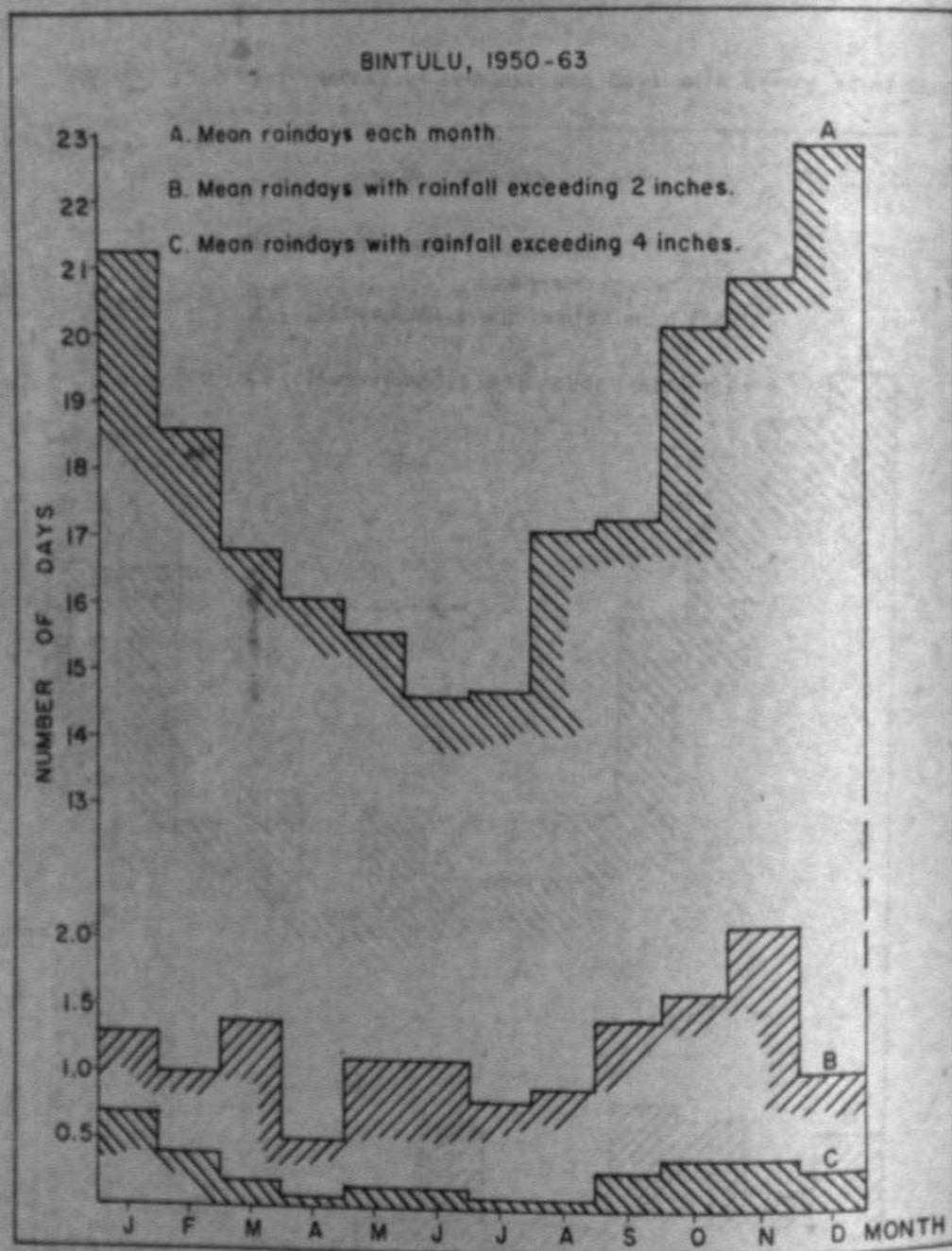


Figure 17. Showing mean rainfall per mean rainy day per month at Bintulu and Miri.

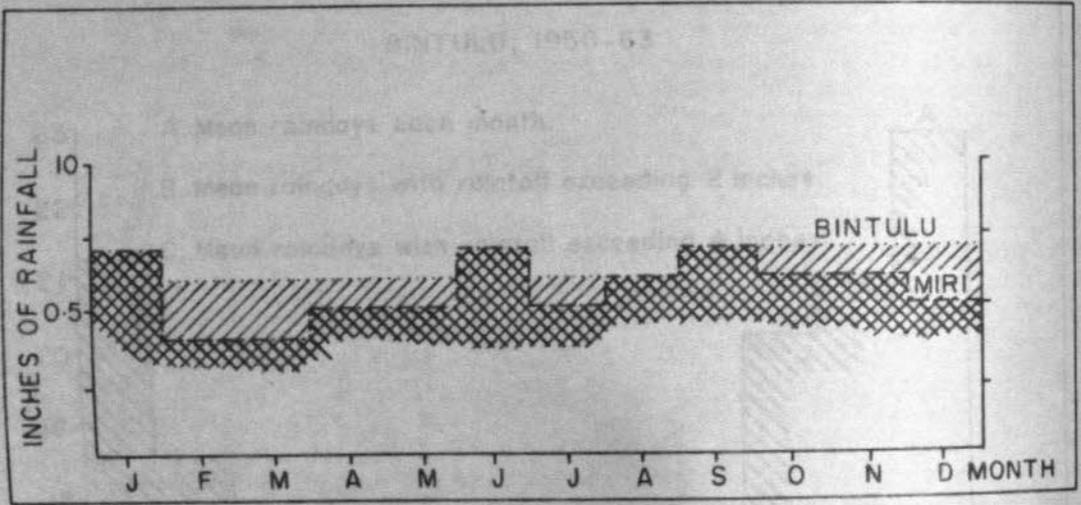
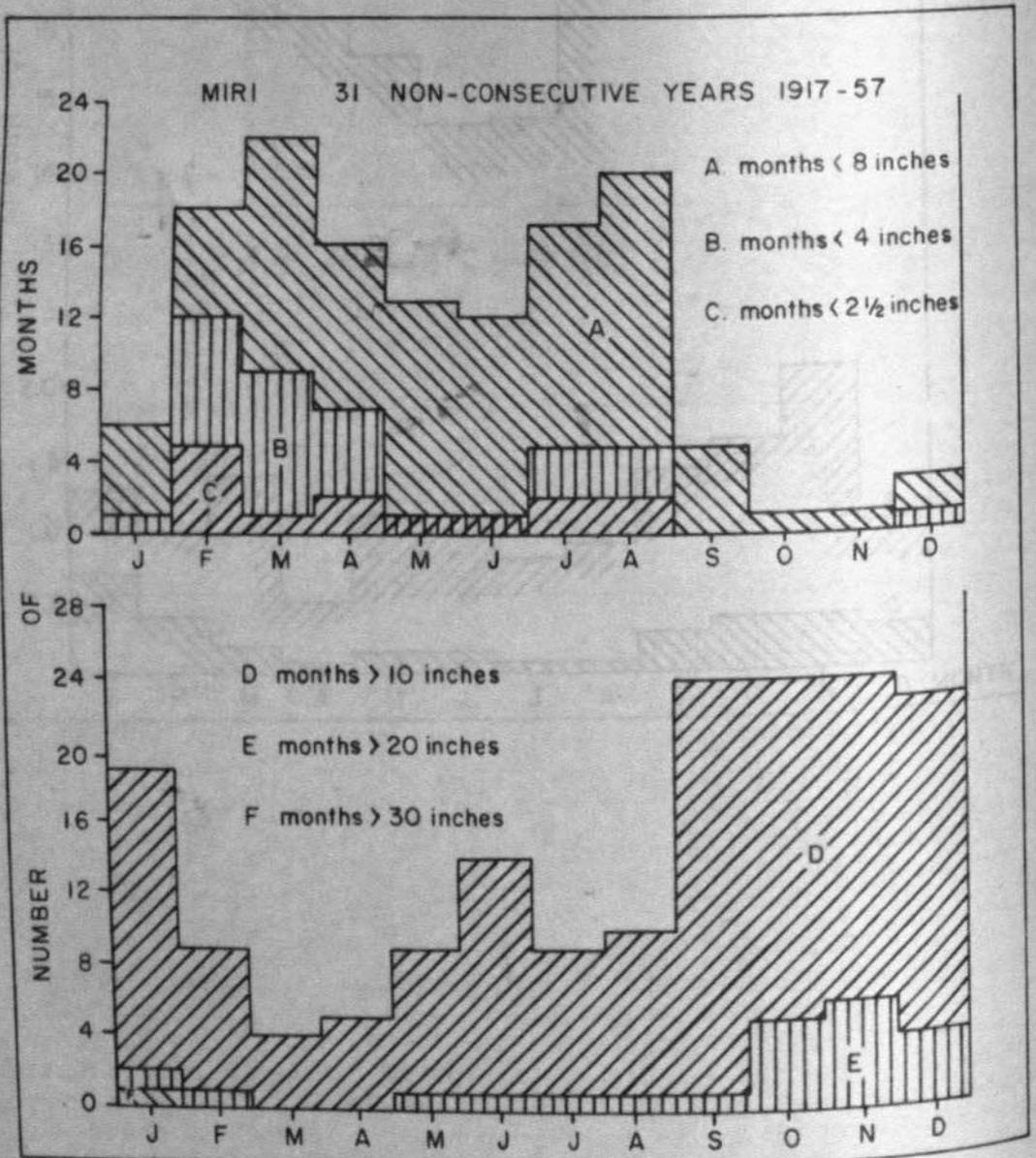


Figure 18 Distribution of 'dry', 'moist' and 'wet' and 'very wet' months at Miri.



Soil Forming Factors  
Climate

The mean daily rain intensity varies little throughout the year at Bintulu but at Miri the 'landas' monsoonal rain slightly surpasses the mean intensity of the drier seasons convectional rain except in June. Over short periods rainfall can be extremely intense. As much as four inches falling within an hour is not uncommon and a mean intensity of one inch/25 minutes for 3 hours 20 minutes has been recorded at Miri.

The maximum periods with no rainfall (less than .01 inch/rain day) at Bintulu are 24 days, at Miri 23 days, and periods of from 8 to 15 consecutive dry days are not uncommon, particularly between March and August. During the same period at Bintulu the mean number of rainless days per month varies from 18 to 14 from year to year. In both Miri and Bintulu, December has the least number of dry days, averaging 8 and 10 respectively.

The limits of 2.5, 4 and 8 inches of rain as mean monthly figures are taken as the upper limits required to maintain 'dry', 'moist', and 'wet' soil conditions (Mohr and van Baren, p.71). Table 2 shows the number of such months at three stations. The annual frequency distribution of dry to very wet months for Miri is shown in Fig. 18 and resembles that at Bintulu and Marudi. From September to February the very wet months form the reciprocal of the graph showing dry, moist and wet months. The driest months on this basis tend to be from February to April and from July to August.

Table 2: Mean number of 'dry', 'moist', 'wet' and 'very wet' months at Miri, Marudi and Bintulu.

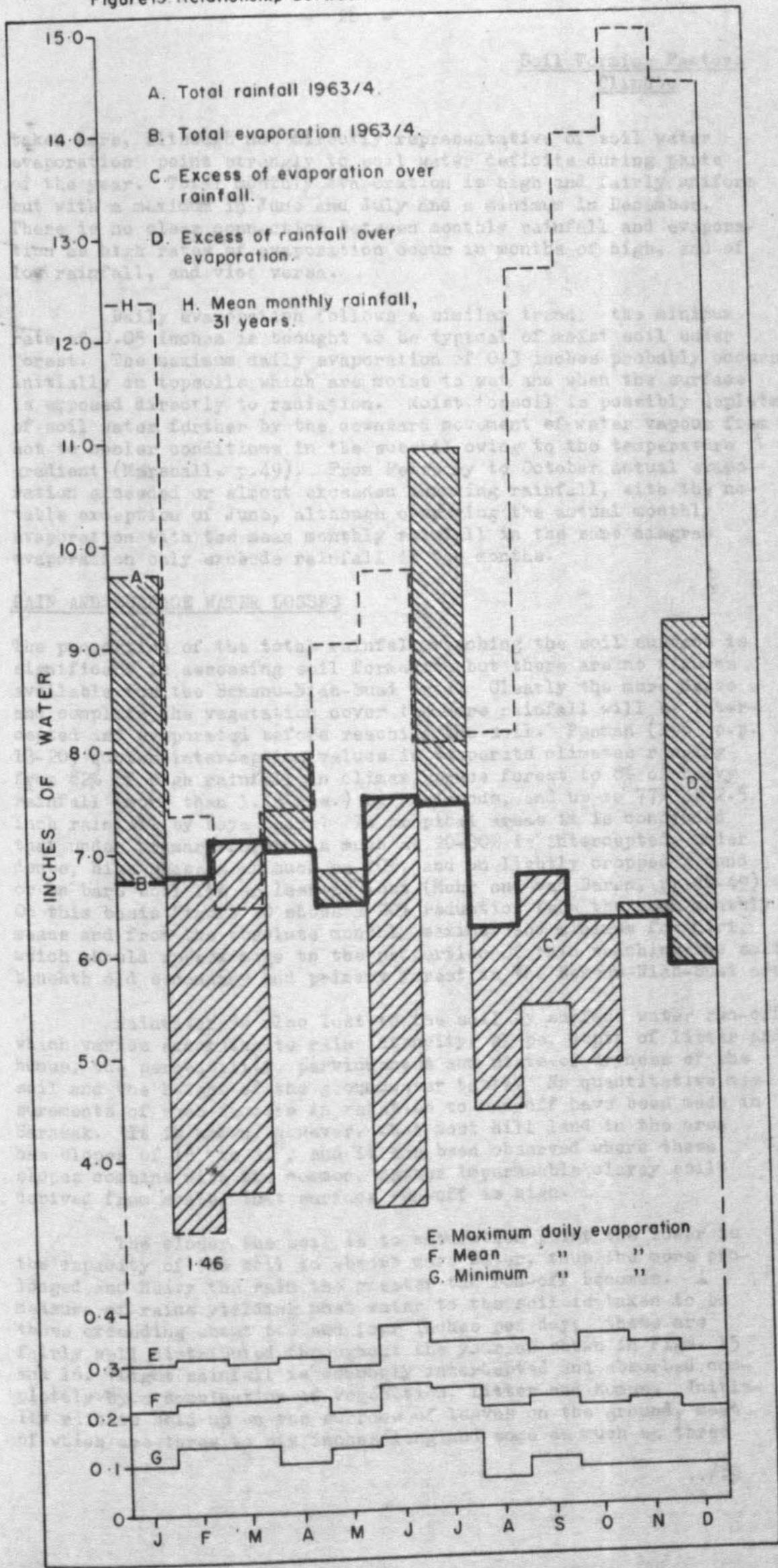
	DRY Mean no. months less than 2½"	MOIST mean no. months 2½ to 4"	WET mean no. months 4 to 8"	VERY WET mean no. months more than 8"
Miri 31 yrs.	.48	.90	3.01	7.61
Marudi 38 yrs.	.39	.46	3.95	7.2
Bintulu 33 yrs.	.12	.39	1.89	9.6

An important aspect of the rain water in relation to soil weathering is its acidity. Twenty samples of rain water were found to have an average pH of 5.5 and a range of 4.9 - 6.0 (Wilford, Wall, p.59). Rain water therefore, ranges from strongly to weakly acid.

EVAPORATION

Figure 19 shows measurements of water evaporation from a class 'A' evaporation pan, installed at Miri in May, 1963, and representing the maximum possible evaporation under radiation from a free water surface, such as may be found in flooded wet rice fields. Potential surface soil water evaporation approximates to that in exposed evaporation pans (Mohr and van Baren, p.51). The measurements

Figure 19 Relationship between rainfall and evaporation at Miri



Soil Forming Factors  
Climate

taken here, although not directly representative of soil water evaporation, point strongly to soil water deficits during parts of the year. Total monthly evaporation is high and fairly uniform but with a maximum in June and July and a minimum in December. There is no clear connection between monthly rainfall and evaporation as high rates of evaporation occur in months of high, and of low rainfall, and vice versa.

Daily evaporation follows a similar trend; the minimum rate of 0.05 inches is thought to be typical of moist soil under forest. The maximum daily evaporation of 0.3 inches probably occurs initially in topsoils which are moist to wet and when the surface is exposed directly to radiation. Moist topsoil is possibly depleted of soil water further by the downward movement of water vapour from hot to cooler conditions in the subsoil owing to the temperature gradient (Marshall, p.49). From February to October actual evaporation exceeded or almost exceeded incoming rainfall, with the notable exception of June, although comparing the actual monthly evaporation with the mean monthly rainfall in the same diagram evaporation only exceeds rainfall in two months.

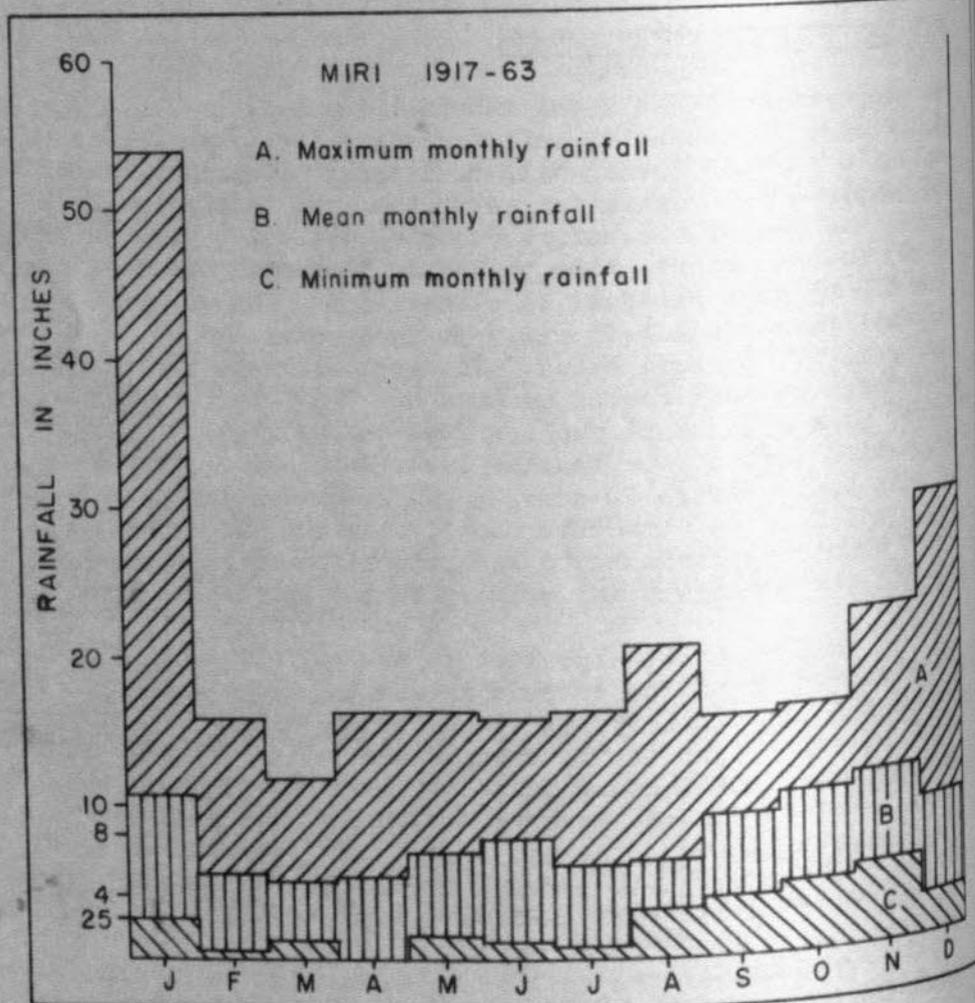
RAIN AND SURFACE WATER LOSSES

The proportion of the total rainfall reaching the soil surface is significant in assessing soil formation but there are no figures available for the Bekenu-Niah-Suai area. Clearly the more dense and complete the vegetation cover the more rainfall will be intercepted and evaporated before reaching the soil. Penman (1963 p.p. 13-20) quotes interception values in temperate climates ranging from 82% of high rainfall in climax spruce forest to 8% of heavy rainfall (more than 1.75 ins.) by hardwoods, and up to 77% of 2.5 inch rainfall by soya beans. In tropical areas it is concluded that under primary forest as much as 20-30% is intercepted, under dense, high grasses as much as 20%, and on lightly cropped ground or on bare soil 15% or less is lost (Mohr and van Baren, pp.48-49). On this basis Figure 20 shows a 20% reduction from the mean monthly means and from the absolute monthly maximum and minimum for Miri, which should approximate to the proportion of rain reaching the soil beneath old secondary and primary forest in the Bekenu-Niah-Suai area.

Rainwater is also lost to the soil by surface water run-off which varies according to rain intensity, slope, depth of litter and humus, the permeability, perviousness and state of dryness of the soil and the height of the groundwater table. No quantitative measurements of such factors in relation to run-off have been made in Sarawak. It is known, however, that most hill land in the area has slopes of 15° to 30°, and it has been observed where these slopes combine with the common, rather impermeable clayey soils derived from shale, that surface run-off is high.

The closer the soil is to saturation point the lower is the capacity of the soil to absorb more water, thus the more prolonged and heavy the rain the greater the run-off becomes. A measure of rains yielding most water to the soil is taken to be those exceeding about two and four inches per day; these are fairly well distributed throughout the year as shown in Figs. 15 and 16. Light rainfall is commonly intercepted and absorbed completely by a combination of vegetation, litter and humus. Initially rain is held up on the surface of leaves on the ground, most of which are three to six inches long and some as much as three

Figure 20. 20% reduction in rainfall likely to reach the soil surface in the Bekenu-Niah-Suai area.



Soil Forming Factors  
Climate

feet in diameter (widest section), later to pour from one to another downslope. Thick humus, common only on the most podsolised soils, readily absorbs rainwater.

In low-lying land where the groundwater table is at or near the surface, rainwater escapes laterally as run-off or is ponded to form swamps. Flat, terrace landscape almost invariably contains extremely sandy porous soil which permits the maximum intake of water and the minimum surface run-off.

CLIMATE AND SOIL FORMATION

The constant high soil temperature and humidity result in a year-round continuously high rate of chemical weathering in which mineral breakdown by chemical action is much greater than in temperate latitudes.

The climate also favours, through prolific vegetation growth, the production of much organic matter and its equally rapid destruction by micro-organisms. The net result is a nutrient cycle restricted almost entirely to topsoil-roots-plants-litter-topsoil with a high proportion of the plant nutrients bound up in living vegetation above the soil.

An important effect of the generally high and well distributed rainfall is to maintain a podsollic leaching process in the soils. This process is most clearly seen in siliceous, sandy, permeable soils, and is one that affects both physical and chemical soil properties.

During the 'landas' season, from October to January, prolonged heavy rainfall causes some residual hill soils to reach saturation point when they become unstable and readily succumb to erosion (p. 46 - Plate 15.)

Between February and September there may be rainless periods of 8-15 days. Also, there are occasional months in the same season during which rainfalls of less than about three inches in primary forest and eight inches in cropped land are probably exceeded by combined near-the-surface soil water evaporation, vegetation interception and surface water run-off, mainly on steeply sloping, impermeable soils. Soil water at such times and in such places may be insufficient for many shallow-rooted crops such as vegetables and pepper. Podsolisation is probably also temporarily reversed as soil capillary water rises to the surface.

The effect of high temperatures on unprotected surface soil is to scorch and dehydrate it, probably inactivating micro-organisms as well and thus disrupting the nutrient cycle. In addition the surface hardens and cracks, developing major channels for rainwater leaching in subsequent rainy spells. The effect is most marked in the traditionally bare-weeded pepper gardens and to a less extent in hill rice fields.

The markedly acid nature of the rainwater is probably effective in removing readily soluble bases from fresh litter and surface soil horizons.

## PARENT MATERIALS

With the exception of peat the soil parent materials in the Bekenu-Niah-Suai area are of sedimentary origin. The rocks consist of moderately to steeply folded Neogene sandstone and shale with some limestone. Most of the rocks were formed in deltaic to shallow marine conditions and were derived from sediments which, prior to final deposition, had undergone several cycles of erosion and deposition following their initial erosion from pre-Tertiary igneous and sedimentary rocks in Central Borneo. The sandstone is characterised by a high proportion of fine- to medium-size quartz grains and is usually well-sorted; the shale is probably kaolinitic and commonly calcareous. Sandstone dominated strata underlie most of the higher hilly country, shale underlies the widespread belts of low-lying country, and limestone forms the cliffed karst hills at Subis. Quaternary, sand and clay occupy the inland valleys and form the frontal portion of the coastal plain, a large part of which is covered by peat.

The variety of rocks present produce both major and minor variations in the overall type and intensity of soil weathering imposed by climate. Parent materials in the alluvial valleys and swamp lands form soils almost independently of the climate.

The lithological features of bed rock important to soil formation are described below. Following the descriptions the parent rocks and materials are assessed for their influence on soil formation.

### PREDOMINANTLY ARENACEOUS FORMATIONS

Rock formations composed predominantly of sandstone are the Nyalau, Lambir, Belait, and Miri Formations. They underlie approximately 22 per cent of the area (Map 3).

NYALAU FORMATION rocks consist mainly of hard, fine-grained, argillaceous, and commonly calcareous sandstone interbedded with varying proportions of sandy shale and clay. Shale is uncommon except north of the Nyalau River where the succession becomes more shaly and interfingers with the Sibuti and Setap Shale formations. Carbonaceous, lignitic and pyritic sandstone and shale are common. Porosity of the few sandstones examined ranges from 9 to 23 percent (Liechi et al, p. 120).

LAMBIR FORMATION rocks outcrop only in the north and comprise sandstone-shale alternations (Plate 16) with a few thin beds of marl, limestone and calcareous sandstone. Most sandstones are fine- to medium-grained, lignitic and become increasingly less consolidated northwards where sands and clays occur.

BELAIT FORMATION sediments outcrop only in the northeast of the area. The dominant rock is a massive, grey to white, fairly soft, medium- to coarse-grained sandstone which is interbedded with subordinate grey shale and clay shale.

MIRI FORMATION rocks underlie a small area in the north. The formation is predominantly arenaceous but contains a few clay and shale beds. The sandstone is poorly consolidated.

Soil Forming Factors  
Parent Materials

PREDOMINANTLY ARGILLACEOUS FORMATIONS

The predominantly argillaceous formations are the Setap, Sibuti and Tangap formations, together totalling 36 per cent of the area (Map 3).

SETAP SHALE FORMATION material occurs throughout the area except in the extreme north. It consists of grey to bluish grey shale with subordinate sandy shale and sandstone. The shale is moderately soft and lignitic in places, hard and nodular in others. The sandstone is thinly bedded, fine- to medium-grained and is commonly calcareous northeast of the Niah River. Thin beds of hard, dark grey limestone outcrop in the Mulis area between the Niah and Suai Rivers.

SIBUTI FORMATION rocks outcrop mainly north of the Niah River. Lithologically they resemble the Setap Shale Formation except that calcareous shale is more prevalent and sandstone less common. (Plate 17)

TANGAP FORMATION sediments underlie a wedge-shaped area between the Niah and Sibuti rivers. The rocks resemble the more calcareous beds of the Sibuti and Setap Shale formations.

LIMESTONE

The Subis Limestone Member of the Tangap Formation is a coral and foraminiferal limestone of low porosity and extremely low permeability, which outcrops over seven square miles close to Niah. (Map 3, Plate 18).

QUATERNARY DEPOSITS

Pleistocene sediments consist of as much as 25 feet of unconsolidated, white, siliceous sand on coastal and near coastal marine-cut terraces, (Plate 19) and less commonly of mixed sand and clay riverine terraces inland (Map 3).

Recent deposits comprise unconsolidated coastal sands, river clays and sands, and peat accumulations of as much as 20 or 30 feet deep (Map 3).

PARENT MATERIALS AND SOIL FORMATION

The parent materials are grouped below into arenaceous, argillaceous, mixed arenaceous-argillaceous, limestone, alluvium and peat types. Distinctive soils are formed from the various parent materials under the same atmospheric macro climate. Parent material alone is responsible for the variations in some cases while in others it is in conjunction with other factors such as topography or vegetation (p. 44 and p. 53 ).

All the rocks are of sedimentary origin, and, except for the small area of limestone which supports skeletal organic soils and the few scattered patches of calcareous shales yielding Brown Forest soils, have weathered to form podsolised soils, some showing latosolic tendencies. The dominance of podsolisation is attributed in part to the prevailing climate and partly to the permeable, siliceous, kaolinitic, base-poor parent materials which form an acid environment, conducive to clay breakdown and the leaching of iron and aluminium in preference to silica.

Soil Forming Factors  
Parent Materials

In the lowlands, although the groundwater table exerts an overriding influence in the formation of hydromorphic and organic soils, and with tides, vegetation and micro-organisms contributing to their formation, the lithological nature of the sediments is important in producing other soil differences through particle size, mineralogy, chemical composition and permeability.

ARENACEOUS ROCKS AND DERIVED SOILS

Soils developing over sandstone are invariably podsollic. The degree of podsolisation varies according to the lithology of the sandstone from which they are formed.

The fairly soft, massive sandstone that is dominant in the Belait Formation and common in the Miri and Lambir formations weathers to a deep soil resting on a thick horizon of soft weathered sandstone (Sample Area IV, Appendix A, Plate 20). Hard sandstone, more typical of the Nyalau Formation, produces a shallower soil with a more rapid transition from soil to fresh rock (Sample Area V, Appendix A, Plate 21 and Fig. 21). Coarse-grained sandstone is more susceptible to leaching than the fine-grained varieties typical of the Nyalau Formation, and thick beds produce a variety of soil distinct from that on thin beds alternating with other rock types. Pyrite-bearing sandstone, common in the Nyalau and parts of the Lambir Formation, colours a soil more strongly than the pale, iron-poor Belait Formation sandstones. Gently dipping hard beds tend to produce a different type of soil from those on more steeply dipping beds as a result of impeded soil drainage.

Silica probably forms the greater part of the mineral suite in sandstone. Secondary minerals in sandstone-derived soil are chiefly limonite, haematite and silicate clay minerals (Table 6). The soils are notably deficient in plant nutrients, because of leaching and the lack of weatherable, nutrient-providing minerals in the rock, this in turn being a legacy of the several cycles of weathering and sorting prior to final deposition.

Weathering of rocks beneath soil through heat and moisture changes is probably minimal since the deep soil temperature is almost constant (p. 26) and it is unlikely that the soils ever become dry at depth. Chemical weathering therefore is the most effective weathering process. Decomposition products of hydration, hydrolysis, and solution, mainly hydrous oxides of iron and aluminium and hydrated silicates, are readily leached through the permeable soils either in solution or in suspension to the B horizon. Dissolved bases, a main source of plant food, are lost once carried beyond root depth. A portion is taken by plant roots, however, to return by way of the trees and falling leaves to the topsoil, while a further part is absorbed or adsorbed by the clay-humus complex. Acidic decomposition by organic and inorganic acids is probably effective also in dissolving the calcareous cements of some sandstones. The oxidation of mobile, iron-containing compounds within the lower subsoil gives a hard iron coating to stone fragments in the B horizon.

Thick, moderately to strongly indurated sandstone weathers slowly by comparison with adjacent shale to form distinctive topography and equally distinctive soil associations (Fig. 22). Hard sandstone is resistant to weathering because of its strong cement but soft sandstone can be equally effective in forming high topography.

Soil Forming Factors  
Parent Materials

This is due to the permeable nature of the soil and weathering rock which effectively absorbs most rainwater, little escaping as surface run-off to cause erosion. Erosion of sandstone areas, apart from normal stream erosion, appears to be principally by large scale movements such as slumps and landslides on steep slopes when the soil becomes saturated and unstable. (Sample Area IV, Appendix A, Plates 15, 22).

ARGILLACEOUS ROCKS AND DERIVED SOILS

Soils formed from shale are weakly podsolised, in places showing deep subsoil features more typical of lateritic soils. They are predominantly kaolinitic, possibly illitic where calcareous, and weakly permeable.

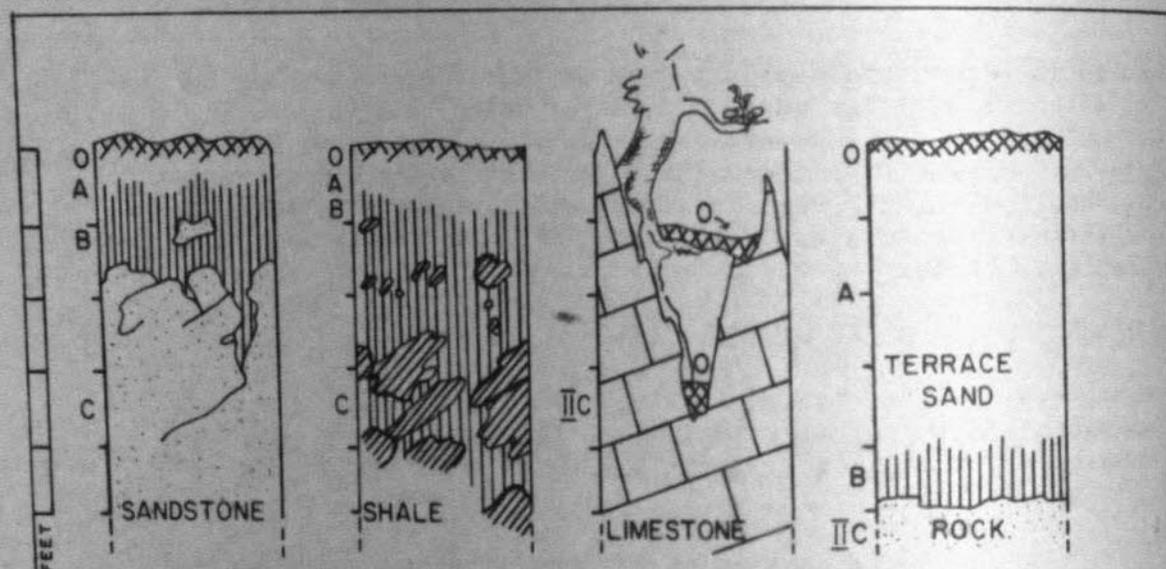
The soft clay-shales of the Miri Formation weather deeply to dense clays (Sample Area IV, Appendix A) while the older and harder Setap, Sibuti and Tangap shales tend to produce more shallow and stony profiles, although deep horizons of multi-coloured, plastic, clayey, partly-weathered shale occur in places (Sample Area V, Appendix A). The many ferruginous beds yield mobile iron compounds on weathering which concentrate and oxidise along bedding planes and joints (Plate 23) and which commonly colour B horizons a rich red colour, and the A2 horizon a yellowish brown. Iron-coated rock fragments and iron nodules are more common than in sandstone-derived soils. Spheroidal weathering seems to be a common feature in the shales exposed by the upper Niah River (Plate 24).

The shales are thought to be predominantly kaolinitic to judge by the analyses of derived soils, (Table 6) namely the invariably low cation exchange capacity and low base status of fresh, and weathered, shale in soil samples. Due to their marine or estuarine depositional environment many shales are enriched with absorbed calcium, potassium and magnesium. The soils overlying such rocks contain weathered rock fragments whose cation exchange capacity is about 30 m.e.%, similar to that of illite. Primary minerals are virtually absent in the shale-derived soils, even quartz being present mainly as secondary amorphous material. The composition of the soils is largely iron and aluminium hydrous silicates and oxides.

Chemical rather than physical weathering of the shale is probably dominant, as in sandstone and derived soils, but the decomposition products tend to be leached from the soil slowly, if at all, partly due to a dense, weakly permeable soil and partly due to the abundance of clay formed in situ. Leaching of clay downwards into the B horizons overlying the weathering shale is proved by the presence of clay skins in cracks and on structural faces of soil peds. Chemical analyses indicate that soluble bases are moved downwards. Such evidence of podsolisation is difficult to detect in the most clayey shale-derived soils where it is assumed that there is a near balance between podsolisation and incipient lateritization.

There is much surface water run-off from bare clayey soils during heavy rainfall when clay particles in suspension are floated off leaving behind fine-grained quartz. The results of the relatively rapid, complete weathering and the surface erosion is the production of distinctive low, moderately sloping topography with equally distinctive soils (Figs. 21 and 22).

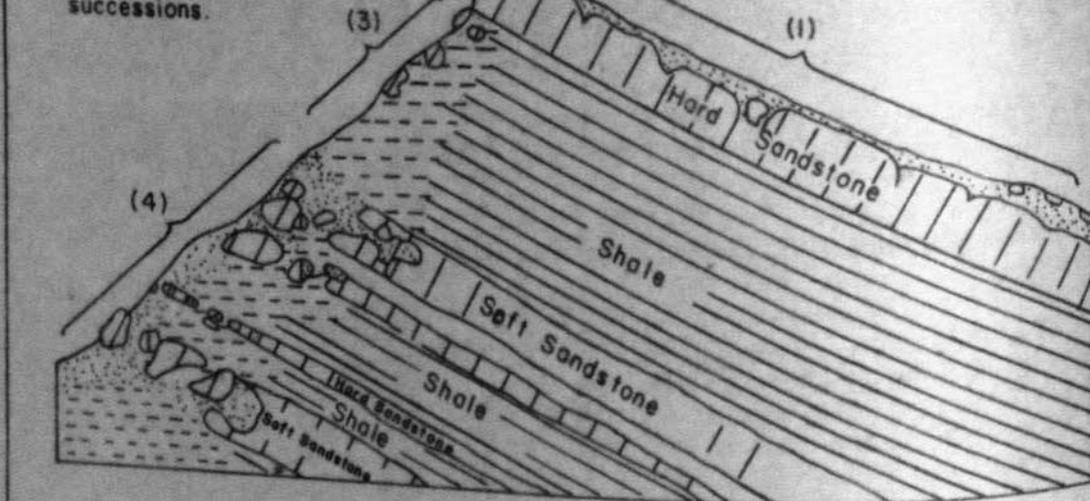
Figure 21. Diagrams showing typical generalized soil profiles developed on sandstone, shale, limestone and in unconsolidated marine terrace sand.



- O Horizon predominantly of an organic nature. The limestone soil rests on roots and in rock crevices.
- A Horizon leached of soluble bases, humus and sesquioxides.
- B Horizon enriched by accumulation of bases, humus and sesquioxides.
- C Parent rock.
- II C Material alien to overlying soil.

Figure 22. Diagram showing soil distribution on a ridge in relation to underlying rocks.

- (1) Dip slope shallow podsollic sandy soil over hard sandstone.
- (2) Bare sandstone outcrop at summit.
- (3) Scarp slope weakly podsollic clayey soil over shale.
- (4) Scarp slope soil of sandy clay loam on clay developed over sandstone-shale successions.



Soil Forming Factors  
Parent Materials

MIXED ARGILLACEOUS-ARENACEOUS ROCKS AND DERIVED SOILS

The presence of shaly sandstone, sandy shale or sandstone beds within shale, and vice versa, results in modifications to the processes described in the two sections above. Mixed sandstone-shale successions are most common in the Nyalau Formation and in parts of the Lembir Formation, and this is reflected strongly in the distribution of soils (Map 4).

Thin, alternating beds of shale and sandstone, sandy shale and shaly sandstone weather to produce podsollic soils with sandy A horizons and clayey B horizons. The thicker the beds the greater is the likelihood of soils occurring with the properties described in the subsections above (Fig. 22). Hard sandstone beds within shale result in a soil with a clay matrix containing angular, little-weathered stone fragments while soft sandstone beds within shale lighten the soil texture generally in patches and act as conducting beds for the downward passage of soil water. Steeply folded, mixed sandstone and shale beds weather to form the soils described above more readily than gently folded beds due to the greater mixing of the weathered rocks following from weathering, solifluction and normal erosion.

LIMESTONE AND DERIVED SOILS

The Subis Limestone produces distinctive rugged, high, cliffed topography (Plate 18). The hills have been fashioned partly by physical weathering, such as root prising and wide temperature variations on bare rock, but principally by solution. The insoluble residue is so small however that the only true residual soil is from rare, sandy limestone beds. The foothill screes contain a clayey, allogenic, inorganic soil, believed to be residual from shales once covering the limestone, that is unusually dense and calcium-saturated; the upper parts of the hills contain Calcic Organic soil derived solely from limestone vegetation.

ALLUVIUM AND DERIVED SOILS

Most soils formed from Quaternary parent materials are characterised by poor consolidation and a profile showing the effect of hydro-morphic processes. The resultant soils vary from organic, hydro-morphic and podsollic to halomorphic types.

Riverine alluvium varies from fine- and medium-grained sands, which are predominant in the headwaters and generally become less common and confined more to levees with increasing distance downstream, to silts and clays found mainly in the lower reaches of the rivers and in small patches behind levees in the headwaters. Brief floods occurring in the headwaters as many as ten times a year are able to carry sand-sized material as far as the lower middle reaches of the three main rivers, below which decreasing gradients and currents only enable clays and silts to be transported. In downriver areas floods are less frequent but tend to be prolonged by the backing-up of tidal water. To judge by their low cation exchange capacity the clays forming the soils are probably kaolinitic (Table 6).

Soil Forming Factors  
Parent Materials

The water table in levee soils is between two and six feet below the surface and the leaching of sesquioxides, clays and dissolved bases to that level occurs particularly in the more sandy soils, so that yellowish brown podsollic soils are formed. In the alluvial basins behind the levees the water table is at or close to the surface and gleization is dominant producing non-leached pale soil.

Estuarine sediments confined to the tidal parts of the three main rivers are principally fine sands, silts and clays. In these areas the water table fluctuates slightly with the tides but is close to the surface for sufficiently long periods to cause gleization of the subsoils. The frequent inundations by saline or brackish water continually replenish the salt content of the soils to high levels producing characteristic halomorphic soils.

Deposits of fine- to medium-grained quartz sand are the main types of coastal alluvium (Fig. 23). The sand is unconsolidated, extremely permeable and pale-coloured on the most recent beaches where podsolisation is intense and the water table is non saline and as much as four feet from the surface (Sample Area I, Appendix A). Soils of sub-recent sandy beaches behind the immediate coast-line tend to be darker coloured and hydromorphic due to a higher water table. Shallow flooding after heavy storms is common in these areas.

Coastal terraces soils are formed in intensely leached, unconsolidated, white quartz sand varying from a few feet to 30 feet in thickness (Sample Area I, Appendix A, Plate 19). The water table is perched above an indurated, humus-enriched B horizon at depths of as much as 12 feet that in turn rests on basal rock or impermeable strata beneath the alluvium (Figs. 21 and 23). The sources of both this terrace alluvium and the more recent coastal sands are probably the coastal outcrops of Nyalau and Lambir Formation sandstone such as that forming headlands at Cape Batu. Little sand reaches the sea from the existing rivers.

#### PEAT AND DERIVED SOIL

Large peat swamps occur in alluvial basins, flanked by coastal sediments seawards, hills landwards and laterally by river levees. The peat mainly overlies estuarine and riverine clays, but near the coast, particularly between the Niah and Suai Rivers it overlies coastal sands (Fig. 23; Sample Areas II and III, Appendix A). The peat in places is at least 30 feet deep and consists of coarse, woody, waterlogged swamp forest debris that has developed into raw, acid bog soil. The water table rests permanently at or close to the surface and decomposition is so slow that the peat accumulates at an overall rate of about one foot per 200 years in the larger swamps (Wilford, p.117).

## TOPOGRAPHY.

Broadly, the topography of the Bekenu-Niah-Suai area consists of wide-spread coastal lowlands, forming about a quarter of the area, backed inland by low, wide belts of dissected hills, and bands of high ridges and escarpments rising to about 1,500 feet above sea level (Map 5). The various landforms are described below under the headings used for photo-associations in PART THREE. Following these descriptions a brief account of the Pleistocene geomorphological history of the area is given. This is succeeded by a section in which it is shown that, through its influence on the ground water table and erosion, topography has a profound bearing on soil formation.

### BEACHES

A thin strip of present-day sand beaches backed by abandoned former sand beaches forms the distinctly smooth and stable coastline (Plate 25) apart from a rocky section in the north between Cape Bungai and the Beraya River and a rounded headland at Cape Payong centred on a small coral reef. The belt varies in width from 100-200 feet in the extreme northeast to almost two miles near the mouths of the Nyalau, Suai, and Niah rivers. Abandoned beach outliers occur close to the lower Suai and Niah rivers and between the Trus River and the nearby hills inland.

Strandlines, or former beaches, lie parallel or nearly parallel to the present beach except near river mouths where river currents combined with longshore drift have formed truncated, curved and compound patterns (Plate 1). The highest parts are generally the most recently formed beaches with crests three to four feet above normal high tide level, although at the Niah river mouth there is an area where old beaches are about three feet higher than the most recent beach (Sample Area III, Appendix A). From the shore inland the crests of the beach ridges diminish in height so that the surface of the sand lies close to present high tide level towards the margins of the peat swamps (Sample Area III, Appendix A); this is believed to be due to a continuing slow rise in sea level, although it could partly be explained as a flattening caused by the impact of rain, that would be increasingly effective on successively older beaches. Nossin (p.177) describes higher beaches on the East Coast of Malaya and by contrast puts forward evidence for a recent gradual fall in sea level. The difference in height between beach ridges and the intervening swales is three feet or less and the change from one to the other is generally gradual.

The swales are commonly occupied by swampy ground and are drained by small streams, particularly between the Niah and Suai rivers and south of Cape Payong. A fine-textured parallel drainage pattern is typical, closely controlled by the old beach line pattern; the sources of the permanent streams are the adjacent peat swamps (Plate 14).

### ESTUARIES

The estuarine areas are subject to tidal water flooding and occur mainly at the mouths of the larger rivers. Smaller patches lie upstream in abandoned meanders and inner meander bends, and some occur as lagoonal land between present and former beach lines particularly in the Niah-Suai river coastal belt and from Cape Payong to the Nyalau River. (Plate 14).

Soil Forming Factors  
Topography

The macro topography is flat but in detail the surface is commonly broken by cone-shaped mounds as much as four feet high and wide, formed by burrowing lobsters (Thalassima anomala). In addition to the main rivers traversing some parts there are many small, interconnected meandering channels filled at high tide, that form a temporary fine-textured, anastomosing drainage pattern.

FLOOD-PLAINS

The main characteristics of riverine flood-plains, which here exclude those parts covered by peat (described below), are an almost flat relief and a weakly developed, irregular drainage system.

The flood-plains of the three main rivers form narrow, winding belts in the coastal plain, restricted by flanking peat swamps to less than about 1,000 feet wide and traversed by the meandering rivers (Plate 4). Among the hills the main river flood-plains are augmented by those of tributaries to form an intricate system as much as two miles wide. Because of the width of their valleys in relation to the river width, both the Suai and Sibuti rivers are believed to be misfits (Plate 7), the latter is strongly braided in one section.

The relief is flat except for the slopes of levees which vary from extremely gentle in the lower reaches to gentle in the headwaters of rivers. Levee widths are mostly less than 300 feet except in the upper reaches of some streams where well-drained, gently undulating land fills valley bottoms. Main stream and river gradients are gentle and no waterfalls or rapids were encountered within the areas where flood-plains are developed.

The river pattern is variable. Within the lowlands the Sibuti and Nyalau rivers maintain fairly straight courses as opposed to the Niah, and particularly the Suai River, which flow in wide, sweeping curves and which have left ox-bow lakes in places (Plate 1). The small tributaries in the lower courses of the main rivers are fed by adjacent peat swamps and are weakly developed, narrow and tortuous in plan. The pattern of the middle and upper courses of all main rivers show moderate structural control; the arenaceous rock formations being crossed generally at right angles to the strike and the argillaceous formations being followed in a northeast-southwest direction for long distances. Flood-plain development is greatest in the belts of country where shale is dominant, the largest basins commonly being peat-covered particularly in the Sibuti and upper Suai valleys. (Plate 2 and Plate 7).

PEAT SWAMPS

Peat swamps have developed in the centres of the largest flood-plains near the coast and in the Bakong Valley (Plate 3) but many small peat swamps occur in the middle and upper reaches of main rivers. Some of the smaller swamps in the hills extend completely across a valley.

Soil Forming Factors  
Topography

The surfaces of small peat swamps are flat or slightly rounded and distinct from those of more highly-developed swamps which have a dome-shaped profile (Anderson, 1964; White, 1956). The doming of the larger coastal swamps in this area is indicated by a tendency to coarse-textured, peripheral radial drainage, a level survey from the coast inland for almost four miles showed a maximum gain in height of 15 feet by 2 miles and then a gradual decrease in height to 9 feet at the end of the traverse (Sample Area III, Appendix A). Streams are few, short and tortuous within a narrow meander belt. Rare allocthonous streams originating from the inland hills cross the peat with particularly straight courses, such as the Trus River (lit. straight river).

TERRACES

The terraces characteristically have flat to gently undulating surfaces and vary from remnants a few square feet in area to fairly extensive tracts of as much as half a square mile, and most occur in a belt along the coastal edge of the hills. The most extensive are near Cape Bungai and between the Nyalau and Suai rivers. Small riverine terraces are found in a few places alongside the main rivers, and have also been noted at Beraya. (Plate 26)

Marginal gullying in many places has resulted in the dissection of formerly large terraces (Sample Area I, Appendix A). In addition, at Cape Batu allocthonous streams flowing over once extensive coastal terraces to the sea have separated the cover into many smaller remnants. In the same area the landward side of the terraces is backed by a continuous line of steep-sided hills, possibly an old sea-cliff (Plate 6). Gully flanks and terrace margins have slopes predominantly in the range  $15 - 35^{\circ}$ . There is no permanent surface drainage.

Terrace heights above sea level vary from 5 to almost 100 feet. Heights above local base level are similar and there are well-marked levels at an estimated 5 - 20 feet in all three main valleys, 30 - 50 feet in the Setap Valley, the upper Sibuti and between the Suai and Nyalau rivers, and at 80 - 100 feet at the coast near Cape Bungai.

LOW HILLS

Low hills are dominant in the middle and upper Sibuti Valley and are widespread in the Niah and Suai valleys as broad belts aligned northeast-wouthwest parallel to the general strike. They are underlain almost entirely by argillaceous rock formations and have accordant summits between 30 and 100 feet above local base level.

Although the amplitude of relief is small the hills are dissected into many cone-like hills, and short ridges, wavy in plan and penetrated by an intricate system of valleys (Luak area, Appendix A, Plate 27).

Slopes vary mainly between  $15^{\circ}$  and  $30^{\circ}$  and tend to be convex at the upper slope and slightly concave at the lower slope; there is almost invariably a sharp break between lower slopes and the valley bottom. Hill tops are sharp to rather sharply rounded.

Soil Forming Factors  
Topography

The main elements of the drainage pattern appear to follow the geological strike, as do minor streams in some places. Together, however, predominantly fine-textured dendritic patterns are formed with many, narrow tortuous flood-plains. (Plate 5)

RIDGES

High ridges are formed on the thicker sandstone beds of the arenaceous rock formations, and are most common in the middle and upper river areas as long narrow belts aligned parallel to the regional strike. They also occur in the land between the Jangalas river area and the coast as an extension of the Lambir Hills. (Plates 12, 28, 29).

The amplitude of relief varies between 150 and 300 feet but rises in places to 500 feet and there is a general accordance of summits at between 200 and 300 feet above local base level. Dissection has produced slopes mainly between  $20^{\circ}$  and  $35^{\circ}$ , and many ridges are asymmetrical in section (Sample Area V, Appendix A). The summits are strongly rounded to sharp, upper slopes tend to be slightly convex and the footslopes to be slightly concave. On the steep upper slopes of some ridges are cliffs with more gently sloping screes beneath; these are the most common source sites of landslides. There is invariably a sharp break in slope between foothill and valley bottom.

The ridges are commonly as much as five miles long, most are straight in plan except in the upper Sibuti Valley where they curve following the strike of rock (Map 4). Dissection of this landscape is principally effected by headward erosion of strike streams which produces series of parallel ridges separated by narrow valleys. Erosion of ridge flanks takes place by landslides and gullying, which become more intense with increasing steepness and length of slope (Plate 6). Intense gullying of a ridge produces fluted flanks, saw-edged in plan, such as in the lower Suai area.

Drainage lines are strongly influenced by the parallel pattern of intervening ridges. Main and minor streams are linear with angular bends where crossing the strike of rocks (Plate 9).

CUESTAS

Cuestas, like the high ridges, are found only on the arenaceous rock formations and occur as narrow belts in the Lambir Hills, in the Upper Sibuti and Niah Valleys, and in the watershed between the Nyalau and Niah rivers and in the Igang Hills.

Most cuestas dip at  $15 - 30^{\circ}$  although in the upper Sibuti (Plate 9) and near the Suai River the slopes are less. The gentler slopes tend to be longer and less gullied than steeper ones, and have a lower amplitude of relief, in places as little as 50 feet. The cuestas of the Lambir and Igang Hills exceed 400 - 500 feet in amplitude and in the former area rise exceptionally to about 800 feet. Here the dip slopes are uniformly moderately steep in the order of  $20^{\circ}$  and the cuestas in places resemble hogback ridges. (Plates 11, 29, 30).

Soil Forming Factors  
Topography

Scarp slopes everywhere exceed 25° and are commonly cliffed; scarp footslopes are generally underlain by fine scree material, through which large boulders protrude. The screes are more gently sloping than higher parts of the scarp. There is a distinct break in slope between scarp foothills and adjacent valley land as opposed to the more gradual change from dip slope to flat valley.

Gullies in gentle dip slopes are fewer and less deeply incised than those on steep slopes. Scarp-slope gullies are most pronounced in the Lambir Hills where headward erosion has resulted in the breaching of scarps in several places. (Sample Area IV, Appendix A).

The drainage pattern is rectangular or trellis-like in most places. The main stream direction is parallel to the strike except in the Lambir Hills where the main streams flow either across the strike towards the Bakong River or to the coast.

LIMESTONE

Limestone, forming typical tropical karst topography (Wilford and Wall, p.44-70) underlies 7 square miles at Subis. The main karst features are high cliffs, rugged pinnacled surfaces, caves and an underground drainage system (c.f. other tropical Karst areas - Verstappen, 1960; Paton, 1964; Sweeting, 1958).

The Subis limestone hills rise to between 800 and 1,300 feet above local base level and form a compact block with few outliers; they are angular in plan with long, straight sides. Their flanks are mostly cliffed (Plate 18) except at the lower slopes in places where high-angle boulder screes occur. The summits of the hills present an even to slightly rounded, bread-loaf appearance from a distance. At close quarters however, it can be seen that the surface is extremely broken and composed of many, sharply pointed and vertically fluted lapies rising from a bouldery, irregular surface, pitted with holes, many of unknown depth (Plate 13). Holes and depressions occur chiefly along well-defined joint lines and joint intersections; they vary in size from a few feet in width and depth to some two hundred feet across; some are floored with alluvium. In the southeast corner of the Subis area intense dissection has left many tall, spire-like limestone remnants rising from scree-covered lower slopes. The footslopes of many cliffs have horizontal grooves and undercuts associated with cave systems.

Surrounding most of the karst hills are alluvial flats with small lapies projecting through the surface. The hills are drained by underground streams. Streams in adjoining alluvial flats all tend to flow close to the foot of the hills; and some, such as a tributary of the Tangap River, flow through hills via caves.

The limestone in the Mulis Valley (Suai) forms a flat-topped platform about six to ten feet above local base level, covered partly by alluvium, and is slightly dissected along joints. In the Gelasah Valley (Suai) sandy limestone outcrops in the scarp slope of a small cuesta dipping at 15° and is deeply dissected along joints. Other lenses of limestone partly covered by soil have been noted in the Penirak area (Sibuti), and close to the coast near Cape Batu.

Figure 23 Diagrammatic section across coastal area showing types of parent material and soils.

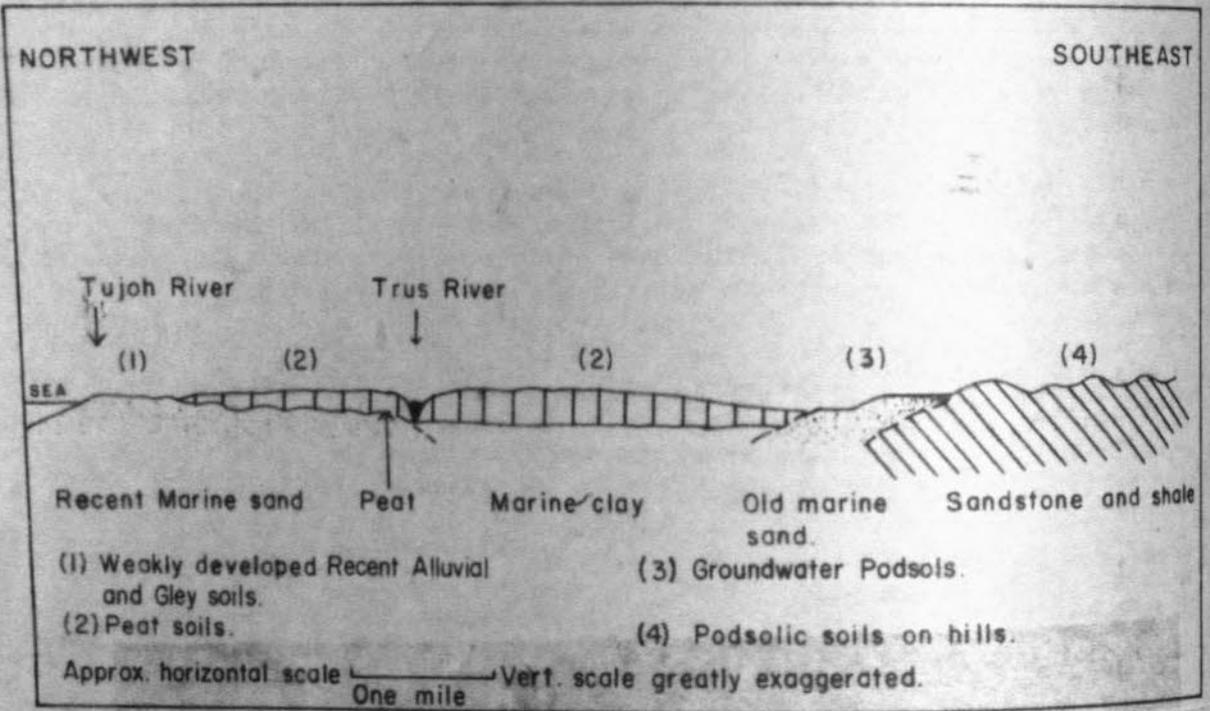
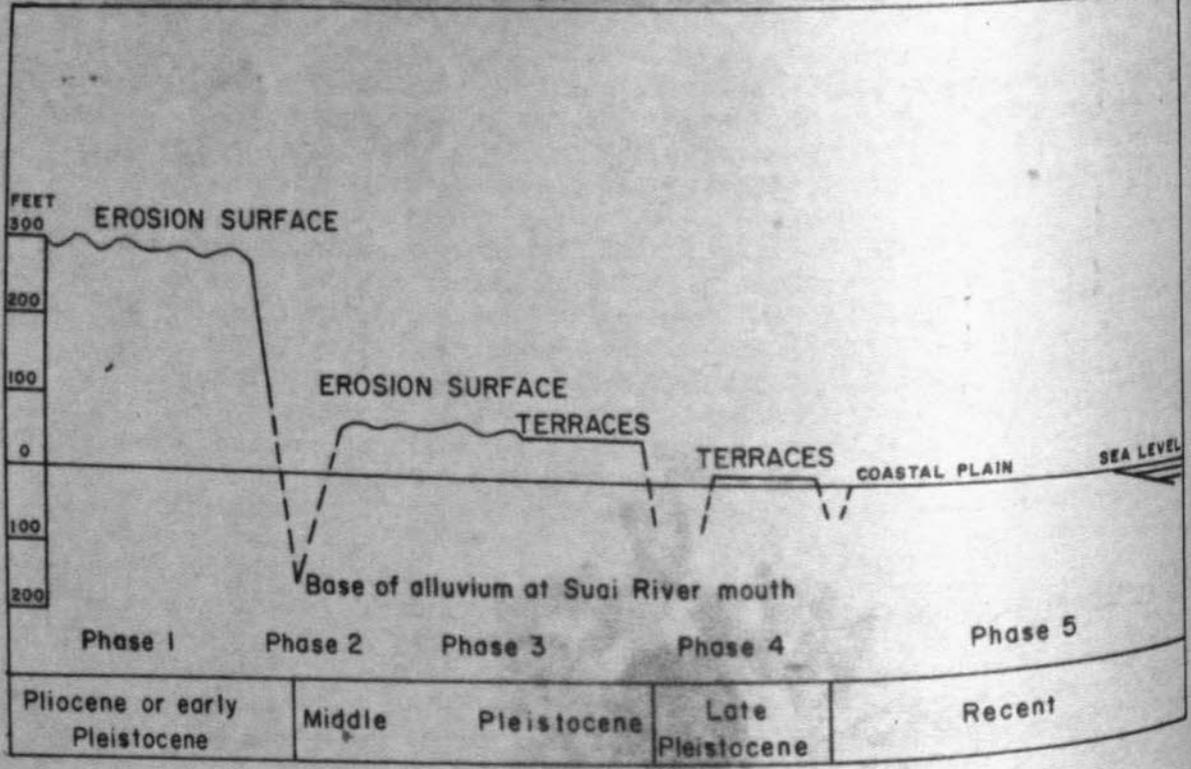


Figure 24 Diagram showing five phases in the geomorphological history of the Bekenu Niah-Suai area (modified from Liechti, 1960, p. 327)



QUATERNARY GEOMORPHOLOGICAL HISTORY

The brief outline given below of the probable geomorphological history of the Bekenu-Niah-Suai area draws on accounts of the regional Quaternary history of Sarawak and Sabah (Liechti et al, ch. VIII), and of Brunei and North Sarawak Wilford, p.125-142) supplemented by additional data collected during the soil survey.

The main phases in the history of the area are summarised below and shown diagrammatically in Fig. 24.

1. Phase of prolonged erosion in the late Pliocene or early Pleistocene producing an erosion surface, now dissected leaving areas of ridges and cuestas with accordant summits 250-300 feet above local base level. Consequent(?) drainage system established.
2. Phase of rejuvenated erosion in the early Pleistocene, produced by regional uplift and supplemented by a withdrawal of the sea, of a maximum of 400-450 feet. Drainage system reestablished in a southeast to northwest direction.
3. Phase of aggradation in the middle Pleistocene following a rise in the sea level of about 150 to 200 feet. Terraces formed which are now 30-90 feet above local base level.
4. Successive phases of degradation and aggradation in the late Pleistocene following eustatic changes, causing the lower terraces to be built now at about 5-20 feet above sea level.
5. Building up of the coastal plain behind offshore bars in recent times.

Details of these phases and evidence for them is given below:

PHASE ONE

Widespread degradation of relief occurred throughout this area during the late Pliocene (Wilford, p.125; Haile, p.83), or early Pleistocene (Liechti et al, p.308) resulting in the cutting of a well-defined erosion surface. In the Bekenu-Niah-Suai area the surface is moderately well developed areally and is inferred by the accordant summits at 250 - 300 feet above local base level of ridges and cuestas which are developed on the more resistant, sandstone formation (Plate 9). Softer shale-built hills have largely been lowered since. (Fig. 25) The massive sandstone underlying the Igang and Tiban hills and the limestone of Subis (Plate 18) probably formed monadnocks during this period (Map 6). It has been suggested (Wilford, p.129) that the gently arching summit line of Lambir Hills (Plate 30) is indicative of an upwarped erosion surface of this age, although it is suspected that the Central Hills at least were already partly uplifted by this time as there is a moderately well-developed accordance of summits at 300-350 feet at their margins. (Fig. 26)

Figure 25 Diagrammatic section showing contrasting landforms caused largely by the much greater resistance to erosion of limestone compared to shale

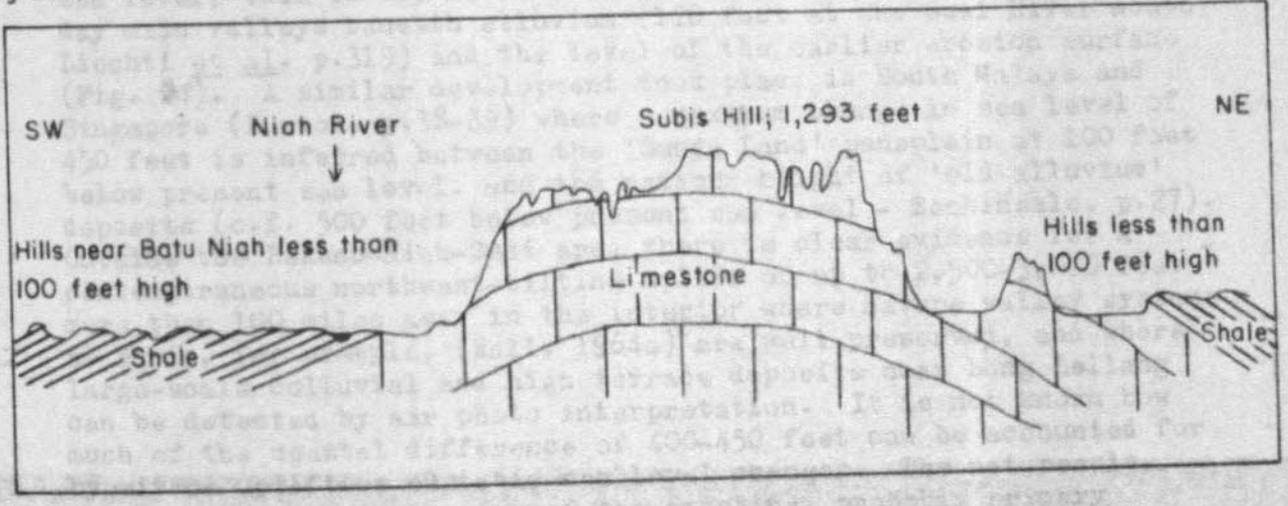
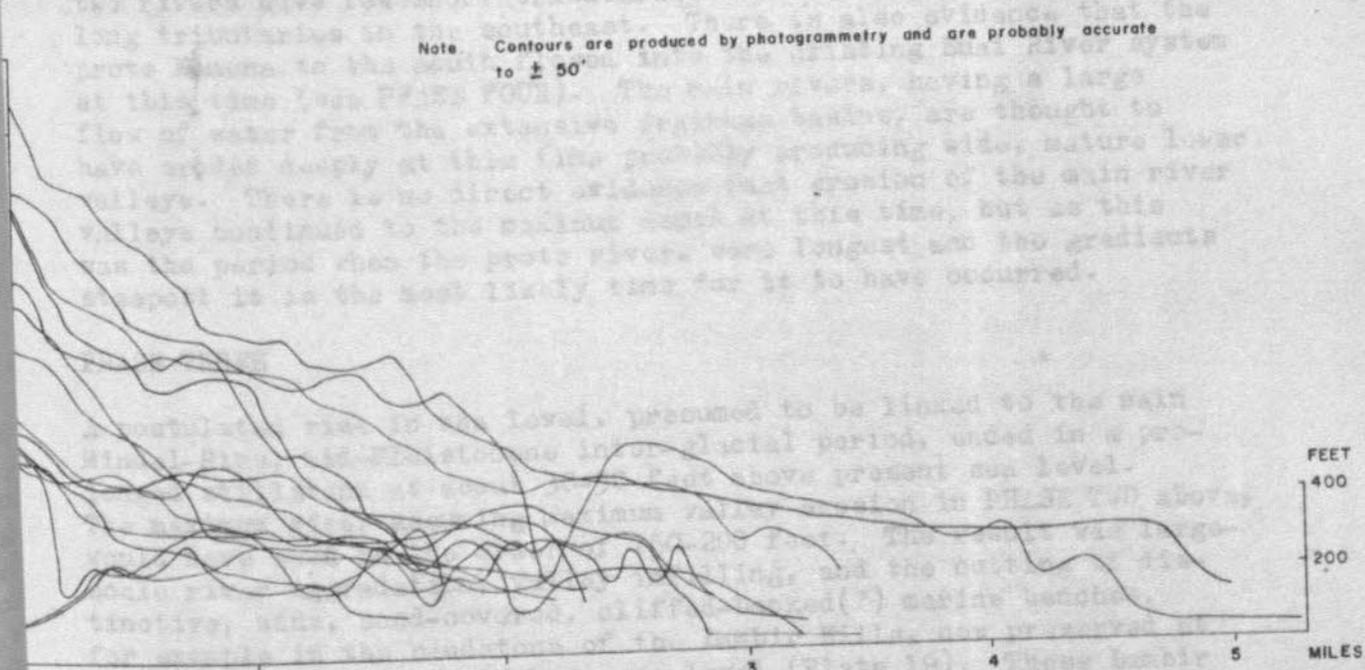


Figure 26 Profiles of main spurs of the Lambir Hills and adjacent areas (from 1:50,000 contoured map)



at an elevation of 30-100 feet above sea level (Plate 19). These Lambir hills are terraced with gentle northeast and are about 20-30 feet above sea level near Marit; the tilting is probably partly a result of middle Pleistocene reactivated unwarping of the adjacent Lambir Hills (Malaya, p. 129) and downwarping of parts of the lower Baram basin and thus the terraces can be considered the equivalent of the wide-spread marine and riverine terraces at 30-50 feet above local base level in Borneo and elsewhere (op. cit.). This level of terrace is particularly common in a narrow belt behind the coastal plain and along to main rivers, such as in the Tayan River area.

During this mid-Pleistocene period the sea probably covered much of the country underlain by shales that is now at an lower level (Map 6). Subsequent erosion however, has removed practically all traces of marine or estuarine alluvium and sea level the general level of the low, higher mountains-hills at least 100-150 feet above local base level (Plate 21).

## PHASE TWO

In the early Pleistocene eustatic movements, probably coinciding with the first major glaciation and possibly concomitant with regional uplift, resulted in a maximum drop of 400 to 450 feet in sea level; this is the maximum height between the base of present-day main valleys beneath alluvium (120 feet at the Suai River mouth; Liechti *et al.*, p.319) and the level of the earlier erosion surface (Fig. 24). A similar development took place in South Malaya and Singapore (Burton; p.38-39) where a maximum change in sea level of 450 feet is inferred between the 'Sunda Land' peneplain at 100 feet below present sea level, and the maximum height of 'old alluvium' deposits (c.f. 500 feet below present sea level - Beckinsale, p.27). Outside the Bekenu-Niah-Suai area there is clear evidence for a contemporaneous northwest-tilting uplift of up to 2,500-3,000 feet more than 100 miles away in the interior where mature valley systems at Bario, for example, (Wall, 1964a) are well preserved, and where large-scale colluvial and high terrace deposits near Long Lellang can be detected by air photo interpretation. It is not known how much of the coastal difference of 400-450 feet can be accounted for by either uplift or eustatic sea level changes. The net result, however, was a rejuvenation of the existing, probably primary consequent, southeast-northwest draining rivers, of which the proto Tinjar River and possibly the proto Baram River flowed over this area to the sea (Map 7). The present main middle courses of these two rivers have few short tributaries in the northwest and many long tributaries in the southeast. There is also evidence that the proto Kemena to the south flowed into the existing Suai River system at this time (see PHASE FOUR). The main rivers, having a large flow of water from the extensive drainage basins, are thought to have eroded deeply at this time probably producing wide, mature lower valleys. There is no direct evidence that erosion of the main river valleys continued to the maximum depth at this time, but as this was the period when the proto rivers were longest and the gradients steepest it is the most likely time for it to have occurred.

## PHASE THREE

A postulated rise in sea level, presumed to be linked to the main Mindel-Riss, mid-Pleistocene inter-glacial period, ended in a prolonged stillstand at about 30-50 feet above present sea level. The maximum rise, assuming maximum valley erosion in PHASE TWO above, would have been in the order of 150-200 feet. The result was large-scale river aggradation, valley infilling, and the cutting of distinctive, wide, sand-covered, cliffed-backed(?) marine benches, for example in the sandstone of the Lambir Hills, now preserved at an estimated 80-100 feet above sea level (Plate 19). These Lambir terraces tilt gently northeast and are about 20-30 feet above sea level near Miri; the tilting is probably partly a result of middle Pleistocene reactivated unwarping of the adjacent Lambir Hills (Wilford, p.129) and downwarping of parts of the lower Baram basin and thus the terraces can be considered the equivalent of the wide-spread marine and riverine terraces at 30-50 feet above local base level in Brunei and elsewhere (*op. cit.*). This level of terrace is particularly common in a narrow belt behind the coastal plain and close to main rivers, such as in the Nyalau River area.

During this mid Pleistocene period the sea probably covered much of the country underlain by shale that is now at or lower than terrace level (Map 8). Subsequent erosion however, has removed practically all traces of marine or deltaic alluvium and has left the general level of the few, higher shale-built hills at less than 100-150 feet above local base level. (Plate 27)

Soil Forming Factors  
Topography

The age of a 50 feet high marine terrace in Brunei can be put at less than 710,000 years (Zahringer and Ventner p.583) based on the presence in the terrace of potassium-argon dated, reworked rounded tektites. Closely similar tektites, both physically and chemically, and thought to belong to the same meteoric shower, have been found in the upper Trinil Beds of Java containing upper Middle Pleistocene vertebrate faunal remains (op. cit.). In addition, wood remains from a possibly contemporaneous Brunei marine terrace have been dated at more than 40,000 years. (op. cit. p.131).

Recently Harrison (pers. comm.) has described in situ marine oysters beds (Oestrus gigus) inside a large cave at Subis, which have been measured at 40-50 feet above sea level. These have been dated by the radio carbon method at 37,500 years (+-2,400 years). The date, however, is late Pleistocene and correlates with the Riss-Wllrm interglacial rather than with the earlier Mindel-Riss interglacial. Clearly, before any definite conclusions can be drawn on terraces ages much more dateable material needs to be found from all the terraces concerned. Detailed contoured maps are required to help differentiate between terrace levels and more knowledge is needed on the extent and location of recent warping movements. It would also be useful to study cave levels at Subis to determine whether there was any concentration at particular heights that coincide with terrace heights.

PHASE FOUR

Subsequent late Pleistocene history is uncertain in detail, but further lower stillstands are indicated by terraces between 5 and 20 feet above local base level. (Plate 26) There is no evidence from this area for or against an oscillatory lowering of the sea level, that would conform with known temperate latitude late Pleistocene interglacial phases.

It is probable that regional downwarping of the present lower Baram area in the middle to late Pleistocene (Wilford, p.132) and subsequent to PHASE THREE above, diverted the middle and upper Tinjar and Baram rivers into it, or allowed their capture, leaving the present Niah and Sibuti rivers as truncated remnants, the last as a misfit river. The Niah River lies in direct line with the middle Tinjar River, with only 150-foot high ridges of sandstone on the watershed between, and maintains as overall primary consequent course following a well-established, Tertiary lithological divide (Liechti, p.281). In addition, the fish species in those two rivers is similar and quite distinct from that of nearby rivers (Harrison, pers. comm.). The Sibuti River has been diverted west in its lower course by the upwarped Lambir Hills; it is a misfit river flowing almost throughout the course in a wide plain of deep peat and alluvium: its headwaters are separated from the Bakong River system only by a narrow but deep peat swamp, and between the Bakong and Baram Rivers at Long Miri is a corridor of low hills following the present Tinjar course for a part of the way.

Soil Forming Factors  
Topography

Similarly the Suai River also appears to be a misfit river and its lower course has apparently changed from time to time: two gaps in the coastal hills have probably been abandoned, in addition to an old course, now occupied by the Trus River, leading from Iran village to the Niah River mouth. This last course is well shown by the distribution of a narrow belt of old alluvial clay between coastal hills and peat-covered beach sand. In the upper Suai area are two pronounced northeast-southwest trending low lying belts composed of argillaceous rocks and containing deep, peat-filled basins (Map 4). The southernmost basin extends to and is partly drained by a tributary of the Kemena River. It is possible that these lines represent Pleistocene downwarps, similar in nature to those postulated in the Baram area to the north, and continuing already proven mid and late Tertiary synclinal movements (Liechti, p.301). Activity of this nature, possibly aggravated by late Tertiary - early Pleistocene block faulting in the Tinjar area (op. cit. p.281) may have interfered with an earlier Suai drainage system. On present morphological grounds it is conceivable in mid Pleistocene times that the river included via the Kemena system upstream from Tubau, the upper Rajang system, but there is a more direct outlet for this course than the Suai River in the Semilajau River area.

PHASE FIVE

In recent times the building out of the coastal plain has added 200 square miles to the pre-existing land mass. Within the last few thousand years sand, derived largely from coastal outcrops of sandstone in the north and to the south of the area, has been distributed by longshore drift to form inshore (near Iran and Niah village) and offshore bars as shown by the present distribution of old beaches (Map 4). Behind the established sand bars and in the progressively calmer waters sedimentation of riverine alluvium gradually filled in the shallow sea aided by pioneer mangrove and nipah vegetation (p.129). As river levees became established on the new mud flats basins were formed enclosed by the hills inland, river levees laterally and sand beaches at the coast. In these basins the hydromorphic conditions required for peat formation were ideal and the peat swamps increased in depth sufficiently rapidly to maintain slow drainage outwards to rivers. The gradual decrease in height of sand beaches with increasing distance inland (Sample Area III, Appendix A) suggested a slow rise in sea level height in recent times, in contrast to the fall postulated in East Malaya. (Nossin, 1964b, p.177).

The present coastline appears to be stable, since apart from the sandstone cliffs at Cape Nyalau, Cape Batu and Cape Bungai and the sea-level headland at Cape Payong, which is formed of coral, the coastline is straight. Old beachlines show that the former coast was aligned more northeast-southwest between the Suai and Niah rivers than at present.

TOPOGRAPHY AND SOIL FORMATION

The shape and size of the landforms have a direct bearing on the position of the groundwater table, which is responsible for the degree of hydromorphism of soils, and on erosion, which is a contributory factor in determining soil depth.

Soil Forming Factors  
Topography

GROUNDWATER TABLE IN RELATION TO TOPOGRAPHY AND SOIL FORMATION

In hill land it is probable that on the upper slopes the water table only temporarily rises to the surface after particularly prolonged rain and that normally the upper level of saturation deep within the hills forms a much flatter curve than that of the surface topography. Road cuttings in the Lambir Hills have exposed gently dipping, soft and dense clay-shale and permeable sandstone successions; these commonly reveal water seeping rapidly out of the sandy layers after heavy rain, but this can be considered more as a temporary rise in the level of local water tables perched above dense clay beds than that of the regional ground water. The almost complete absence of high ground water in the hills is shown by the non-hydromorphic character of residual soils within auger depth (48 inches): the soils only show signs of impeded drainage in the weathering zone of weakly permeable shale, and in the small areas of shallow soils on gentle dip slopes in the upper Bakong-Sibuti-Niah area.

Terraces in the area have an almost level surface and a highly permeable sandy soil which together allow maximum penetration of rainwater as far as underlying impermeable rock or soil horizons, either of which form the base for a perched water table. This commonly lies within 5 to 10 feet of the surface and is a zone of slow lateral water seepage.

In the lowlands permanently high water tables produce completely gleyed hydromorphic soils in the large alluvial basins bounded by the coastal beaches, river levees and hills. The largest and most poorly drained of such basins, for example, those in the coastal and Bakong River plains, form ideal situations in which organic bog soils can accumulate under permanently anaerobic conditions; similar but small deep peat swamps occur in the Sibuti and Suai valleys where formerly large rivers produced wide alluvial basins.

Soils in the lowlands are subjected to water table movements that fluctuate periodically within two to six feet of the surface, and occur in river levees, old and recent beaches and in some narrow inland valleys. The alternately dry and wet conditions cause partial gleying and the local concentration of soluble ions seen as strongly-coloured mottles within the zone of fluctuation and characteristic of semi-hydromorphic soils. The water table of the highest river levees and most recent beaches lies deeper than four feet except during rare floods and the soils in these locations are non-hydromorphic.

The ground water in parts of the coastal and estuarine areas is saline due to the proximity to the sea, or brackish due to proximity to tidal rivers. The water table lies close to the surface and fluctuates regularly, by as much as three to six feet close to rivers. Continuous flooding by saline or brackish water causes large quantities of salts to be deposited in the soil. These tend to be retained in clay and organic soils long after tidal flooding ceases, but in highly permeable coastal sands the freshwater gradient from high peat swamps inland washes out much of the salts to within a few feet of the sea.

Soil Forming Factors  
Topography

EROSION

Erosion is only significant among the hills and terraces and in particular effects the sandy soils. From observations of surface water, runoff water, and stream water during heavy rain it appears that in fine-textured soils clay is loosened by the impact of rain and removed downslope in suspension by the high surface runoff leaving behind a surface residue of fine sand grains. Dense, weakly permeable clay soils are generally found on gentle to moderately steep, slightly gullied low hills; on clay soils of higher hills the gullies tend to be more pronounced, possibly because the sand fraction of the soil and permeability is invariably greater than on lower hills, particularly in the upper subsoil (see below).

The most sandy residual soils occur on the high knife-edged ridges and cuestas where slopes vary from gentle to cliffed. In this type of topography clay is apparently removed in a similar fashion to that described above, but despite the steep slopes there is relatively low surface water runoff and a correspondingly high rate of soil water penetration and therefore much less removal of soil by surface wash. Most of these highly sandy soils are under forest and the thicker litter that is prevalent compared to that on more clayey soil is instrumental in protecting the soil from surface erosion. Gullies, however, are common on both steep and gentle slopes. These develop principally by headward erosion forming steep-sided, rock-floored, narrow, V-shaped clefts, terminating in steep gully heads commonly containing a spring. Incipient gully formation also develops in some places by underground sapping, as revealed by strings of oval hollows on the slopes above and in line with existing gullies. These probably develop by the removal of soil particles down through widened joints in the sandstone.

Large scale erosion occurred in permeable sandy soils during 1963/64 after abnormally prolonged heavy rain. Landslides, slumps, slips and mass wasting of all kinds pock-marked primary forest areas and devastated some recently planted rubber land just to the northeast of this area (part of the Lambir Hills, Plate 15, and Plates 6, 1, 22, 29). No measurements of soil moisture were taken but it is probable that this type of permeable soil (Nyalau Family, p. 66) reached saturation point readily, causing the soil on steep slopes to become unstable through increased weight and decreasing friction. A slope of about 20° appears to be the lower limit for landslides in very sandy soil. In Sample Area V, (Appendix A), 11% of the 60 acres studied were affected by landslides or mudflows.

Soil depth is partly a measure of erosion effectiveness and varies with steepness of slope and resistance of rocks to weathering. The deepest soils in the area develop in the gently sloping alluvial areas and in soft shales of low hills with moderately steep slopes, where soil profiles of 5 - 10 feet are common. In general the sandstone-derived soils are shallower than those on shale and develop on steeper, in places cliffed, slopes, although those developed over Lambir Formation rocks are commonly deep. Bare rock is dominant at Subis (Plate 18) where the highly resistant limestone forms cliffed karst topography, whose origin is explained in terms of lithology and structure under a wet environment. (Wilford and Wall, p.44-70).

Fig. 27. SCHEMATIC VEGETATION PROFILE OF LITTORAL FOREST AND PEAT SWAMP FOREST MARGINS based on SAMPLE AREAS II AND III

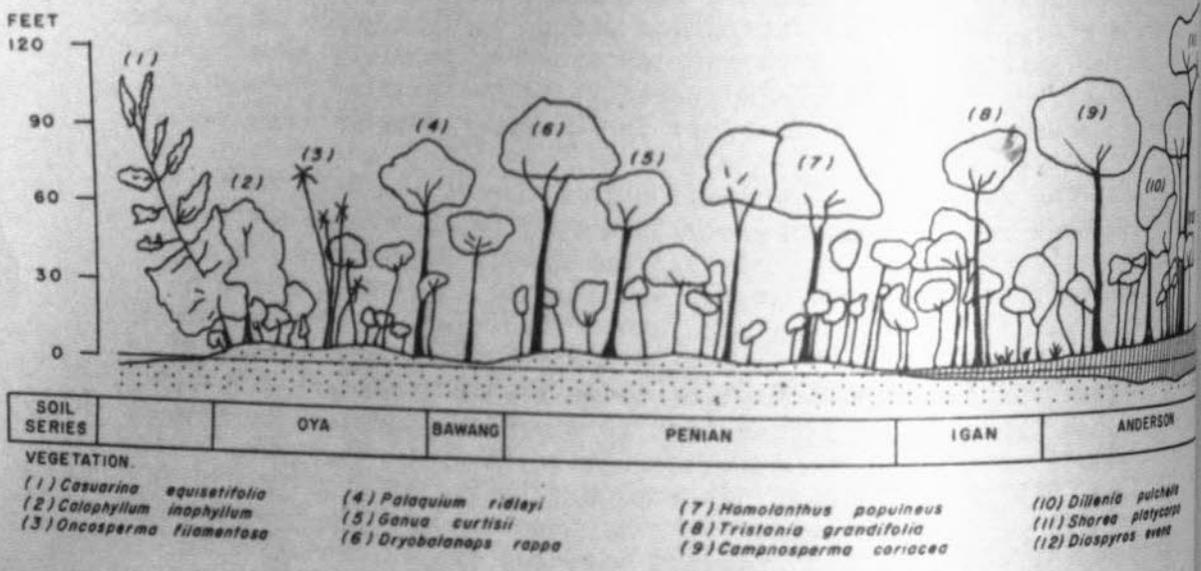
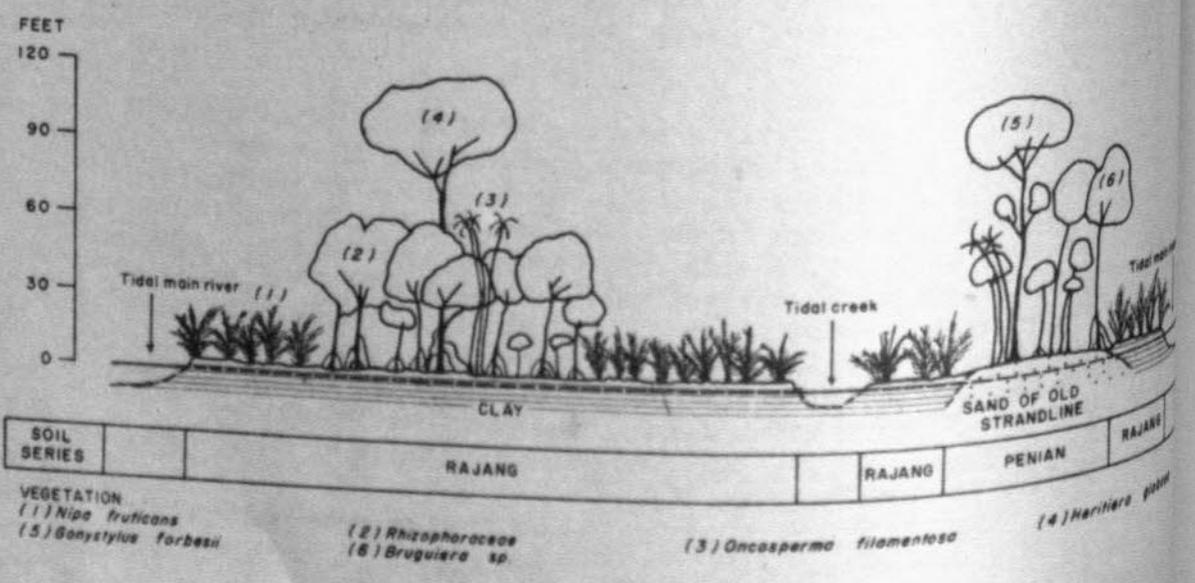


Fig. 28. SCHEMATIC VEGETATION PROFILE OF SALTWATER SWAMP FOREST



## VEGETATION

Primary forest covers approximately 70 per cent of the surveyed area, the remainder being either secondary forest or areas under cultivation. The primary forest can be divided into seven broad vegetation types on an ecological basis, as shown on Map 9; six types correspond to similarly named photo-associations in PART THREE and to soil associations described in PART FIVE. The physiognomy and floristic composition of each are described briefly below and the section is concluded by a discussion of the role of vegetation in soil formation. Detailed descriptions of Sarawak forest communities are given by Richards (1952), Anderson (1958, 1963, 1965), Ashton (1964) and Browne (1952), mainly from the ecological aspect.

### PRIMARY FOREST

#### LITTORAL FOREST

Littoral Forest is characterised by a narrow range of habitat found close to the shoreline, an evergreen, predominantly broadleaf and commonly sclerophyllous composition of varying height and density and a marked floristic succession of trees from the coast inland.

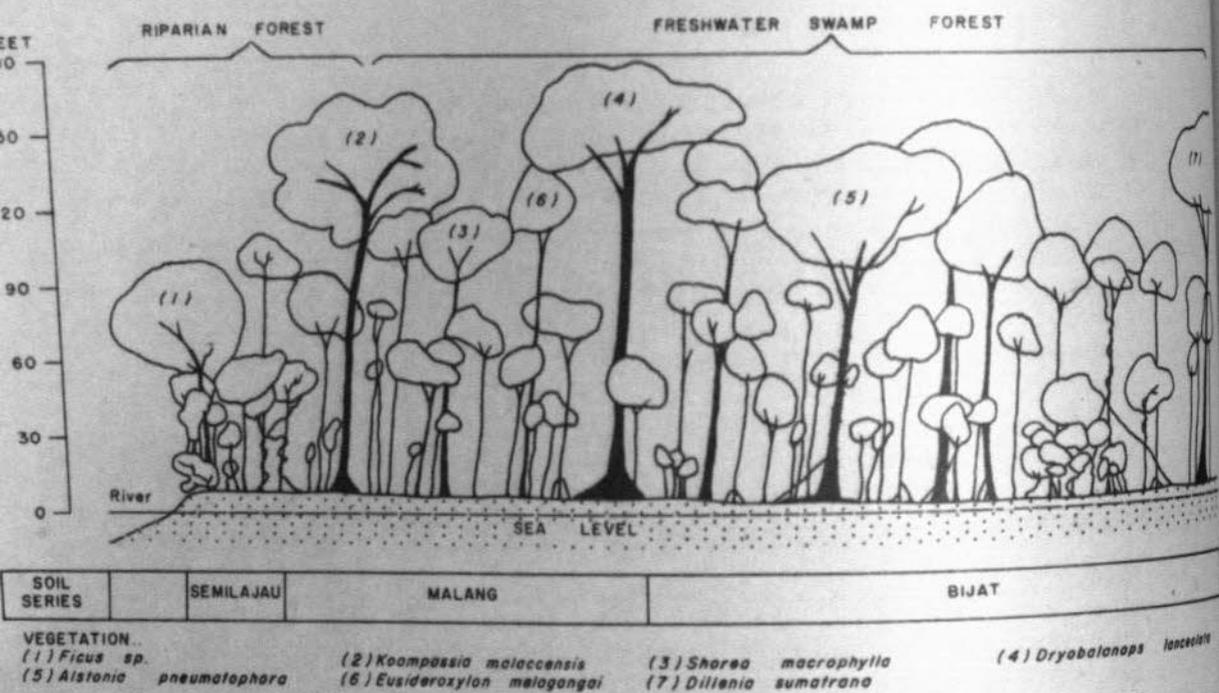
The distribution of Littoral Forest is confined to parts of the narrow coastal belt between the main rivers as described already under BEACHES in a previous section (p. 36) and the boundaries are predominantly clear except with those of Peat Swamp Forest. The vegetation and associated soils are shown on the maps of Sample Areas II and III (Appendix A) and schematically in Fig. 27.

On the shoreline the trees present a dense appearance with little light reaching ground level. They range widely in appearance from the tall, slender, conifer-like Casuarina equisetifolia (Plate 25) to the 30- to 60- foot high, sclerophyllous Calophyllum inophyllum. Pandans, saplings and bushes fill the lower levels. Soils on the shoreline are sandy, weakly leached, of low fertility and well to excessively drained members of the Kabong Family (p. 147) with impersistent scattered litter and thin topsoil.

Immediately behind the shoreline the density of trees tends to be lower. Thickets of the tall, stemmed palm Oncosperma filamentosa are common and the main tall trees attain heights of 80 to 100 feet, such as Palauquium ridleyi, Dryobalanops rappa and the strangling fig Ficus crassiramea. The soils in this belt are sandy, strongly leached, infertile and predominantly well-drained; they range from weakly developed Kabong Family soils to well-developed Miri Family (p. 92) humus podsoils. The topsoil is commonly disturbed by the rooting activity of wild pigs. In this belt it is common to find poorly drained swales (Plate 31), some with small, sluggish permanent streams. The large-canopied tree Heritiera globosa is present in swales subject to brackish water flooding.

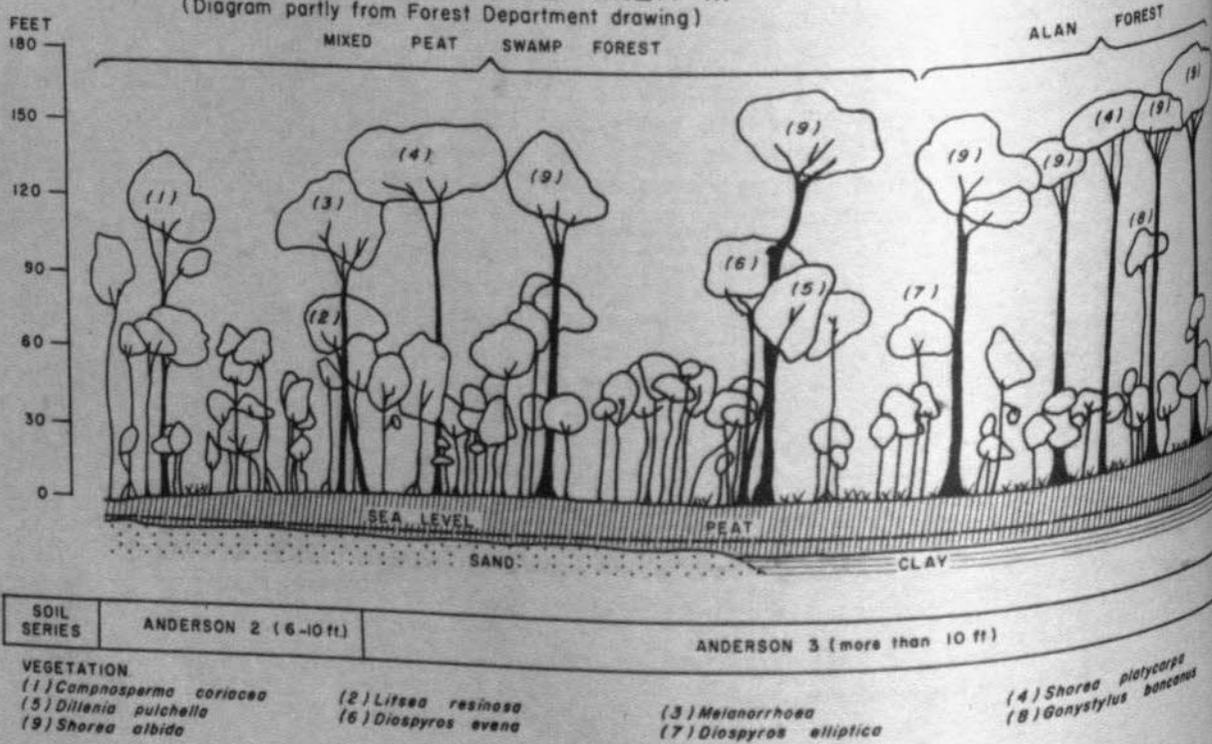
g. 29.

# SCHEMATIC VEGETATION PROFILE OF FRESHWATER SWAMP FOREST AND RIPARIAN FOREST



# Fig. 30. SCHEMATIC VEGETATION PROFILE OF PEAT SWAMP FOREST

based partly on SAMPLE AREA III  
(Diagram partly from Forest Department drawing)



Soil Forming Factors  
Vegetation

With increasing distance inland the tree density tends to increase and light density of ground level correspondingly decreases to about 90-95% shade. The canopy is rather irregular at between 100 and 130 feet high, the main trees being Tristania grandifolia, Ganua curtisii, Dryobalanops rappa and Parishia sericea. Many trees have buttresses, a few have stilt roots. The underground contains common saplings, sedges and stemless palms such as Salacca conferta. Soils in this belt are sandy but poorly and very poorly drained, most are members of the Matu (p.105), and Buso (p. 93) families with thick, slightly peaty, surface organic horizons overlying sands of low fertility.

Beyond this zone the vegetation rapidly resembles that of peat swamps. The canopy increases in height slightly but remains somewhat irregular and gives 95-100% shade at ground level. The dominant trees are Dillenia pulchella, Shorea platycarpa and Camposperma coriacea; many are buttressed while some have pneumatophores or stilt roots. The undergrowth is fairly thick and contains many pandans at ground level. The soils belong to the Igan Family (p. 126) and comprise 10 to 40 inches of raw, water-logged peat overlying sand.

SALTWATER SWAMP FOREST

The distribution of Saltwater Swamp Forest is the same as that described in a preceding section for ESTUARIES (p. 36) and the boundaries with other forest types are sharp. The vegetation is shown diagrammatically in Fig. 28 with the associated soils.

The forest canopy is regular, and less than 20 to 30 feet high wherever the dominant stemless palm Nypa fruticans occurs (Plate 32). Interspersed with this gregarious palm are clumps of mangrove reaching 40 to 60 feet high; Rhizophora apiculata (Plate 33) form the dominant vegetation near the Sibuti River mouth. Some mangrove have pneumatophores and some have stilt roots. Despite the high density of vegetation light penetration is moderately high, but undergrowth density is conspicuously low. On the margins of this forest type clumps of Oncosperma filamentosa occur and on river banks the distinctive tall tree Heritiera globosa with sinuous, plank-like buttress roots is common.

Soils associated with this forest are almost entirely poorly drained, grey saline clays to sandy clays of the Rajang Family (p. 116). There is impersistent raw organic litter in patches and the surface soil is commonly broken by two- to three foot high mounds built by the burrowing lobster.

Thalassima anomala.

FRESHWATER SWAMP FOREST AND RIPARIAN FOREST

In the alluvial basins of the main tributaries of the upper Sibuti, Niah and Suai rivers, and in the headwaters of some streams near the coast is Freshwater Swamp Forest bordered on river banks by strips of Riparian Forest. Although the two types are distinct the Riparian Forest occupies such a narrow fringe on the river bank and commonly is almost engulfed by the Freshwater Swamp Forest that it is convenient to describe them both in this subsection. Both forest types are evergreen, broad-leaved and are varied in physiognomy and

Soil Forming Factors  
Vegetation

composition. The boundaries with other vegetation types are clear, except in places with that of Peat Swamp Forest. The vegetation and associated soils are shown diagrammatically in Fig. 29.

Freshwater Swamp Forest has a highly irregular closed canopy with common emergents rising to more than 120 feet above ground level such as Alstonia pneumatophora, Eugenia spp. and Eusideroxylon melagangai. At lower levels the vegetation varies from being almost closed by thickets of bushes and woody and palmaceous creepers to being almost clear. Shade at ground level varies between about 70-90%. Many trees are buttressed, some have stilt roots and pneumatophores. The soils associated with this forest type are characterised by poor to very poor internal drainage. They are predominantly clays of the Bijat and Sebandi families. (p. 101 and p. 104 ), and contain thin peaty topsoil in places. Those places subject to most frequent flooding have the clearest undergrowth.

Riparian Forest occupies the thin fringe on river banks and merges inland with Freshwater Swamp Forest. In upstream areas where it is best developed Freshwater Swamp Forest presents an impenetrable appearance from the river with a thick ground cover of bushes and climbers giving way to saplings then medium height and tall trees. Emergents such Koompassia excelsa, Shorea macrophylla and various Ficus spp. are common, and Dryobalanops lanceolata also occur a little further inland, where the undergrowth is thin and shade at ground level is between 70 and 90%. Buttresses and other adaptations to a wet soil environment are rare. Soils are typically the well drained and generally deep members of the sandy Semilajau Family (p. 69 ) or the more clayey Malang Family (p. 70 ). Topsoil and surface litter are impersistent and thin. Flooding is periodic but not long-lasting.

#### PEAT SWAMP FOREST

The distribution of Peat Swamp Forest is widespread and coincident with that of the PEAT SWAMPS described in a previous section (p. 37 ). It is evergreen, broadleaf forest varying widely in physiognomy and composition and, as with Littoral Forest, there is a perceptible zonation from the fringes towards the centre. Boundaries are clear except in places with Heath Forest, Littoral Forest and Freshwater Swamp Forest. Associated soils are shown the maps of Sample Area III (Appendix A) and diagrammatically in Fig. 30.

The forest of the outer margins of the most highly developed and generally largest swamps, such as the Bakong River swamps and those behind the coast, is termed Mixed Peat Swamp Forest. This type has an irregular canopy rising to 130 to 160 feet high. In Sample Area III the dominants included Camposperma coriacea and Melanorrhoea tricolor giving way inland to Diosphyros elliptifolia, D. evena and Gonystylus bancanus. Trees of grith exceeding 12 inches average about 60 to 70/acre. At ground level the vegetation density is generally high due to the presence of pandans, Salacca sp., aroids, sedges and saplings (Plate 34). Shade at ground level reaches 90 to 100%. Buttresses, stilt roots and pneumatophores are common features.

g. 31. SCHEMATIC VEGETATION PROFILE OF  
HEATH FOREST  
based on SAMPLE AREA I

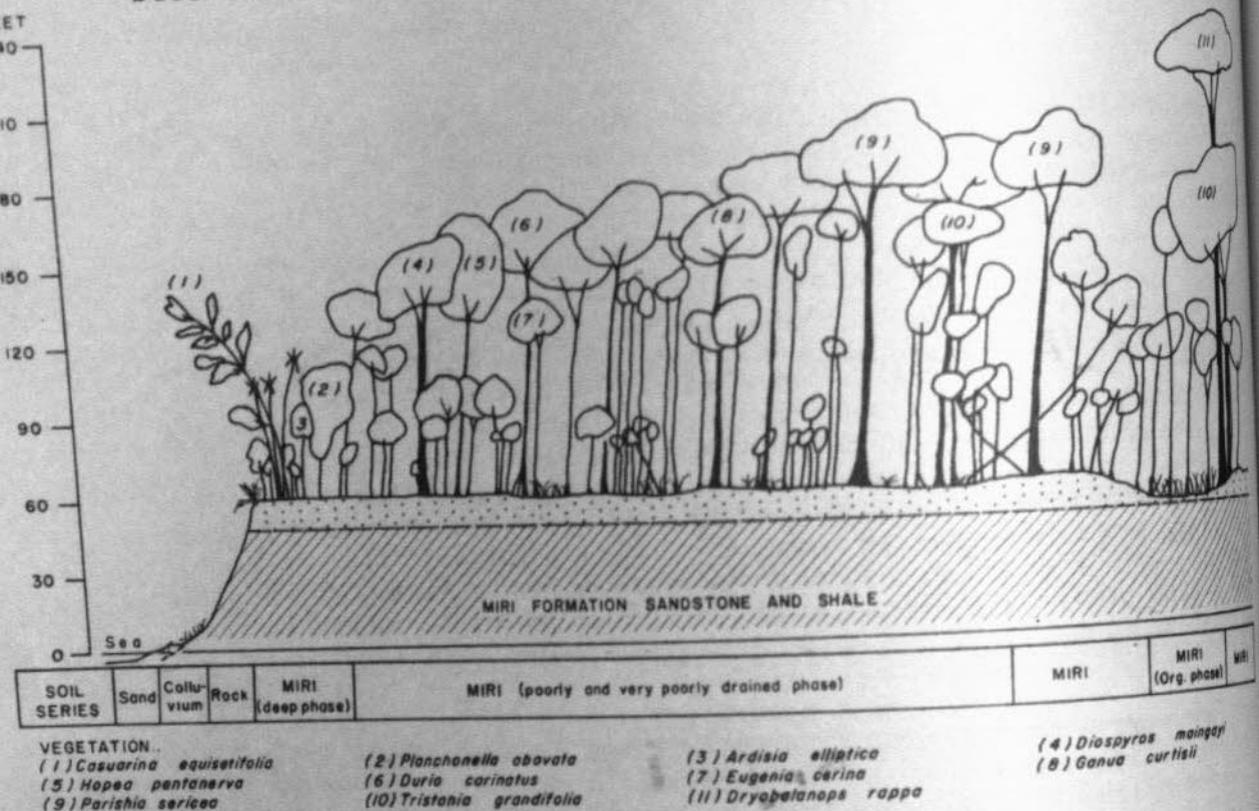
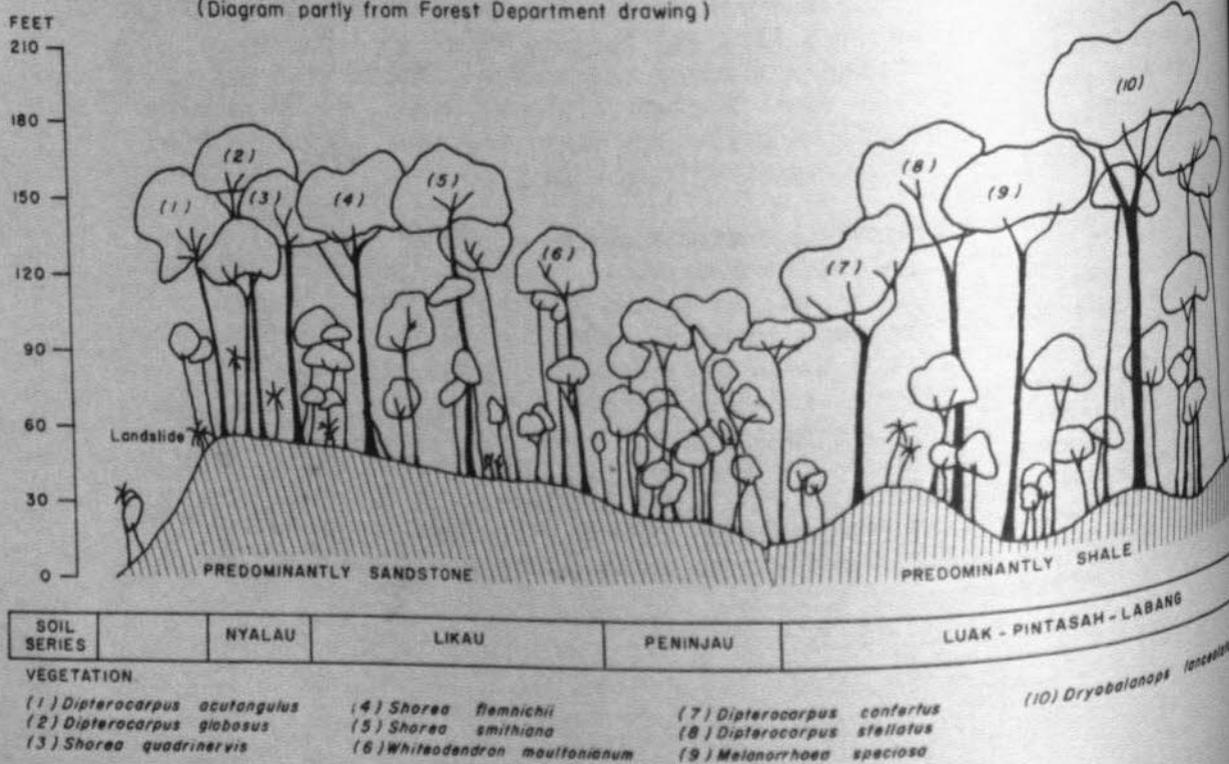


Fig. 32. SCHEMATIC VEGETATION PROFILE OF  
LOWLAND DIPTEROCARP FOREST  
based on SAMPLE AREAS IV AND V

(Diagram partly from Forest Department drawing)



Soil Forming Factors  
Vegetation

The forest type changes inland, in places rapidly, to that termed Alan Forest. The canopy is even, closed and rises to 150 to 190 feet above ground level, and is formed predominantly of the gregarious S. albida. The trees are moderately dense (about 30 to 50 Shorea large girth trees/acre; Anderson, 1963, p.143) of uniform size and buttressed. Light penetration is moderately high and shade at ground level may decrease to 60%. Pandans and sedges are common at ground level.

Soils found beneath both types of Peat Swamp consist of waterlogged, raw, woody peats of the Anderson Family (p. 127). The depths tend to be greater under Alan Forest than on the margins, and slight differences are discernible in the chemical composition, principally of phosphorus concentration.

HEATH FOREST

Heath Forest is restricted in distribution to the terraces described in a previous section (p.38), and in the area studied the composition resembles in some respects that of Mixed Peat Swamp Forest. The boundaries are clearly defined except between the Telong and Nyalau rivers where low terraces in places merge with Peat Swamp Forest. The associated soils are shown on Map 1 of Sample Area I (Appendix A), and diagrammatically in Fig. 31.

The canopy is closed and fairly regular at heights of between 120 and 150 feet. The main dominants recorded in the sample area are Dryobalanops rappa, Parishia sericea, many Eugenia spp. and Stemonaurus umbellatus; emergents are few. Beneath the canopy growth is moderately dense with many pole-like saplings and patches of Pandanus sp., sedges and Salacca sp. Shade density is high at ground level and varies between 70 and 95%.

The associated soils are mainly ground-water podsolis of the Miri Family (p. 92) which are well-developed, strongly leached and vary widely in internal drainage. The poorly and very poorly drained phases are most common in Sample Area I (Appendix A) and it is thought that this is also the case on the large terraces near the Telong River; the water table is high and the topsoil is thick and peaty. On terrace margins and on degraded old strand lines crossing the terraces where drier soil conditions prevail the undergrowth is almost clear and Oncosperma filamentosa occurs in thickets. On the coastal margin of the terraces there is a subtype of forest consisting of low sclerophyllous trees such as Planchonella obovata, Ardisia elliptica and the conifer-like Casuarina equisetifolia; Pandanus fascicularis and Salacca conferta form thickets on the terrace slopes (Plate 35).

LOWLAND DIPTEROCARP FOREST

Forest found on all hill land in the area, with the exception of that on limestone at Niah, and spreading onto some small head-stream valley floors is classed broadly as Lowland Dipterocarp Forest. It is characterised by a varied physiognomy, and a rich variety of evergreen, broadleaved trees dominated by Dipterocarps. Two semi-qualitative subdivisions can be made, and in a few areas these have been mapped (Map 9) with the aid of air photographs. The boundaries of Lowland Dipterocarp Forest are confused in those valleys bounded by low hills such as the Mulis and Lamaos Valleys. The relationship between vegetation and soil distribution is shown in maps of Sample Areas IV and V (Appendix A) and diagrammatically in Fig. 32.

Soil Forming Factors  
Vegetation

Lowland Dipterocarp Forest associated with hills having markedly sandy soils has the following features. The canopy is closed, except for gaps caused by landslides and is irregular and between 120 and 180 feet above the ground. There are common, large-crowned, semi-emergent trees (Plates 16, 36) among which in Sample Area IV (Plate 22) in the Lambir Hills are species of Dipterocarpus, principally globosus sp., many Shorea spp. and species such as Whiteodendron moultonianum, and Dryobalanops aromatica which characteristically prefer sandy soils. Many of the dominant trees are buttressed to some extent. Beneath the canopy the growth is moderately clear although shade at ground level invariably exceeds 85%. In the shrub layer are common saplings, palmaceous climbing rotan, and palms, particularly the species Eugeissona minor and Licuala sp. The soils belong mainly to the Nyalau Family (p. 66 ) intermixed with those of the Bekenu (p. 67 ) and Matang (p. 65 ) Families. They are well drained, siliceous, leached, permeable and moderately deep. Topsoil tends to be less than six inches thick, and litter, although impersistent, accumulates to depths of 9 to 12 inches on the most strongly podsolised soils. Similar soil vegetation relationships are described by Ashton (p.57-59) in Brunei.

Associated with this type of forest in places is that on the long, gentle dipslopes of the hills in the upper Sibuti, Nyalau and Bakong rivers where soils are poorly drained (Semadoh Family, p. 100 ) and more strongly podsolised (Bako Family, p. 92 ). In such areas however the physiognomy more closely resembles that of the Heath Forest on terraces described above.

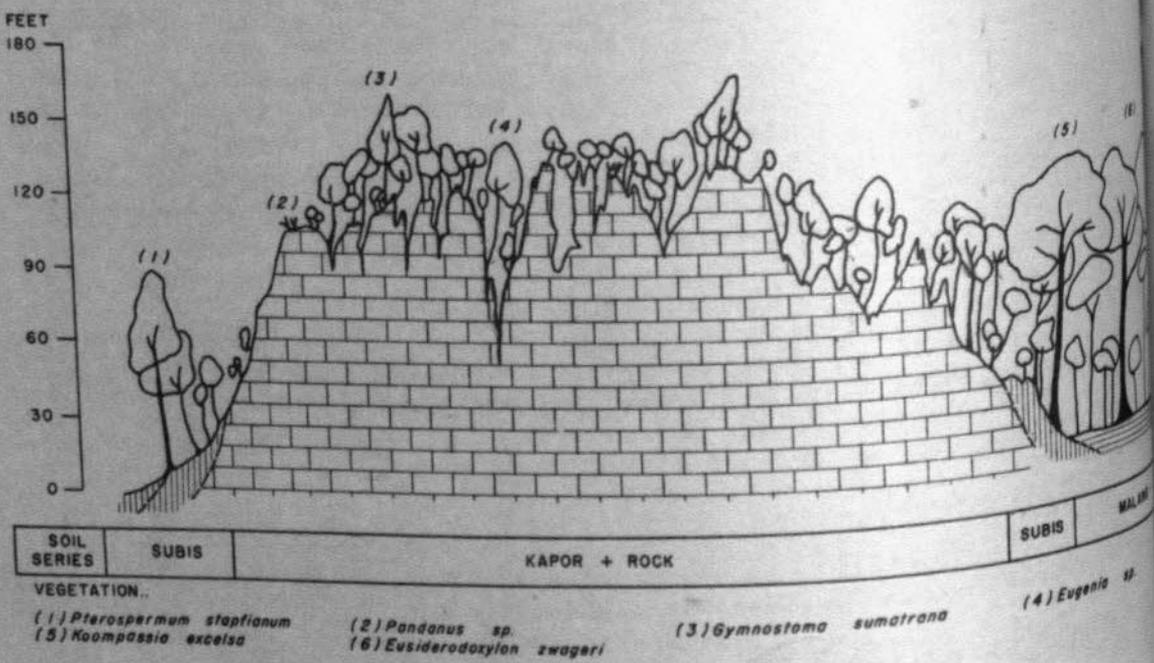
Lowland Dipterocarp Forest associated with hills having clayey soils has a similarly closed, irregular canopy but has more large-crowned dominants rising to 150 to 180 feet above the ground (Plate 27). Common tall trees specific to clay soils in Sample Area V (Appendix A) include various Eugenia spp. Shorea leprosula, Santiria tomentosa and Alangium javanicum. Dryobalanops lanceolata is particularly common above well-drained clayey soils derived from the Sibuti and Tangap rock formations which are known to be relatively rich in calcium and magnesium compared to the other formations. Some of the taller trees are lightly buttressed. Undergrowth is light although shade at ground level remains at more than 80%. There are common saplings and in some areas a stemmed palm, (? Livistona sp.) forms groves which completely shade out all undergrowth.

The soils belong to either the Merit (p.68 ) or Bekenu (p. 67 ) Families. They are predominantly fine-textured with coarser topsoils in places, well- to moderately well-drained, shallow to moderately deep and moderately to weakly leached. The topsoil is thin and surface litter is impersistent, commonly absent.

LIMESTONE FOREST

Much of the vegetation on the karst hills at Subis is specialised and varies extremely widely in physiognomy and composition (Anderson, 1965, p.50). The relationship between the vegetation and soils is shown diagrammatically in Fig. 33.

Fig. 33. SCHEMATIC VEGETATION PROFILE OF LIMESTONE FOREST



Soil Forming Factors  
Vegetation

Three main habitats are clearly recognisable (c.f. seven by Anderson - op. cit.) namely the lower scree slopes, the middle and upper slopes, and the summits. The lower scree slopes support a sparse cover of predominantly Dipterocarp species, with individual trees attaining heights and girths similar to those in non-limestone areas. Many species are related to, or are the same as, those occurring in the Lowland Dipterocarp Forests, for example, Koompassia excelsa, Pterospermum stapfianum and Eusideroxylon zwageri. Beneath the irregular canopy, which rises to 80 to 100 feet high and gives 80 to 90% shade, is an open growth of medium-size trees, such as Laportea stimulans, saplings and woody creepers, with at ground level various herbs and sedges. Associated soils are well drained dense clays, rich in calcium, with deep topsoil and impersistent litter.

The middle and upper slopes of the karst topography comprise both steep rock faces and sheltered clefts and hollows (p. 40). On the rocky parts live short plants, herbs and pandans, while in the clefts and corridors are small to medium-size trees with common ferns, seedlings and fleshy herbaceous ground plants. The roots of the trees stretch across and span gaps in the limestone forming a dense network over the surface that traps and collects litter. The only soil in these places is limestone rubble and slightly acid to alkaline humus (Kapor Family, p. 135) that rests in crevices, hollows and in the root mats: litter is common and thick.

Summits of the hills support a thin, stunted cover of 20- to 30-foot tall, commonly sclerophyllous and calcifugal trees (Plate 8) including the conifer-like Casuarina sumatrana with umbrella-shaped crowns, and Eugenia spp., Hopea spp., Elaeocarpus spp. and Sapotaceae. Pandanus and Nepenthes spp. form the ground cover in places. Soil found on the summits resembles the humic material on the flanks but it is leached and acid. (p.136)

SECONDARY FOREST

All regrowth vegetation is classed as secondary forest until it becomes indistinguishable from primary forest at ages generally exceeding 25-30 years. Secondary forest is predominantly the after-growth of hill and swamp rice shifting cultivation, which entails the felling of vegetation in July to August and the burning of the dried material in late August. Rice and subsidiary crops such as maize and cassava are planted in the ashy topsoil and superficial weeding is practised in the early part of the growing season which extends until April or May. The length of fallow varies from none to more than 15 years. Pepper and rubber gardens are generally started on land formerly used for rice rather than on land requiring the felling and clearing of primary forest.

Differences in floristic composition are discernible within secondary forest but these are difficult to establish due to the complication of their rapid development. Four broad types of regrowth are outlined below, the divisions being based on ecological factors.

Soil Forming Factors  
Vegetation

SECONDARY FOREST - on poorly drained clayey and peat soils.

In the larger valleys and on peat swamp margins where the ground water is permanently high and river water flooding is common the rate of regrowth on clays and peat is rapid (principally Bijat, p.101 ; Sebandi, p. 104 ; Pendam, p.117 ; and Mukah, p. 126 Families). Dense thickets of grasses, sedges and ferns are dominant initially, giving way to light-loving woody saplings and young trees such as Lithocarpus sundaica, Alstonia spatulatus, Macaranga spp. particularly M. Saniculata and Dillenia spp. Within 5 to 8 years the trees are 20 to 40 feet tall and the undergrowth has become almost clear. The thorny, stemless palm Salacca conferta is common on the peats.

SECONDARY FOREST - on poorly drained sandy soils.

Poorly drained sandy terrace soils and sandy soils situated in the coastal areas (Miri Family, p. 93 ; Igan Family, p. 126 ) have slow-growing secondary vegetation (Plate 37). Grasses, sedges and ferns are the first colonizers with hardy shrubs gradually competing such as Vitex pubescens, Melastoma malabathricum, Glochidial littorale, Guloa plueroptis, Alphitonia philippinensis and Trema orientalis. Secondary forest on ground-water podsols at the Niah River mouth following from periodic burning, contains abundant sedges, mosses, pitcher plants, orchids and sclerophyllous 15- to 30-foot tall trees. These include the distinct, conifer-like Casuarina nobile, also Calophyllum flagrans, Eugenia cerina and Timonius peduncularis (Plate 31).

SECONDARY FOREST - on moderately well-drained clayey soils.

Regrowth is generally rapid on both clayey soils of hills and on alluvial land near rivers unless continued cultivation with short fallows have exhausted the soil. The initial vegetation consists of dense thickets of sedges, pandans and woody shrubs. Saplings and light-loving young trees rapidly become dominant (Plate 26) leaving a moderately clear undergrowth; those most common in Sample Area I at Beraya (Appendix A) are Anthocephalus cadamba, Dehassia incrassata, Macaranga spp. and Pternandra coeurulescens. Thickets of Eupatorium sp. occur on hills near Luak Agricultural Station.

SECONDARY FOREST - on impoverished sandy and clayey soils.

The colonizing vegetation on exhausted hill soils is slow-growing and consists of sheet grasses such as Imperata cylindrica interspersed with the shrubs Melastoma malabathricum, Dillenia spp. and hardy ferns. It may take more than 10 years for the composition to be altered appreciably and for tall trees to become dominant.

VEGETATION AND SOIL FORMATION

Vegetation in the area affects soil formation through modification of the general climate, the production of different amounts and types of humus, the reduction of mineral leaching in the soil by root systems, the checking of soil erosion and the amelioration of topsoil conditions by the presence of humus. These different aspects are discussed below.

Soil Forming Factors  
Vegetation

Different vegetation types produce different microclimates at ground level (p.76 ) which materially affects the rate of breakdown of litter. Beneath cultivated crops such as pepper and rice the ground is clean weeded, litter production is low and organic compounds in the topsoil are oxidised without being replenished. Under forest cover however there is continual leaf fall and less extreme temperatures at ground level resulting in the maintenance of humus-rich surface soil. In addition, the presence of vegetation modifies the effectiveness of rainwater by transpiration, and the presence of thick humus under Limestone, Heath and Peat Forest actively slows down surface water run-off.

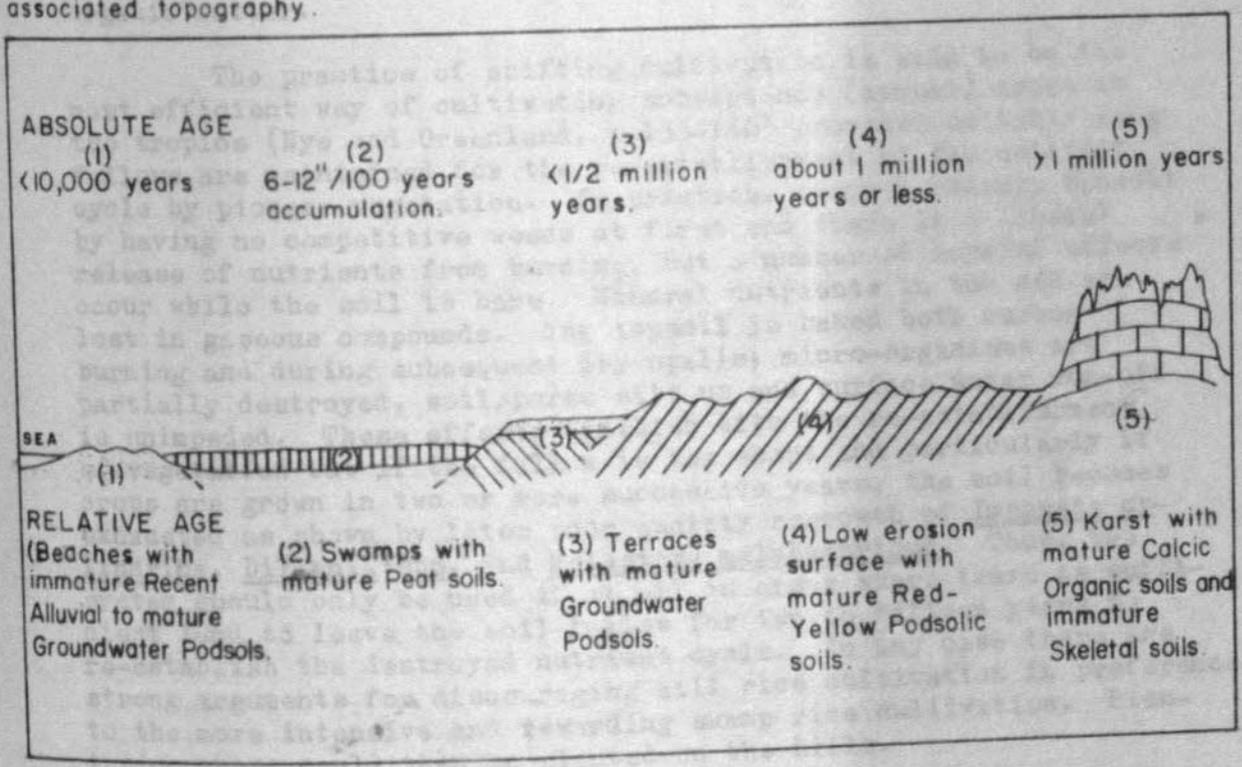
Trees differ in their food requirements and it is known, for example, that in general needle-leaved trees require smaller quantities of mineral nutrients from the soil than the broad-leaved varieties (Lutz and Chandler, ch.16) consequently their litter is base-poor by comparison and this quality is inherited by the derived humus. Thus under needle-leaved and under many sclerophyllous trees the humus tends to be acid and is raw (mor) by comparison with that beneath broad-leaved trees (Handley, p.11-14). Whole plant communities in the area reflect this trend. Under similar edaphic conditions, Ashton (p.46) reports that in Brunei the mean pH of leaf extracts of species growing on different residual soils is related to the soil pH, although some species tended to have different pH levels on different soils. The acidophyllous Peat Swamp Forest and Heath Forest in particular produce, and live on, thick, dark reddish brown to black, poorly decomposed humus. Of the two types of Lowland Dipterocarp Forest described that on the sandiest and most siliceous soils of the Nyalau, Bako, Semadoh and Matang Families produces the thickest and least decomposed humus. By comparison the humus development on clayey soils beneath Lowland Dipterocarp Forest is invariably minimal.

The presence of roots in soil partly reverses the leaching of nutrients by binding them into the tree-litter-topsoil-tree nutrient cycle. This is a most important feature of the soil-vegetation relationship in tropical areas since comparatively little food is supplied to the vegetation from the subsoil - in limestone areas virtually none. Root systems in most soils in the area are restricted largely to the upper 12 inches of soil; this is particularly noticeable in the most strongly leached and in the most poorly drained soils where root mats develop in the A1 and O soil horizons. By world standards soil fertility in the area is generally low or extremely low (Appendix C) but luxuriant vegetation can be maintained so long as the nutrient cycle is not broken. Once broken by felling and burning the vegetation may not reach its former density and luxuriance for at least 80 years.

Soil erosion is restricted by the binding effect of root systems (Plate 17), particularly in the most sandy soils. On the slopes of the Lambir Hills, however, the trees are unable to prevent large scale landslides occurring under extremely wet conditions, such as during 1962/3 when the soils became saturated and unstable (Plate 22). Tree roots in the limestone at Subis both hold screes and broken blocks together (Wilford and Wall, Plate 17) and prize them apart by exploiting cracks and fissures. In dense clayey soils root channels improve aeration, drainage and water circulation as shown by mottling along them.

The thickness of humus overlying sand is, in general, inversely related to the age of the soil. It is very thin on the youngest soils (Plate 17, 39) and thick on the oldest (Plate 44, 48). The process of soil formation is retarded by binding soil particles together into aggregates, which in turn aids drainage and aeration. Water acts as a filter for penetrating water, and where water is not infiltrated, the topsoil pores commonly become blocked by silt-carried silt and very fine sand. Chemically, the weathering products and cations fertilize the soil. The topsoil is generally covered with the topsoil litter. In absence of litter, the soil is generally very poor.

Figure 34. Diagram showing approximate age and relative age of various soils with associated topography.



TIME

The time factor in relation to soil formation is discussed below from the point of view of both absolute and relative age, of the degree of soil maturity. (Fig. 34).

In terms of absolute age there is little accurate data available. The soils range in age from the most recent alluvial deposits to the oldest pre-historic residual soils. It is almost certain that the same pattern of soil-forming processes described above has been in operation throughout this time.

Peat accumulations are geologically young, as shown by age determinations on basal peat samples from the Bering swamps, contiguous with and about 10 miles from the swamps shown on the north-east of Map 3. Radio carbon tests indicate an overall rate of growth of about 12 inches/100 years during the last 4,270-70 years (Wilford, 1917). The basal peat contains mangrove (*Sonneratia* and *Xylocarpus*) and abundant large pollen. This peat is very thick.

Soil Forming Factors  
Vegetation

The thickness of humus overlying soils in the area varies markedly, from almost none on clay-rich soils, such as the Merit (Plates 17, 39) and Malang Families, to thick 4- to 12- inch O horizons on the siliceous sandy soils of the Bako and Miri Families (Plates 44, 48). The presence of humus improves soil structure by binding soil particles together (Baver, pp.139-144), which in turn aids drainage and aeration. Humus acts as a filter for penetrating water, and where absent, as in cultivated land, the topsoil pores commonly become blocked by water-carried silt and very fine sand. Chemically, the exchange complex and hence fertility status of the topsoil is closely connected with the topsoil humus. An absence of litter implies scarcity of food for micro-organisms, which aid in the release of mineral nutrients from raw organic matter.

The practice of shifting cultivation is said to be the most efficient way of cultivating subsistence (annual) crops in the tropics (Nye and Greenland, p.133-140) provided suitably long fallows are maintained for the re-establishment of the nutrient cycle by pioneer vegetation. In practice, crops certainly benefit by having no competitive weeds at first and there is a liberal release of nutrients from burning, but a number of harmful effects occur while the soil is bare. Mineral nutrients in the ash are lost in gaseous compounds. The topsoil is baked both during burning and during subsequent dry spells; micro-organisms are partially destroyed, soil pores silt up and surface water run-off is unimpeded. These effects diminish with the re-establishment of vegetation but if the fallow is too short and particularly if crops are grown in two or more successive years, the soil becomes exhausted as shown by later poor quality regrowth of Imperata cylindrica, Dillenia spp. and Melastoma malabathricum. Thus, the system should only be used if at all in areas where there is sufficient land to leave the soil fallow for ten to fifteen years to re-establish the destroyed nutrient cycle. In any case there are strong arguments for discouraging hill rice cultivation in preference to the more intensive and rewarding swamp rice cultivation. Plantation crops could then be planted on the hills.

TIME

The time factor in relation to soil formation is discussed below from the point of view of both absolute and relative age, or the degree of soil maturity. (Fig. 34).

In terms of absolute age there is little accurate data available. The soils range in age from the most recent alluvial deposits to the oldest pre-Quaternary residual soils. It is almost certain that the same pattern of soil-forming processes described above has been in operation throughout this time.

Peat accumulations are geologically young, as shown by age determinations on basal peat samples from the Bakong swamp, contiguous with and about 16 miles from the swamps shown on the north-east of Map 4, Radio carbon dates indicate an overall rate of growth of about 12 inches/100 years during the last 4,270<sup>±</sup> 70 years (Wilford, p.117). The basal peat contains mangrove (Sonneratia and Rhizophora) and abundant Nypa pollen. This swamp is more highly

Soil Forming Factors  
Time

developed than those in the coastal parts of the Bekenu-Niah-Suai area where it is possible that the rate of accumulation is different. Material from the base of a 10-foot deep peat swamp overlying coastal sand in Fifth Division (Fig. ) was determined at 1,840<sup>±</sup> 120 years old giving an average accumulation rate of about 12 inches every 200 years (op. cit.)

Tektites found in a 50-foot high marine terrace in Brunei (p.43 ) are known to be less than 710,000 years old (Zahringer and Gentner, p.583). These terraces can be correlated tentatively with the marine terraces at Cape Bungai and date the earliest time of soil formation in the alluvium to about half a million years before present.

The residual soils of the area, apart from hill land below the highest Quaternary eustatic oscillations at about 250 feet above present sea level (p.41 ) began developing at least before the beginning of the Quaternary about 1 million years ago. The Nyalau Formation rocks in the southwest may have been uncovered well before this time.

EFFECT OF TIME ON SOIL FORMATION

The relative ages of soils is a measure of their maturity, that is the degree to which they have become adapted to the prevailing soil-forming processes and has little connection with the soils absolute age. These processes have favoured podsolisation in this part of Sarawak wherever the groundwater table is sufficiently low for the leaching of sesquioxides, humus, and bases. Where the ground-water table is high gleization predominates.

The most strongly leached mature soils of the area are Humus Podsoles developed in loose, siliceous sand on flat-topped marine terraces of middle to late Pleistocene age, and in recent beach sand at the mouth of the Niah River (Plate 49). Less strongly leached are the Red-Yellow Podsolitic soils found overlying Miocene sandstone; those that occur on gentle dip slopes generally have the most marked podsolitic features. Weakly podsolised but mature residual soils are these developed on Miocene argillaceous rocks and in some respects they have affinities with Latosols. Soils of poorly drained flood-plains consist of mature gley and bog soils developed in recent clays and peats and dominated by the continual presence of a high water table.

Immature soils show little profile development (A/C profiles) and vary from those found on young river levees and recent beaches to those on hills over Miocene rocks, kept immature by continual surface erosion on steep slopes.

SOILS OF THE AREA

The soil is a... (faint text describing soil characteristics)

PART FIVE

SOILS OF THE AREA.

The soil is a... (faint text describing soil characteristics)

SOILS OF THE AREA

The concept of the soil... (faint text describing soil concepts)

1. RED-BROWN PERSIAN SOIL

These are defined as... (faint text describing Red-Brown Persian soils)

## TAXONOMIC CLASSIFICATION

A taxonomic classification of soils is used primarily to enable the grouping of like soils at various levels of complexity in order that comparisons, predictions, usage and genesis can be described and studied, not only within an area but within and between countries. Most proposed taxonomic schemes have originated in, and are designed largely for temperate environments. That which at present is most adaptable to Sarawak conditions classifies soils genetically at a high level and was prepared by Baldwin and colleagues (Baldwin et.al., 1938) and developed by Thorp and Smith (1949). The same system has been used in Malaya (Pantan, 1965) and elsewhere in South-East Asia (Dames 1955, 1962; Dudal and Moorman, 1964). Sarawak soils have been classified at group and family level following this system (Soil Survey Staff, Sarawak, 1966) although the definitions of groups and families used in this thesis are those of the Sarawak classification. The advantages of Thorp and Smith's scheme are that most soils of the country can be classified and that it has international usage. Disadvantages are that the classes are loosely defined and insufficient regard is paid to soil morphology. A subsequent American, high-level classification, the '7th Approximation' (Soil Survey Staff, U.S.D.A., 1960), has the additional advantages of detailed and closely defined limits for each class of soil and is based on soil morphology rather than soil environment, but it is inadequate for the soils most common in Sarawak.

Table 3 shows the Bekenu-Niah-Suai soils as arranged within Thorp and Smith's scheme (op. cit.) below the suborder level. The genetic bias of the scheme enables a natural grouping of the soils which conforms well with the environment descriptions of Parts D and E above. At levels of classification lower than the great soil group schemes are generally devised on a national basis. In Sarawak, such a scheme has been in use since 1964 with families, series, phases, and variants as the taxonomic units. These subdivisions of great soil groups are defined almost entirely on soil morphology.

### GREAT SOIL GROUPS (Table 3)

The concepts of the great soil groups are basically those proposed by Baldwin et.al. as revised by Thorp and Smith. Changes in the nomenclature of the groups have been made in several cases where the range has been altered, and of the eleven soil groups so far recognised in Sarawak, all but the Lateritic and Groundwater Laterite soils are represented in the Bekenu-Niah-Suai area (Soil Survey Staff, Sarawak, 1966). One group, not included in any of these schemes, is defined by the writer.

#### 1. RED-YELLOW PODSOLIC SOILS

These are defined by Thorp and Smith (p.120) as 'a group of well-developed, well-drained acid soils having thin organic (O) and organic-mineral (A1) horizons over a light coloured, bleached (A2) horizon, over a red, yellowish-red, or yellow and more clayey (B) horizon. Parent materials are all more or less siliceous. Coarse, reticulate streaks or mottles of red, yellow, brown, and light grey are characteristic of deep horizons where parent materials are thick'.

Table 3. Taxonomy of the soils of the Bekenu-Niah-Suai area at Great Soil Group and Soil Family level.

GREAT SOIL GROUP	SOIL FAMILY
* Red-Yellow Podsollic soils	Matang, Nyalau, Bekenu, Merit, Semilajau, Malang.
** Grey-White Podsollic soils	Triboh, <u>Gong</u> .
Groundwater Podsoils	Bako, Miri, Buso.
* Gley soils	Semadoh, Bijat, Sebandi, Tatau, Matu, Plan. <u>Gong</u>
* Saline Gley soils	Rajang, Pendam, Limbang, Nonok.
* Peat soils	Igan, Mukah, Anderson.
** Calcic Organic soils	Kapor.
Brown Forest soils	Kabuloh.
* Recent Alluvial soils	Kabong, Kayan.
* Skeletal soils	Kapit, Meluan.

\* Groups whose range is slightly different from that outlined by Baldwin et. al. (1938) or by Thorp and Smith (1949).

\*\* Groups not defined by Baldwin et. al. (op.cit.) or by Thorp and Smith (op. cit.).

In the Bekenu-Niah-Suai area, however, as within Sarawak as a whole, the soils are not entirely well-drained, the A2 horizon is not necessarily bleached, and in the most clay-rich soils the A2 horizon is only weakly developed texturally. The local definition is therefore modified to include these characteristics as follows:

Local Definition

Red-Yellow Podsollic soils are mineral soils in which:-

1. An R or C horizon, if present, is not within 10 inches of the base of an O horizon.
2. There is no gley horizon within 20 inches of the base of an O horizon.
3. There is an A2 (possibly albic) horizon over an argillic horizon.
4. If a Bir horizon is present there is no gley horizon within 48 inches of the base of an C horizon.
5. Chromas of the B horizon are 5 or more.

Taxonomic Classification

The minimum depth separates these from Skeletal soils, the absence of a shallow gley horizon from Gley soils, the albic and argillic horizons from Lateritic and Recent Alluvial soils; the lack of a gley horizon beneath a Bir horizon from Groundwater Laterite soils and the strong colours from Grey-White Podsollic soils.

2. GREY-WHITE PODSOLIC SOILS

This is a locally defined group not described by Thorp and Smith (1949). It is distinguished from the associated Red-Yellow Podsollic soils principally by paler soil colours, attributed to low iron content. They are similar to the 'Bleached soils' of Indonesia (Dames, 1955, p.91-94).

Local Definition

Grey-White Podsollic soils are mineral soils in which:-

1. An R or C horizon, if present, is not within 10 inches of the base of an O horizon.
2. There is an argillic horizon.
3. There is no gley horizon within 20 inches of the base of an O horizon.
4. There is no spodic horizon.
5. Chromas are 3 or less in the A2 horizon, 4 or less in the B horizon. Hues are yellower than 2.5YR in the A2 and B horizons. Values are 6 or more in the A2 and B horizons.

The minimum depth separates these from Skeletal soils, the argillic horizon from Recent Alluvial soils, the lack of a gley horizon from gley soils, the lack of a spodic horizon from Podsollics and the colour limitations from Red-Yellow Podsollic soils.

3. GROUNDWATER PODSOLS

Although it is not certain that all soils with a podsol morphology in Sarawak have formed because of the presence of groundwater, it is believed that those examined in the Bekenu-Niah-Suai area can be explained in such terms (p. 97). Groundwater Podsollics are described by Baldwin et.al. (p.1000) as having an organic mat, over very thin acid humus, over a whitish-grey, leached layer up to 2 or 3 feet thick, over brown or very dark brown cemented hard pan or ortstein. They are imperfectly to poorly drained.

In this area podsollics characteristically have a thick O horizon, a thin to thick A1 horizon a thick A2 over a soft to hard Bh horizon. They are excessively to very poorly drained.

Local Definition

Groundwater Podsollics are mineral soils in which:-

1. An R or C horizon, if present, is not within 10 inches of the base of an O horizon.
2. There is a spodic horizon.

Taxonomic Classification

The presence of a spodic horizon differentiates these soils from those of all other groups, except from some Skeletal soils which have this feature close to the surface.

4. GLEY SOILS

Gley soils are formed in a hydromorphic environment, and include Low Humic Gley soils as defined by Thorp and Smith (p.120) - 'a group of imperfectly drained to poorly drained soils with very thin surface horizons, moderately high in organic matter, over mottled grey and brown gley-like mineral horizons with a low degree of textural differentiation. They range in texture from sand to clay, and the parent materials vary widely in physical and chemical properties. A large proportion of them range from medium to very strongly acid in reaction. Few are neutral to alkaline.' In addition they include some Half Bog soils described by Baldwin et.al. (p.1000) as 'dark brown or black peaty material over greyish and rust-mottled mineral material; they are poorly drained'.

The maximum thickness of surface peat in Gley soils is 10 inches. Shallower accumulations readily compact and oxidise after drainage and cultivation. Deeper peat is classed as Peat soil.

Local Definition

Gley soils are mineral soils in which:-

1. An R or C horizon, if present, is not within 10 inches of the base of an O horizon.
2. A peaty O horizon, if present, does not exceed 10 inches in thickness.
3. A gley horizon is present within 20 inches of the base of an O horizon.
4. Groundwater conductivity does not exceed 500 micro mhos/cm at 25°C at any time of the year.
5. There is no spodic horizon.
6. There is no hardened plinthite.

Groundwater conductivities in excess of 500 micro mhos qualify for Saline soils, peat deeper than 10 inches is classed as Peat soil, a spodic horizon is diagnostic for Groundwater Podsoils, plinthite for Groundwater Laterite soils, and the minimum depth separates these from Skeletal soils.

5. SALINE GLEY SOILS

The Saline Gley soils are a locally defined group. They are included in the Saline soils of Thorp and Smith (1949) and are restricted to hydromorphic soils developed in areas subject to salt- or brackish water flooding.

Local Definition

Saline Gley soils are mineral soils in which:-

1. An R or C horizon is not within 10 inches of the base of an O horizon if present.
2. Groundwater conductivity exceeds 500 micro mhos/cm. at 25°C at some time of the year.

Taxonomic Classification

3. A gley horizon occurs within 20 inches of the base of an O horizon.

The groundwater conductivity level of 500 micro mhos separates freshwater Gley from Saline Gley soils. This means the inclusion of weakly saline soils, which can be used for agriculture with strongly saline soils under halophytic natural vegetation that cannot be used without expensive reclamation. In some countries the conductivity of 'fresh' riverwater used for irrigation exceeds 1,000 micro mhos (U.S. Sal. Staff, p.77) but in Sarawak the critical level of 500 micro mhos can be used conveniently as it is unusual for fresh riverwater to exceed 100 micro mhos, reflecting the low amounts of soluble salts being leached from the soils.

## 6. PEAT SOILS

Peat soils include the Bog soils described by Baldwin et.al. (p.1000) as 'brown, dark brown or black peat or muck over brown peaty material with very poor internal drainage', and some Half Bog soils (see Gley soils above). The local definition simply specifies a minimum depth, a minimum permissible salinity, and that the soils must be wet throughout the year.

### Local Definition

Peat soils are organic soils in which:-

1. The O horizon consists of peat and is more than 10 inches deep.
2. Groundwater conductivity does not exceed 500 micro mhos/cm at 25°C at any time of the year.
3. The groundwater lies close to the surface throughout the year.

The definition separates these from Gley and Saline Gley soils, and from the Calcic Organic soils.

## 7. CALCIC ORGANIC SOILS

These soils cannot be accommodated in Thorp and Smiths classification (1949) nor as far as known, have such soils been described before in literature. The concept of the group is that of well drained accumulations of organic matter and humus, rich in calcium and principally found in karst landscape.

### Local Definition

Calcic Organic soils are organic soils in which:-

1. The O horizon consists of mull or well decomposed organic matter.
2. The total calcium content exceeds 2.01 of the dry matter.
3. The groundwater table is not present.

They are separated from Peat soils by their good internal drainage and by the high amount of calcium.

## 8. BROWN FOREST SOILS

This group of soils is described by Baldwin et.al. (p.1001) as consisting of 'very dark brown friable surface soil grading through lighter coloured soil to parent material. They show little illuviation, have high absorbed calcium and good internal drainage.' The soils are rare in the area studied and, as in other countries, are associated closely with karst topography or with rocks rich in calcium. (Dudal and Moormann; p.62; Dames, 1955, p.100-103; Stephens, p.30; Cline, p.83-84).

### Local Definition

Brown Forest soils are mineral soils in which:-

1. There is no C or R horizon within 10 inches of the base of an O horizon if present.
2. The cation exchange capacity of the lower B horizon exceeds 20 milli. equivalent percent.
3. The chromas are 4 or more in the B horizon.
4. There is no Gley horizon within 20 inches of the base of an O horizon if present.
5. There is no argillic horizon.

The chemical features, the colour and the lack of an argillic horizon separate these from Podsollic soils and the lack of a shallow gley horizon from Gley soils. The minimum depth excludes Skeletal soils.

## 9. RECENT ALLUVIAL SOILS

These soils resemble the Alluvial soils of Baldwin et.al. (p.1001) described as 'stratified soils with little profile development, some accumulated organic matter and a wide range of internal drainage from poor to good'. The definition in Sarawak, however, excludes poorly drained soils which are classed as Gley soils.

### Local Definition

Recent Alluvial soils are mineral soils in which:-

1. An R or C horizon, consisting of weathered rock in situ, is not within 10 inches of the base of an O horizon.
2. Where the profile comprises bands of coarse and fine earth, there is no band of material consisting of more than 80% coarse earth and which is more than 20 inches thick lying within 10 inches of the base of an O horizon.
3. A gley horizon, if present, is not within 20 inches of the base of an O horizon.
4. Neither albic, nor spodic, nor argillic horizons are present. The minimum depth and the depth to thick, coarse earth bands separate these from Skeletal soils, the absence of a shallow gley horizon from Gley soils and the other features from podsol and podsollic soils.

## 10. SKELETAL SOILS

These are the equivalent of Lithosols, defined by Thorp and Smith (p.119) as 'having an incomplete solum or no clearly expressed morphology, and consisting of a freshly or imperfectly weathered mass of hard rock or rock fragments'. Skeletal soils also include soils with extremely shallow profiles having some profile differentiation.

### Local Definition

Skeletal soils are mineral soils in which:-

1. An R or C horizon is present within 10 inches of the base of an O horizon.

## SOIL FAMILIES OF THE BEKENU-NIAH-SUAI AREA

The soil families of the area are described under the great soil group headings listed in Table 3. The concept of the soil family is that it should provide a link between the basic soil unit, the soil series, of which several may be present in even small areas, and the great soil group, which inherently is lacking in sufficient detail to be of much use in either agronomic or pedological studies. In Sarawak the soil family represents a grouping of soil series primarily on the basis of soil properties reflecting soil genesis, but which at the same time are of direct or indirect significance to plant growth.

### SOIL FAMILIES OF THE RED-YELLOW PODSOLIC GREAT SOIL GROUP

Six soil families in the Bekenu-Niah-Suai area (Table 4) are classed as members of the Red-Yellow Podsollic group. Together, the Nyalau, Bekenu and Merit families comprise practically all the residual hill soils and so are highly important in assessing the area's agricultural potential. The characteristics of the families as found in this area are described first, followed by discussions of the essential difference between them, their genesis and an outline of their relationship with the environment as described in previous sections.

Soil Families  
Red-Yellow Podsollic Group

Table 4. Diagnostic features separating Red-Yellow Podsollic soil families in the Bekenu-Niah-Suai area.

ORIGIN OF PARENT MATERIAL	ALBIC HORIZON	TEXTURE GROUP	SOIL FAMILY
Residual	present		MATANG
	not present	Light-textured	NYALAU
		Medium-textured	BEKENU
		Heavy-textured	MERIT
Alluvial		Light-textured	SEMILAJAU
		Heavy-textured	MALANG

Elsewhere in Sarawak the percentage of Group III elements in the A2 and B horizons, and the age of the alluvial parent material are used to separate three other families.

1. MATANG FAMILY

The Matang Family soils are localized and consist essentially of deep, well drained, weakly structured, light grey to pale yellow sandy loam overlying yellowish to reddish sandy clay loam derived from sandstone.

The O and A1 horizons are well-developed and there is an abrupt change to the contrasting A2 horizon which varies in thickness from a few inches to more than 12 inches. There is a sharp change to the B horizon which is deep and moderately well developed and commonly deeper than 48 inches before giving way to weathering sandstone.

Colours of the moist soil are strongly contrasting. At the surface the organic material is dark coloured and rests on similarly dark-coloured topsoil. The underlying A2 horizon however ranges from pale yellow to light grey. With increasing depth chromas intensity, largely of 10YR - 7.5YR Hue. Yellowish and reddish shades are dominant in the B horizon, although in places there is a suggestion of humus accumulation at the top of the B horizon giving dark yellowish brown colours. Mottles in the lower subsoil are chiefly those of weathering sandstone.

Soil textures range from light to heavy loams. The A horizons consist of sandy loam or loamy sand: there is a distinct textural change to the B horizons which are sandy clay loams, in places almost sandy clays. Inclusions have not been noted except in the C horizon, where they consist of iron-coated sandstone.

The consistence in field conditions ranges from very friable in the A horizons to friable or firm below. Structure has not been observed. The soils are well-to moderately well drained internally and are believed to be highly permeable.

Soil Families  
Red-Yellow Podsollic Group

No chemical analyses are available for Matang soils in this area, but they are probably midway between the Nyalau Family (p. 66 ) and the Bako Family (p. 92 ) in soil fertility.]

2. NYALAU FAMILY p. 70

The Nyalau Family soils comprise deep, well drained, poorly structured, yellowish loamy sands to sandy loams on yellowish to reddish sandy loams to sandy clay loams, derived mainly from sandstone (Plates 16, 20, 21, 38). Detailed descriptions and analyses of the main soil series in the family are given in Appendix B1.

Surface litter and humus is variable in thickness but commonly amounts to a 3-inch layer. The A1 is well developed and from 2-6 inches thick, and there is a clear change to the underlying, well developed A2 horizon, unlike the gradual transition from A to B horizons. The B horizon may extend to depths exceeding 6 feet before giving way to C horizon weathering sandstone.

Moist soil colours are largely yellow to reddish yellows of 10YR to 7.5YR Hue with high chromas remaining the same or strengthening towards lower parts of the profile. Pale yellow, yellowish- and reddish brown mottles characterise the lower subsoil in places, but these are inherited from weathering rock rather than from poor internal drainage.

Textures of Nyalau soils are sandy. The A1 varies from loam to sandy loam and the A2 ranges from loamy sand to sandy clay loam. An increasing clay content in the B horizons gives sandy loam to almost sandy clay textures. The sand grade is rarely coarse. Bulk densities of six profiles below the A1 horizon range from 0.52 to 1.98 with a peak in the B horizon.

The consistence in field conditions of the A1 is very friable, and of the A2 loose to friable. The B horizons range from very friable to firm or rarely very firm. In addition there is commonly a plastic or sub-plastic consistency of moist A and B horizon soil which is attributed to the high amounts of silt and very fine sand present. Structure is weakly developed. In the topsoil it is weak crumb and grades with depth to massive or weak (angular) blocky in the subsoil. Clay skins are apparent on some structural faces. The soil is readily permeable, particularly in the sandy A2 horizon. (Physically these soils are considered to be unstable and difficult to work after rain in connection with road-building - Clare and Beaven p.28 - although they can be stabilised readily with cement - op. cit. p.30).

Inclusions of soft to hard sandstone are commonly present in the lower B and in the C horizon. In addition, slabby, iron-coated and iron-enriched dark red sandstone forms stonelines within the B horizon in places, generally marking the line of a sharp textural increase.

Roots form a thick network in the humus and A1 horizon, beneath which they decrease steadily in number and size despite the easily penetrated soil. Internally, Nyalau Family soils are well- to moderately well drained. External drainage is medium to slow.

Soil Families  
Red-Yellow Podsollic Group

Chemical analyses of the soil below the A1 horizon show low to very low cation exchange capacities of less than 8 m.e.% and base saturations of less than 5%, low reserve levels of major mineral nutrients, except potassium, low pH levels (pH 4.4 - 5.5) and low Group III levels which increase with depth from about 4% to 10%. The sandiest soil, the Peninjau Series, is poorest in all nutritional and clay-bound characteristics. The topsoil of all component series is the most fertile part of the profile.

The clay mineralogy of Nyalau soils is thought to be kaolin-dominated; the sand fraction is predominantly quartz with correspondingly low amounts of weatherable minerals.

3. BEKENU FAMILY

The Bekenu Family soils are moderately well drained, of varied depth, weakly structured yellowish sandy clay loams overlying yellowish to reddish clays derived mainly from sandstone and shale alternations. Detailed descriptions and analyses of a soil series belonging to this family are given in Appendix B2.

Surface O horizon material varies from less than an inch to 2 inches in thickness. A horizons are moderately well developed and together vary in thickness from 12-30 inches. There is generally a distinct change to the underlying well developed B horizons which commonly extend downwards more than 48 inches. The C horizon is varied in both depth and stoniness.

Moist soil colours are predominantly yellows to reddish yellows of Hue 10YR - 7.5YR. Chromas are high and either remain constant with increasing depth or become stronger. Subsoil mottling is common in some places, principally of light grey, yellow and reddish brown colours. The mottling reflects the presence of weathering rock in some cases, particularly shale, and in other reflects impeded soil drainage.

Textures range from light sandy loams in the A1 and A2 horizons to heavy textured clays in the deep subsoil. Textures, by definition, increase markedly from A to B horizons. Inclusions are in places common in the B horizon and consist of both shale and sandstone, generally coated and impregnated with limonitic material as in Merit Family soils (p. 68 ). The C horizon is invariably stony. Bulk density measurement of one profile below the A1 horizon ranged from 1.59 to a peak of 1.86 in the B horizon.

Moist consistence of the soils ranges from very friable to friable in A horizons, commonly with the sub plastic consistency of Nyalau soils, to friable to very firm in B horizons. Soil structure is only weakly developed, but is (angular) blocky in the B horizons where structural faces are commonly covered by clay skins. Permeability is moderate in the upper subsoil, decreasing noticeably with depth.

Rooting is largely confined to the organic-rich topsoil despite the lack of obstructions below. Some medium-sized roots however penetrate both B and C horizons. External drainage is slow to medium; internal drainage is moderate to good.

Soil Families  
Red-Yellow Podsollic Group

The chemical features of Bekenu soils reflect the marked increase in clay content with depth. Beneath the A1 horizon exchangeable and 'reserve' mineral nutrients, except potassium, are low throughout but are higher in the lower subsoil, as are the values of the cation exchange capacity and the Group III elements. The topsoil is the richest part of the profile in all nutritional aspects; its C/N ratio is moderately wide.

The mineralogy of one Bekenu soil analysed to the south of this area (Table 6) resembles in character that of Merit soils: that is, the clay fraction is principally kaolinitic, the sand fraction largely quartz. Weatherable minerals are consequently sparse. The sand fraction of a profile in the Lambir Hills contained largely quartz with limonite.

#### 4. MERIT FAMILY

Characteristically the widespread Merit Family soils are moderately deep, moderately well drained, weakly structured yellowish clay loams on yellowish to reddish clays derived from shale (Plates 17, 39, 40, 41). Detailed descriptions and analytical data of the main component soil series recognised are shown in Appendix B3.

Surface O horizon material is thin or absent. The A horizons are weakly developed and together amount to less than 18 inches. They merge gradually to the B horizon, which by comparison is strongly developed and deep, forming the bulk of the profile. The C horizon is separated clearly from overlying horizons at depths usually between 24 and 48 inches.

Moist soil colours are predominantly yellows to reddish yellows of 10YR - 7.5YR Hue. The high Chroma of the matrix remains constant or becomes stronger in B horizons. Pale yellow, light grey and reddish brown weathering shale mottles characterise the C horizons. In places light grey gley horizons occur below the B horizon.

Soil textures range from light to heavy loams (rarely sandy) in the A horizon, to heavy loams and fine textures (not sandy) in the B and C horizons. Inclusions are only common in the lower subsoils. They consist of small, platy, hard stones coloured yellowish to reddish brown, coated and commonly impregnated with amorphous limonitic material. The material may form stone lines within the B horizon and resting on, or close to the C horizon. Quartz fragments form stone lines in Merit soil near the Upper Trus River (Niah). Where road cuttings have exposed soil profiles it is common to find large lumps of earthy material that outwardly retain the platy structure of shale, but which on breaking open consist of elliptical bands of illuvial soft yellow clay alternating with bands of hard, iron-enriched material within a vesicular earthy matrix. Hard to soft sandstone fragments are common B horizon inclusions in some Merit soils. The bulk density of one profile ranges from 1.40 in the A2 to 1.80 in the B horizon.

The consistence in field conditions ranges from very friable in the A to very firm in the B horizon. In newly dug pits the structure is weak, fine crumb in the A1 to weak or moderate (angular) blocky in the B horizon, clearly defined in many cases by clay skins coating structural faces. Permeability is thought to be low.

Soil Families  
Red-Yellow Podsollic Group

Roots are confined mainly to the shallow A1 horizon, although some penetrate well into the subsoil and even into the C horizon if the soil is shallow. There is a marked tendency for structural faces to be exploited by roots.

External soil drainage is medium to rapid, while internally the soils are predominantly well- to moderately well drained.

The chief chemical features of Merit soils below the A1 horizon, are a low cation exchange capacity (less than 15 m.e.%), a base saturation of generally less than 10%, low reserve levels, of major mineral nutrients except potassium, low pH levels (pH 4.0 - 5.5) and an increasing amount of Group III elements with depth, from about 6% to 20%. The A1 is richer in all nutritional aspects than the underlying soil. The C/N ratio is moderately wide.

The mineralogy of one Merit soil analysed just to the south of this area contains predominantly kaolin in the clay fraction and quartz in the sand fraction (Table 6). The data show that the amount of weatherable minerals in the soils is low.

#### 5. SEMILAJAU FAMILY

The Semilajau Family soils are deep, well drained, weakly developed sandy loams to sandy clay loams derived from recent alluvium in the present-day flood-plain. They are closely related to the sandy Kayan Family Recent Alluvial soils (p. 146). Detailed description and chemical analyses of a common soil series are given in Appendix B4.

There is impersistent surface litter and humus. The A1 horizon is also varied in depth but commonly 3 -4 inches thick. The A2 horizon is well developed and deep, in contrast to the underlying B horizon which, although it may be deep, is generally poorly developed. At depths exceeding 20 inches the basal gley horizon may occur. Bedrock occurs at shallow depths beneath the soil in some parts of the upper Niah River.

Moist soil colours of the Semilajau Family have a narrow range, generally of 2.5Y or 10YR Hue with moderate Chromas of pale yellow to yellowish brown. Reddish and light grey mottles characterise the zone immediately above the gleyed light grey to grey deep subsoil.

Textures are predominantly light to heavy loamy in at least the upper 20 inches of soil. Sandy loam to loamy sand textures are characteristic of the A horizons, with an increased clay content in the B horizon. It is possible to detect recent additions of alluvium to the topsoil in places by faint texture and colour banding. Inclusions other than fine quartz pebbles are rare.

The field consistence of the soil is loose, very friable or friable, increasing in firmness with depth. All profiles examined were virtually structureless. Rooting is unimpeded although most roots are found in the upper 12 - 18 inches of soil. External drainage is slow, internal drainage is good to imperfect.

Soil Families  
Red-Yellow Podsollic Group

The main chemical features of Semilajau soils reflect the sandiness of the soil, namely uniformly low levels of exchangeable and 'reserve' mineral nutrients, a base saturation of less than 10%, low Group III levels of less than 10% and low pH levels (pH 4.0-5.0). Where the A1 is well developed it is in all nutritional respects the richest horizon.

Soil mineralogy, judging by analyses of Semilajau soils just to the south of this area (Table 6) and judging by the source rocks, is dominated by kaolin and quartz.

6. MALANG FAMILY

Malang Family soils consist of deep, moderately well drained, weakly structured yellowish brown clay loams on clays, mottled reddish brown and light grey at depth. They are derived from recent alluvium in the present-day flood-plain. Detailed descriptions and analyses of a common soil series are given in Appendix B5.

Surface litter and humus are shallow and impersistent. The A1 horizon is a distinct feature of the topsoil, generally between two and four inches thick. It changes within a small depth to a weakly expressed shallow A2 horizon which merges with the B horizon, that is both well developed and deep. At depths exceeding 20 inches the basal gley horizon may occur. In a few areas the soils are known to rest at shallow depths on hard bedrock ranging from shale to limestone.

The moist colours of Malang soils are almost entirely in the 7.5YR - 10YR Hue range, principally yellow to yellowish brown merging to reddish yellow. Matrix colours tend to intensity slightly with increasing depth. Mottles characterise the lower subsoil in the zone above the light grey gleyed horizon and range from light grey through yellow to strong brown and black. A characteristic feature of some Malang soils is the presence of many fine, dark brown to black mottles in the lower B horizon, that show as dark-coloured streaks on the polished faces of augered soil.

The soils are predominantly heavy textured (non sandy) in at least the upper 20 inches of the profile. Clay loams are characteristic of A horizons and clay loams and clays of the B and Cg horizons. Recent additions of alluvium rapidly become incorporated within the soil since texture banding in the topsoil is generally not recognised. Inclusions are rare with the exception of dark-coloured, soft to moderately hard ferro-manganese concretions.

The moist soil gives consistencies ranging from friable to very firm, the degree of firmness increasing down the profile. The gley horizons are invariably wet, plastic, and sticky. The gleyed subsoil is structureless, but overlying horizons show fine to medium, weak to moderate (angular) blockiness grading to fine crumb in the topsoil. Clay skins characteristically coat structural faces in the B horizon.

Rooting is well developed in the A horizons with a few fine to medium roots extending as far as the gleyed soil. External drainage is medium to slow, internal drainage is predominantly imperfect to moderate.

Table 5. Generalised profile differences between Red-Yellow Podsollic soils.

GENERALISED FEATURES	MERIT (R)	BEKENU (R)	NYALAU (R)	MATANG (R)	SEMILAJAU (A)	MALANG (A)
1. MOIST COLOUR A2 HORIZON	Yellowish (chroma > 3)	Yellowish (chroma > 3) Light to heavy loam (sandy)	Yellowish (chroma > 3) Light to heavy loam (sandy)	Pale (chroma < 4) Light to heavy loam (sandy)	Yellowish (chroma > 3) Light to heavy loam (sandy)	Yellowish (chroma > 3) Heavy loam (non sandy)
	A2	Heavy loam (non sandy)	Heavy loam (non sandy)	Light to heavy loam (sandy)	Light to heavy loam (sandy)	Heavy loam (non sandy)
2. TEXTURE	Fine texture (non sandy)	Heavy loam to fine texture	Light to heavy loam (sandy)	Light to heavy loam (sandy)	Light to heavy loam (sandy)	Heavy loam to fine texture (non sandy)
	B	Weak blocky	Weak to very weak blocky	Weak to very weak blocky	Massive to very weak blocky	Weak blocky
3. STRUCTURE	Weak to mod- erate blocky	Weak to mod- erate blocky	Weak blocky	Weak blocky	Massive to weak blocky	Weak to moderate blocky
	A2	Friable to firm	Very friable to friable	Very friable to friable	Loose to friable	Friable to firm
4. MOIST CONSISTENCE	Firm to very firm	Friable to very firm	Very friable to firm	Very friable to firm	Very friable to firm	Friable to very firm
	B	Absent to thin	Absent to 2 inches	Thin to 3 inches	Absent to 2 inches	Absent to thin
5. O HORIZONS	24 to 48"	24 to 48"	36 to > 48"	36 to > 48"	24 to > 48"	24 to > 48"
	Good to moderate	Good to moderate	Good	Good	Good to imperfect	Good to imperfect
6. DEPTH TO C or G HORIZON	Medium to rapid	Medium	Medium	Medium	Slow	Medium to slow
	A2	4-6	2-6	?	< 8	6-8
7. INTERNAL DRAINAGE	B	8-15	4-12	?	6-10	8-20
	A2	5-10	4-8	?	2-8	5-10
8. GROUP III ELEMENTS (%)	B	8-15	6-12	?	5-10	8-15
	A2	5-10	4-8	?	2-8	5-10
9. CATION EX. CAPACITY (m.e.%)	B	8-15	6-12	?	5-10	8-15

(R) - Residual

(A) - Alluvial.

Soil Families  
Red-Yellow Podsollic Group

Soil analyses show Malang soils to be rather variable, probably reflecting the variations between source rocks. The most common soils derived from non-calcareous shales mainly contain low levels of exchangeable mineral nutrients beneath the organic rich Al horizon, which, combined with low exchange capacities of less than 15 m.e.% give base saturations not exceeding 10%. 'Reserve' nutrients analysed are similarly low, except potassium, and the acidity ranges from pH 4.0 to 5.5. C/N ratios of the Al horizon are moderately wide and in all nutritional aspects this horizon is richer than the underlying soil.

Data on the mineralogy of Malang soils is not available but it is probable that the soils are rich in kaolin and that quartz is dominant in the sand fraction.

DIFFERENTIATING FEATURES BETWEEN RED-YELLOW PODSOLIC FAMILIES

The dominant ranges of the most important features used to distinguish between Red-Yellow Podsollic soil families are shown in Table 5.

The Merit and Malang soils are dominated by clayey textures in the A and B horizons. In both families this causes the consistencies to be firmer, the structure to be clearer, the internal drainage to be more impeded and the levels of Group III elements and the cation exchange capacity to be slightly higher than in the other families. Merit soils are distinguished from Malang soils by their residual as opposed to alluvial nature, that is by their development in situ as opposed to development by accretion of new soil during periodic flooding. Malang Family soils do not contain weathering bedrock in the C horizon.

Nyalau and Semilajau soils have similar profiles dominated by sandy textures and good permeability. Internal drainage is good and structure, if present, is weakly developed, the levels of the Group III elements and of the cation exchange capacity are low. These two families can be differentiated primarily by their origin; Semilajau soils are periodically flooded, while Nyalau soils are residual. Matang Family soils strongly resemble some in the Nyalau Family but can be separated from them by the presence of a light-coloured (albic) A2 horizon.

Bekenu soils have A horizons resembling the sandy Nyalau and Semilajau Families, and B horizons more like those of Merit and Malang Families.

GENESIS OF THE RED-YELLOW PODSOLIC SOILS

The processes leading to the formation of Red-Yellow Podsollic soils are the leaching of clay sesquioxides and soluble ions from the A2 to the B horizon, and of clay breakdown in the strongly siliceous acid environment to form free sesquioxides (Harris, 1963). A similar process is said to lead to the formation of Latosols which Harris distinguishes from podsollic soils by their strong structure and firm consistencies (op. cit.). These soils (probably the equivalent of Lateritic soils in Sarawak) have not been noted in this area although Wood and Beckett (1961) classify soils to the south, near Bintulu as Latosols, which by the descriptions resemble Red-Yellow Podsollic soils in this area. Dames (1962, p.26-31) also discussed Latosols in Sarawak, but considered them to be characterised chiefly by uniform texture gradients down the profile in contrast to Red-Yellow Podsollic Soils.



Soil Families  
Red-Yellow Podsollic Group

Clay Movement. This can be detected down the profile of all the soils in the group by qualitative field textures, and visually by the presence of clay skins in the lower A and B horizons particularly, both in the field and by thin section analyses. Laboratory mechanical analyses of residual soils confirm this, the amount of clay increase being least in the most clayey soils of the Merit Family and, by contrast, in the most sandy of the Nyalau soils (Fig. 35). The increase in clay from A to B horizons is sufficient for part of the B to qualify for an argillic horizon.

Sesquioxide Movement. An increase of 'reserve' iron and aluminium (indicated by Group III percentage) from the A to B horizons is clear in almost all of 20 profiles analysed. In the more clayey Merit soils the increase between A2 and B2 horizons is about 6-10%, and in the most contrasting sandy Nyalau soils it is less than one percent. Analyses of a Merit profile (Fig. 36) show steady total aluminium and appreciable total iron accumulation in the B horizon, to the detriment of silica.

Base Movement. The sandier Nyalau, Bekenu and Semilajau soils generally show a distinct decrease in the A2 horizon compared to the topsoil in both exchangeable bases and the cation exchange capacity, reflecting a decrease in organic matter. (Fig. 37) The amounts of bases in the subsoil are invariably extremely small and only in the case of potassium is there generally any increase in concentration downwards in the lower subsoil, reflecting clay accumulation in the B horizon. (Fig. 37) With stronger soil extractions it is possible to show increases with depth in the concentration of potassium, magnesium and in places, sodium. These are attributed partly to mineral breakdown, but mainly to leaching.

Clay Breakdown. Soils from the Semilajau area have kaolin as the dominant fine-earth clay mineral (Table 6). Wood and Beckett (1961) report mica, chlorite and vermiculite in addition from similar soils just to the south and Dumbleton (in Clare and Beaven, p.65) found considerable amounts of illite or muscovite and some chlorite and vermiculite in addition to the dominant kaolin, in residual soil on shale. Both authors considered the mica to be in the process of weathering through chlorite to vermiculite and possibly kaolin. Under acid, siliceous conditions clay minerals breakdown to form sesquioxides. The silica content of the most clay-rich and presumably least siliceous family in this group ranges from 85% to 55% in two profiles and the content in the C horizon of the more sandy soils in the group is as much as 97.0%. High quartz levels occur in Bekenu, Merit and Semilajau soils southwest of this area with subordinate minerals rich in silica (Table 6). The acidity (distilled water) of most Red-Yellow Podsollic soils ranges from pH 3.7 - 4.3 in the A1 horizon, increasing to pH 4.5 - 5.8 in the lower subsoil. Rainwater in the Kuching area of First Division averages pH 5.5 (range pH 4.9 - 6.0, 20 samples - Wilford and Wall, p.59) and probably becomes even more acid as it enters the soil and absorbs carbon dioxide. The conditions therefore are highly favourable for kaolin breakdown and the formation of free aluminium. Most Nyalau soils have higher levels of total aluminium in the B horizons than in the zone of weathering rock, and levels of Group III compounds (representing near-total levels) also show a peak in the B horizon of most Red-Yellow Podsollic profiles analysed (Fig. 36): this probably reflects a breakdown of clay in the A horizon and the downward leaching of the products.

Figure 36 Silica, iron and aluminum and Group III compound concentrations in a Meritt Family profile (Luak Series)

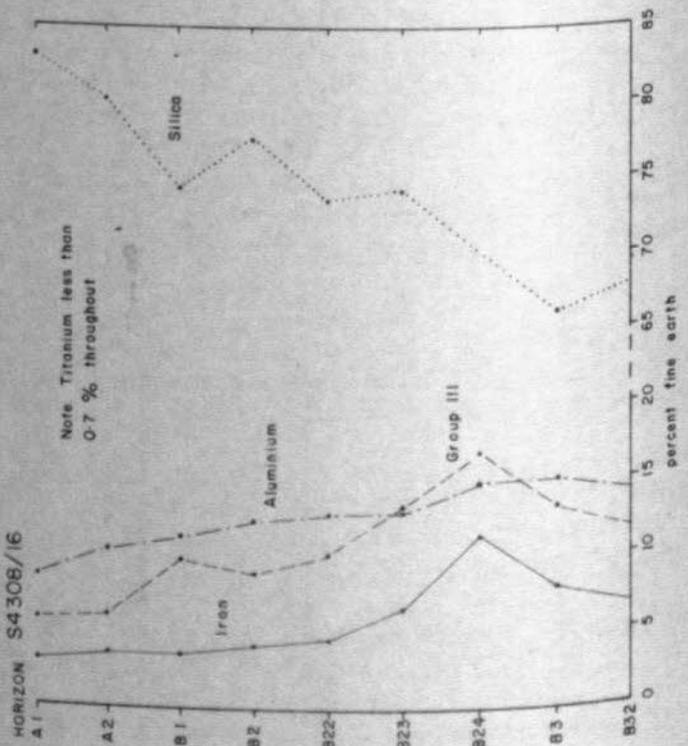
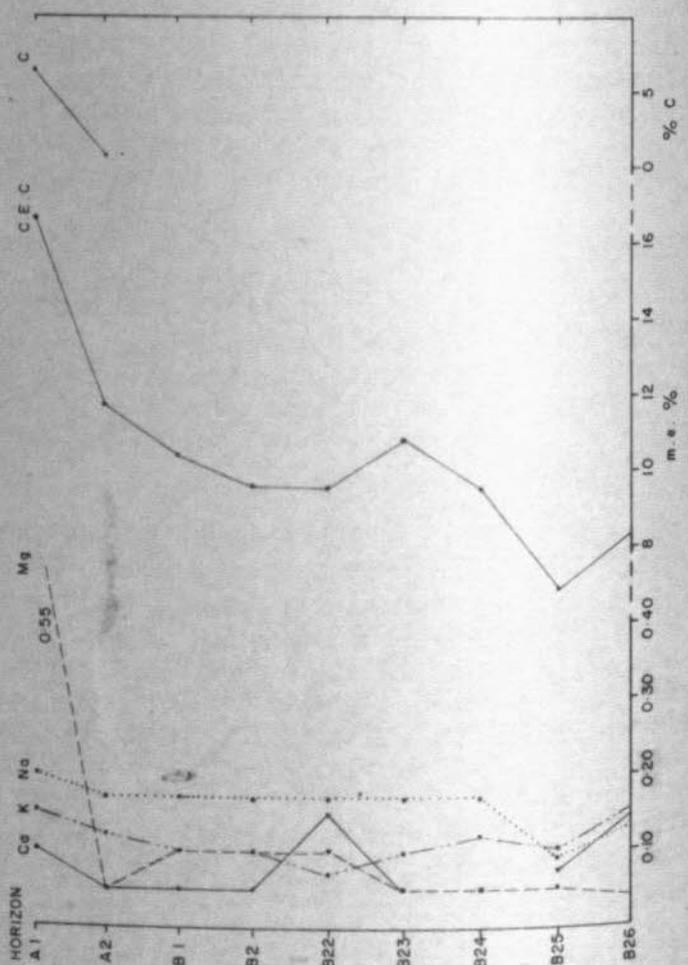


Figure 37. Cation exchange capacity, exchangeable bases and carbon in a Meritt Family soil (Pintasah Series) S4410/18



Soil Families  
Red-Yellow Podsollic Group

Genesis of Malang and Merit Family soils

In the Malang and Merit families podsolisation is not well expressed. The lack of A2 horizon development is attributed to the weakly permeable soil matrix which favours surface run-off of rainwater, and hence topsoil truncation, as much as vertical leaching.

Thin sections of Merit soils under the microscope show a dense yellowish ground mass that between crossed polars is birefringent in irregular patches, strongly so in the B horizons. The patches with clear boundaries and that are oriented internally are interpreted as completely clay-infilled pores and root channels, while the irregularly birefringent matrix is thought to be due to orientation of clay-sized material caused by pressures and stresses in the soil following from drying and wetting, possible intensified by slow solifluction (Brewer, pers. comm.). The ground mass of the B horizons is traversed by a few linear pores, most of which contain oriented, birefringent clay coatings. The birefringence of material coating the abundant subangular quartz grains embedded in the matrix is also believed to be due to pressure and soil movement.

Where the shale (p.33 ) underlying Merit soils is at least moderately rich in iron, for example, at Beraya, iron tends to accumulate in bedding and joint planes deep within the C horizon as discontinuous sheets up to three inches thick, and as thin coatings around shale plates. (Plate 23) These are probably the channels preferred by soil solutions draining downwards, and in which soluble, mobile iron is deposited in the form of oxides and hydroxides during periods of deep soil aeration. Subsequent differential weathering of the rock causes fragmentation and breakdown of the shale and leaves the hard iron and iron-coated shale as a platy stoneline. The stone line generally has a distinct, broken upper boundary and rests in the B horizon or at the junction of the B and C horizons. Quartz stone lines derived from quartz stringers in shale have been seen in one area close to Niah village.

The form of iron deposition described above is due to podsolisation. Iron accumulation, however, is also thought to occur in Merit and possibly Malang soils as a result of groundwater lateritization. This process is generally thought to be that in which bases, iron and silica in the soil are taken into solution by the groundwater. The bases and silica are removed while the iron is redeposited by oxidation in periodic dry periods at the highest level the groundwater reaches. The zone of iron-enrichment is in the lower B horizons and it causes the soil to be strongly mottled with reddish colours against a yellow to white clayey matrix. The underlying Cg horizon is depleted of iron and bases, is gleyed white, and may be deep, although most commonly it merges with the C horizon of weathering shale within a few feet of the surface. Both soil-forming processes of podsolisation and lateritization appear to be taking place in the Luak Series soil described in detail in Appendix B. This is a common soil in the area and typical of the Merit Family: the relevant chemical data showing these processes are shown in Fig. 36. It has not been determined to what height the groundwater rises in hill country during the rainier season and whether the gleying is in fact due to this but it is conceivable that a wet season water table perched above dense shale is sufficient to cause the gleying and iron movement. The degree of iron accumulation as a possible result of lateritization is nowhere sufficient in the soils analysed in the present area to justify classing them as Ground-Water Latelite soils.

Figure 38 Graph showing relationship between total phosphorus and cation exchange capacity in Red-Yellow Podsollic soils.

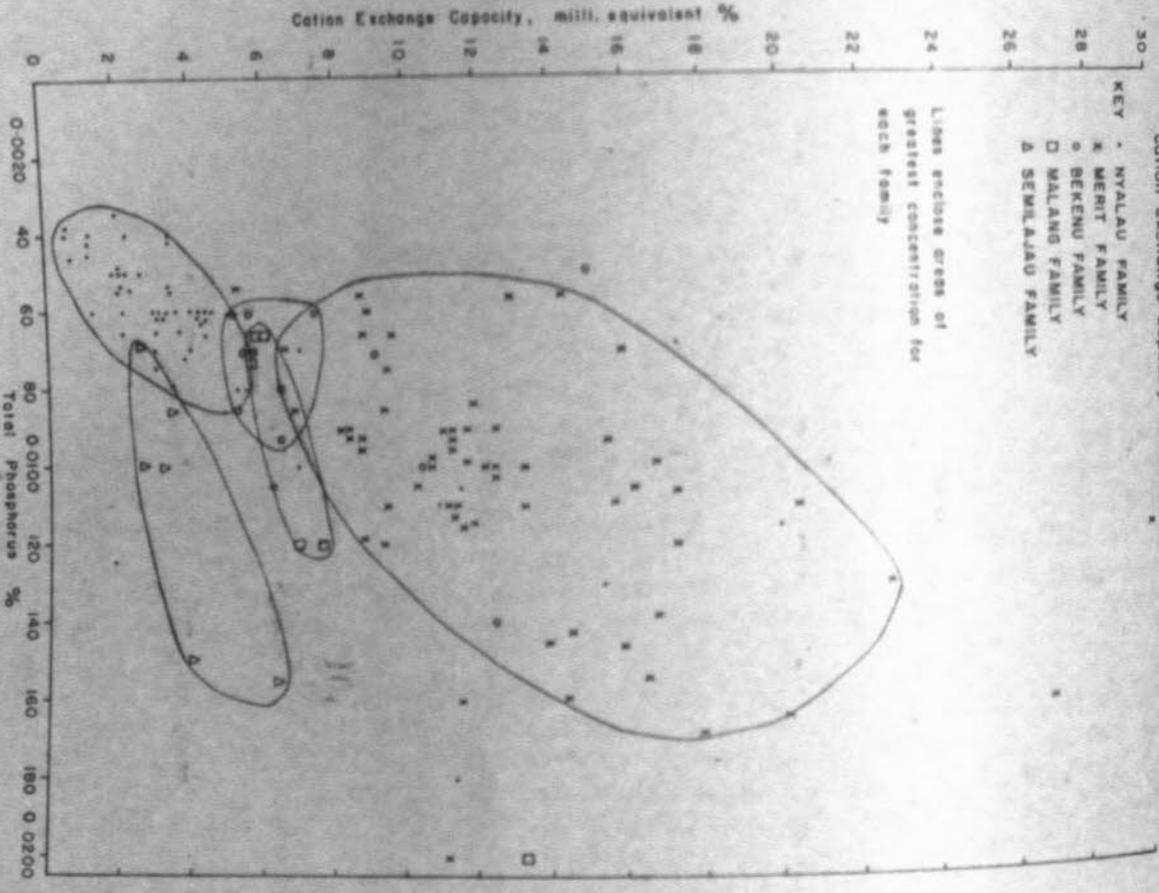


Figure 39 Graph showing relationship between clay content and reserve potassium in Red-Yellow Podsollic soils.

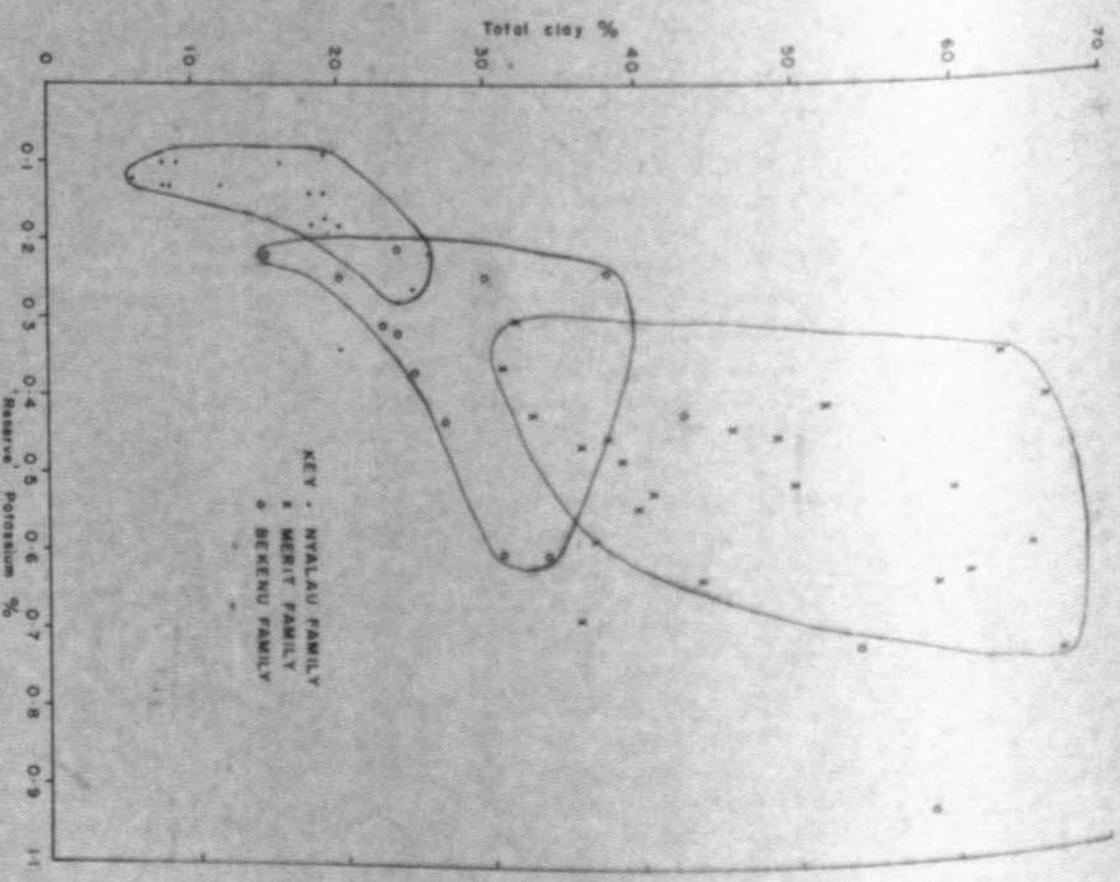
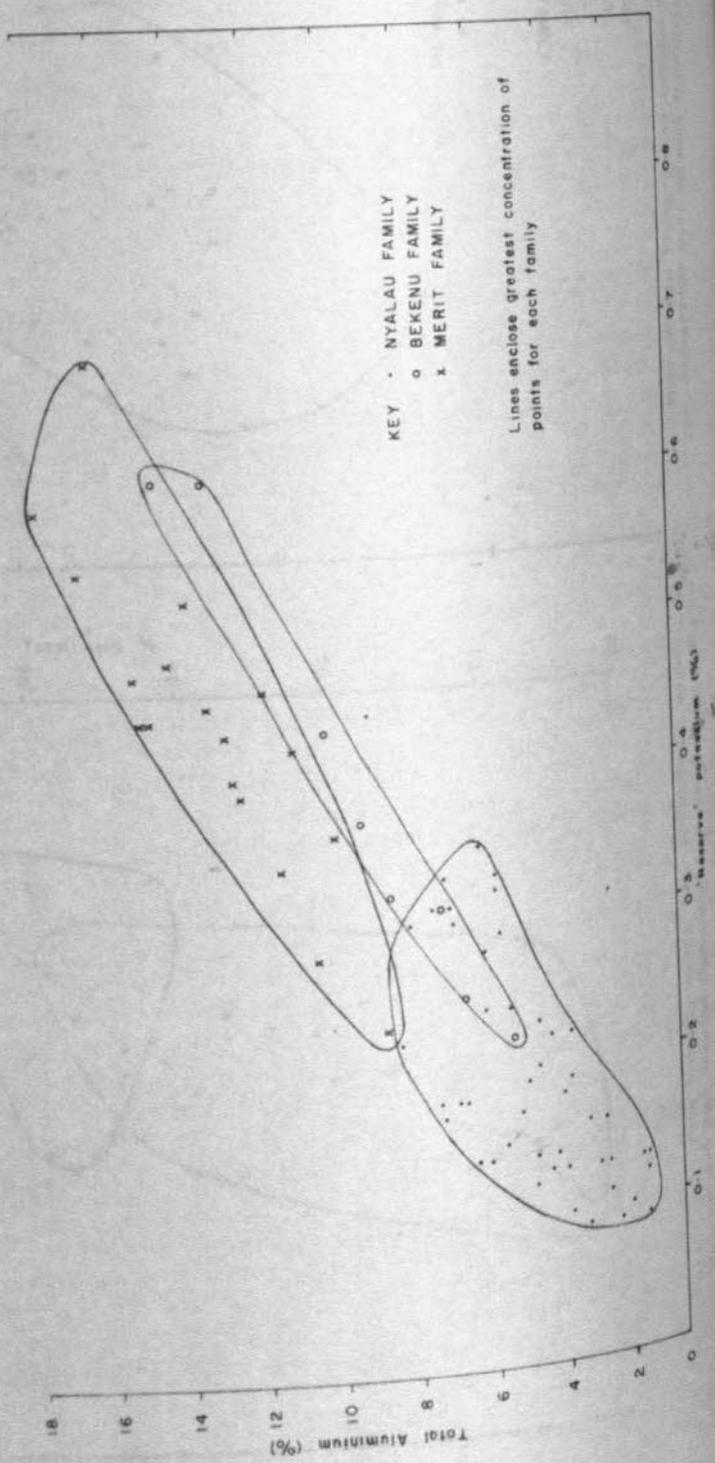


Figure 40 Graph showing relationship between 'reserve' potassium and total aluminium in Red - Yellow Podsollic soils.



Soil Families  
Red-Yellow Podsollic Group

The total phosphorus concentration in Merit soils appear to be linked closely to the cation exchange capacity in the topsoil, but to the total iron content in the subsoil (Figs. 38 and 43), which is interpreted as a predominance of organic phosphorus in the A horizons compared to inorganic phosphorus below. The C.E.C. of the two soils examined is not well related to clay, aluminium or Group III levels in the A and upper B horizons and therefore the exchange complex by inference is essentially organic. The phosphorus may be bound to iron in the subsoil in a form largely unavailable to plants, as has been shown in detail for Merit soils elsewhere in Sarawak (Department of Agriculture, 1966, p.6). 'Reserve' potassium is associated clearly with total aluminium in Merit soils and not to iron (compare Figs. 39, 40 and 41), implying that either a large part of the potassium is absorbed in the clay-aluminium exchange complex, or that there are clay-size aluminium silicates in the soil containing potassium. The low levels of exchangeable potassium throughout Merit soils confirm the latter alternative.

Genesis of Semilajau, Bekenu and Nyalau Family soils

Podsolisation (p. 72 ) is moderately well expressed in most soils of these families. The A2 horizon, although not albic as in the Matang Family is well developed. The B horizon shows clear accumulation of clay and the colours and structure commonly strengthen with increasing depth.

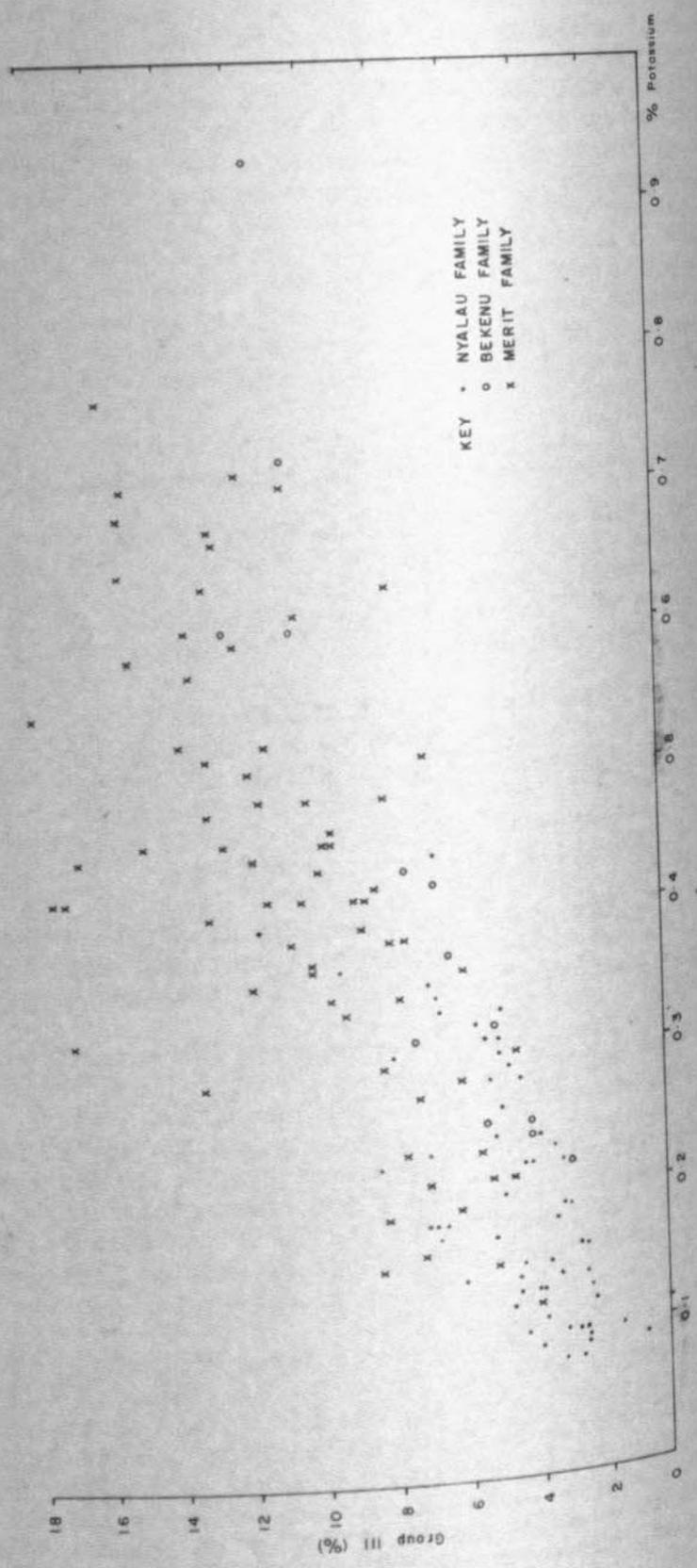
Thin sections of Nyalau and Bekenu soils under the microscope reveal a moderately dense yellowish groundmass embedding abundant subangular quartz grains. There are common, fine, irregular pores in the A horizons, and few in the B horizons. Clay skins coating the walls of pores and of some mineral grains are evident in the B horizons particularly.

The soils are generally deeper than Merit soils, probably reflecting the lower resistance of these generally weakly cemented arenaceous rocks to weathering and they are better drained internally.

Stone lines characterise the subsoil in many areas. Road cuttings in the Lambir Hills show that the stone line commonly forms as a one inch thick continuous sheet at the base of weathered sandstone beds overlying shale where the dip is less than about 30° (Plates 42 and 43). Subsequent weathering and solifluction combine to arrange the stones as a B horizon stone line. Incipient lateritization, as described in the Merit soils above, appears to be absent, probably due to the deep, well drained and permeable nature of the soil, which does not promote waterlogging.

Total phosphorus in these essentially sandy soils is linked predominantly with the cation exchange capacity (Figs. 42 and 38) and by implication to the organic matter content, as the C.E.C. is not well related to the clay fraction, except in the deep subsoil. The phosphorus is probably therefore predominantly organic, and as the levels of iron in these sandy soils is low throughout the profile there is little probability of phosphorus absorption being important, except possibly in deep subsoils of the Bekenu Family.

Figure 41. Showing relationship between 'reserve' potassium and Group III compounds (predominantly iron and aluminium) in Red-Yellow Podsolc soils.



Soil Families  
Red-Yellow Podsollic Group

'Reserve' potassium is clearly related to the clay content (Fig. 39), and even more closely to the aluminium concentration (Figs. 40 and 41) which, in view of the low levels of exchangeable potassium, point to the presence of clay minerals containing potassium as in the Merit soils - rather than the mineral being absorbed into the clay exchange complex.

These sandy soils are particularly prone to erosion by slumping. In Sample Area IV (Appendix A) landslips occupy approximately 11% of the total area, especially in those places where thick sandstone beds and sandy soil overlies impermeable shale. (Plate 15)

Genesis of Matang Family soils

Podsolisation (p. 72) is intense in the Matang Family. The surface organic horizons are deeper and rawer than on soils of the two preceding groups and the A2 horizon is light-coloured, contrasting strongly with underlying horizons. The cause of the strong A2 leaching is attributed to the high permeability, the acid nature of the overlying litter and the strongly siliceous nature of the soil. In effect there is probably little iron and aluminium present in the soil to be leached down (Group III% is believed to be similar to the related sandy Peninjau Series of the Nyalau Family) and the podsollic leaching is predominantly that of humus movement. In the B horizons the humus is washed steadily down the profile, as in Nyalau Family soils, there being no physical barrier to cause its accumulation: the clay content increases slightly and colours tend to be stronger, reflecting a similar increase in iron and aluminium. The soils are deep, as in many Nyalau soils, and similar dark red stone lines in the B horizon have been noted.

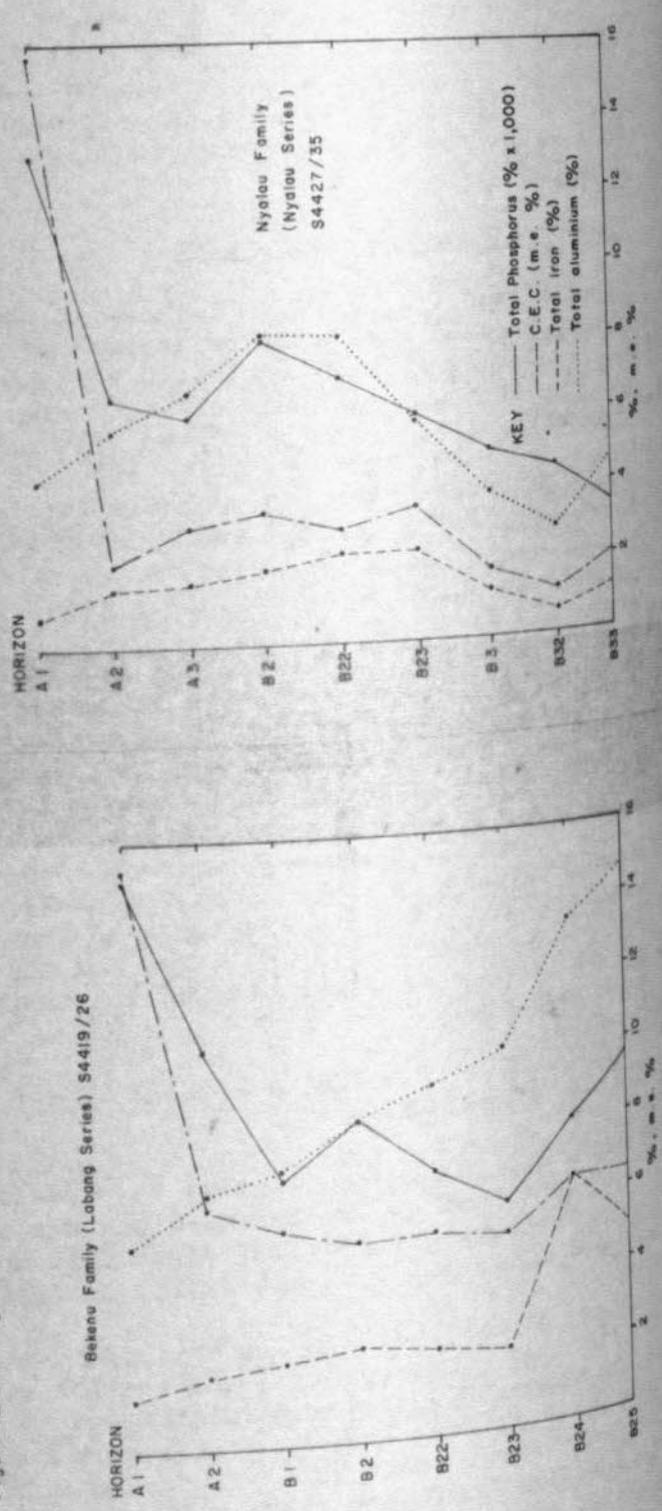
Although in most places it can be shown that Matang soils are of a residual nature by their location on ridge sites, it is suspected that some are developed at least in part in colluvium. Such soils occur on sloping sites and the highly sandy, leached A2 horizon rests rather abruptly on the contrasting B horizon giving a bisequum profile.

DISTRIBUTION OF RED-YELLOW PODSOLIC SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

The soil map (Map 4) shows that the Red-Yellow Podsollic soils cover the largest part of the Bekenu-Niah-Suai area and comprise almost all the residual hill soils. Each soil association shown (Map 4) is named after its dominant family or families.

Merit family soils coincide well in distribution with the argillaceous rocks (p. 31) and the low hills (p. 38), and with parts of the ridges (p. 39) and cuestas (p. 39). They are the natural habitat of primary Lowland Dipterocarp Forest (p. 50) and are among the first soils in newly formed hill land to be cultivated. The Low Hill Photo-association (p. 19) proved to consist predominantly of soils of the Merit Family (Luak Area, Appendix A1); and the High Ridge and Cuesta photo-associations (p. 21) were found to contain unexpectedly large areas of these soils (Sample Area V, Appendix A).

Figure 42 Showing the relationship between total phosphorus, and total iron and aluminium and C.E.C in Red- Yellow Podsolc soils.



Soil Families  
Red-Yellow Podsollic Group

Bekenu Family soils are most common where mixed argillaceous and arenaceous rocks outcrop (p. 30 and 30 ), particularly over the Nyalau, Lambir and Miri rock formations, where ridge and cuesta country are found (p. 39 and p. 39 ) and to a small extent among the low hills (p. 38 ). The natural primary forest is Lowland Dipterocarp Forest (p. 50 ) and the Bekenu soils are commonly selected for cultivation where the slopes are not too steep. It was found that the High Ridge Photo-association (p. 21 ) was dominated by Bekenu soils (Sample Area V, Appendix A) but they also occurred in parts of the Low Hill and dip slopes of the Cuesta photo-associations. (p. 19 and p. 21 ; Luak Area, Sample Area IV, Appendix A).

Soils of the Nyalau Family are the dominant members of the Nyalau and Nyalau-Bako associations. They occur only on arenaceous rocks (p. 30 ) and particularly on the high ridge and cuesta country (p. 39 and p. 39 ) under Lowland Dipterocarp Forest (p. 50 ). The soils are cultivated in places where better soils are not available. Large parts of the Ridge Photo-association (p. 21 ) were found to contain Nyalau soils, commonly shallow, but they are most extensive on the Cuesta Photo-association (p. 21 ) dip slopes (Sample Area IV, Appendix A).

Matang soils are not widespread and they form only a minor part of the Nyalau-Kapit Association. The soils develop solely on strongly arenaceous rocks of the Lambir and Belait Formations (p. 30 ) in conjunction with cuesta and ridge topography (p. 39 and p. 39) and beneath Lowland Dipterocarp Forest (p. 50 ). Matang soils are rarely cultivated where better soils are available. They are found only in the Ridge and Cuesta photo-association (p. 21 and p. 21 ) in similar sites to those described in Brunei (Ashton p. 15-17) for soils with a closely similar morphology.

Semilajau Family soils are limited in distribution to the river levees of the upper Niah and Suai rivers and to banks of small streams draining areas with predominantly arenaceous soils. The soils are developed in young arenaceous river sediments (p. 31 ) with a poor cover of Riparian Forest (p. 48 ), that in places is cleared for settlement and cultivation. Semilajau soils were found to occur only in the Floodplain Photo-association (p. 17 ) where they can be distinguished on air photographs from more poorly drained associated soils if cultivated (Sample Area V, Appendix A; Luak Area, Appendix A).

Malang Family soils are found both as levees in lower river courses and as extensive parts of upper stream flood-plains. They have developed in recent argillaceous river sediments (p. 31 ) with mainly Riparian Forest (p. 48 ) commonly cleared for cultivation. They were found in both the Low hill and Flood-plain photo-associations (p. 19 and p. 17 ; Luak Area, Appendix A). Malang soils have also been found in association with mainly Merit Family soils in wide bands between the middle Suai-Niah-Sibuti-Bakong rivers. These areas coincide clearly with the distribution of argillaceous rocks, low hills and Lowland Dipterocarp Forest: cultivation for hill and swamp rice is common. The Malang soils occupy low-lying, almost intricate pattern. Small patches of Gley and possibly Peat soils occur in places, particularly it is believed between the Saeh (Niah) and Genatan (Bakas) streams and in the Kuop (Sibuti)- Mera-a (Bakong) areas, where they cannot be differentiated clearly in air photographs.

Soil Families  
Red-Yellow Podsollic Group

AGRICULTURAL VALUE OF THE RED-YELLOW PODSOLIC SOILS

Crops as diverse as hill rice, rubber and tobacco are grown on Red-Yellow Podsollic soils in Sarawak, and with an equally varied success, reflecting in part the inherent limitations of the soil and partly the skill of the farmer. The main cultivation limitations of the families in this soil group are described below and suggestions are made for the most suitable range of crops for them in the Bekenu-Niah-Suai area.

Tentative soil fertility ratings (Appendix C) for Sarawak mineral soils (Department of Agriculture, Sarawak, 1966, p.66) are based on experiments with annual crops. While it is clearly invalid to use these levels for all crops, they serve as a useful guide on the low, medium and high soil nutrient levels needed by shallow-rooted annual crops having no unusual nutrient requirements. With circumspection they can be used similarly for perennial crops, although the root network volume and efficiency in nutrient extraction of such crops is probably more varied than those of annuals and therefore subsoil nutrient ratings are of less value. The soil extractions found to correlate most closely with crop yields are those giving 'available' levels (op. cit.). This extraction method has not been used for soils in the Bekenu-Niah-Suai area, as the method giving the most useful results for soil classification yield values approximating to the total levels in soil, called the 'reserve' level (op. cit.) in the case of the bases. The 'reserve' levels given in the tables of this and other sections on soil agricultural value, therefore are used mainly as a guide to soil fertility in the topsoil and subsoil respectively. In many cases the chemical poverty of the soil can be shown by the 'reserve' levels being lower than the 'available' levels rated as low (Appendix C). The total phosphorus figures are probably the most important single values in assessing the soil fertility. (op. cit.)

Agricultural value of Matang and Nyalau Family soils

The Matang and Nyalau families are grouped together as they are known to have similar physical, and probably, chemical properties. Both consist of largely deep, well-drained, poorly structured and coarse-textured soils which are strongly susceptible to gully and landslide erosion (Plates 22, 43) on slopes exceeding about 15° (Wall, 1965c, p.3 and 12). It is recommended that soils of these families should only be cultivated on slopes below this limit. The rooting depth is probably sufficient for most crops, although shallow phases (less than 24 inches to weathered rock) have been recorded in several places over Nyalau Formation rocks.

The topsoil fertility of Nyalau soils varies widely even in small areas under primary forest (Wall, 1964d, p.41) as shown in Table 7, and overall is low. The acidity of the topsoil is rated as moderately to strongly acid by Sarawak standards. (Appendix C)

The most significant deficiency is in phosphorus, and both nitrogen and calcium values are low. It is probable that there is sufficient potassium and possibly magnesium for most crops, although analyses for 'available' levels are needed to confirm this. The average cation exchange capacity of the top soil is low as are the levels of Group III compounds (Table 8) and the few analyses of exchangeable ions all show the topsoil to be poor in these lightly

Table 7. Analyses of the top six inches of Nyalau Family soils from Luak Experiment Station ( a and b ), and from the A1 horizon of Nyalau Family profiles elsewhere in the Beken-Niah-Suai area.

No. of samples	Level	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' K (%)	Total N (%)
a) 8 samples from a one tenth acre site collected on a grid pattern.	Lowest	0.009	0.009	0.03	0.10	0.15
	Highest	0.02	0.07	0.14	0.25	0.22
	Average	0.01	0.02	0.06	0.18	0.19
b) 5 composite split samples from 5 one tenth acre sites, from each of which 8 or 9 subsamples were collected on a grid pattern.	Lowest	0.01	0.02	0.07	0.17	-
	Highest	0.01	0.04	0.10	0.31	-
	Average	0.01	0.03	0.09	0.24	-
Al horizons, 8 samples; primary forest.	Lowest	0.007	0.01	0.006	0.08	-
	Highest	0.02	0.05	0.06	0.18	-
	Average	0.01	0.03	0.03	0.12	-

Note:-- 'Reserve' figures represent amounts between total and easily available figures. Analyses by Agricultural Chemist and Staff Department of Agriculture, Sarawak.

Soil Families  
Red-Yellow Podsollic Group

bound nutrients. It is possible that the exchangeable ions are bound most closely with organic-rich topsoil, and since the topsoil in most nutritional aspects is the richest part of the profile, it is important to prevent its erosion.

Levels of nutrients in Nyalau Family subsoils are rather less varied from area to area if genetic horizons are used as the basis of comparison (Table 8). The overall concentration of nutrients throughout the subsoil however is low. The pH level range from medium to high. (Appendix C).

Table 8. Analyses of Nyalau Family profiles by genetic horizons.

No. of samples	Horizon	Level	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' K (%)	'Gr.' III (%)	C.E.C. (m.e.%)
9	A1	Lowest	0.007	0.01	0.006	0.08	2.5	1.7
		Highest	0.02	0.05	0.06	0.18	4.5	20.4
		Average	0.01	0.03	0.03	0.12	3.2	9.4
14	A2	Lowest	0.004	0.005	0.01	0.08	2.6	0.7
		Highest	0.008	0.03	0.10	0.22	6.1	5.6
		Average	0.006	0.02	0.04	0.14	3.8	2.9
22	B2	Lowest	0.004	0.006	0.006	0.12	2.4	0.6
		Highest	0.01	0.05	0.17	0.44	11.7	11.6
		Average	0.006	0.03	0.06	0.25	6.1	3.6
1	C		0.01	0.02	0.13	0.34	6.8	1.8

Note:- If more than one A2 or B2 horizon is present in a profile, all are included for the purpose of compiling this table.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

It is probable that only potassium and possibly magnesium, values in the subsoil are adequate for most crops. Phosphorus particularly is deficient especially so with increasing depth. The average levels of both Group III compounds and the cation exchange capacity are low throughout showing that added nutrients will be readily leached. Fertilisers are, therefore, best added in frequent small doses rather than single massive ones.

Without fertilisers, Nyalau and Matang soils are not entirely suitable even for deep-rooted hardy crops like rubber whose root network is great and efficient in nutrient extraction, or for shallow-rooted crops such as water melon, groundnut and pineapple feeding primarily on the topsoil. Fertilisers are required for the best results from all crops (Dames, 1952, p.38) and with appropriate mixtures the crop range is potentially as great as on the Bekenu and Merit soils described below, the main limitation then being an economic one. For crops such as bananas and coconut, requiring better than average soil drainage, Nyalau and Matang soils are probably superior to others in the group. Coconuts have been grown on these soils on a small scale near Bintulu, but, despite growing satisfactorily for five years with local phosphatic guano manuring, had to be abandoned due to ravaging by wild pigs from adjacent primary forest.

Soil Families  
Red-Yellow Podsollic Group

Agricultural Value of Merit Family Soils

Physically, the Merit Family soils are slightly inferior to the sandier soils of the group. They are less well drained and although having a similar volume of air space are denser and more intractable when either wet or when dried out. They have a superior structure, however, and are more resistant to erosion. Serious gully erosion tends to occur on unprotected slopes exceeding about 25°, and for this reason it is recommended that cultivation be restricted to slopes below this limit. The soil depth is generally adequate for most crops although shallow phases are common in some areas.

Topsoil fertility varies widely within small areas, even under primary forest (Wall, 1964d, p.40). This feature is shown in Table 9, which also shows that the overall topsoil fertility is low. The pH levels are low to medium. (Appendix C)

Table 9. Analyses of the top six inches of Merit Family soils from Luak Experiment Station (a and b), and of the Al horizons of Merit soils elsewhere in the Bekenu-Niah-Suai area.

Number of samples	Level	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' N (%)	Total N (%)
a) 38 samples from 4 one tenth acre sites collected on grid patterns.	Lowest	0.009	0.0	0.03	0.13	0.12
	Highest	0.09	0.10	0.25	0.75	0.88
	Average	0.02	0.02	0.14	0.37	0.23
b) 5 composite split samples from 5 one tenth acre sites, from each of which 8 or 9 sub-samples were collected on a grid pattern.	Lowest	0.004	0.01	0.05	0.07	-
	Highest	0.03	0.19	0.27	0.58	-
	Average	0.01	0.06	0.17	0.31	-
Al horizons, 11 samples, primary and secondary forest.	Lowest	0.008	0.005	0.02	0.15	-
	Highest	0.03	0.14	0.19	0.41	-
	Average	0.01	0.05	0.14	0.31	-

Note:- 'Reserve' figures represent amounts between total and easily available figures.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Phosphorus levels are as low as in the Nyalau soils and the calcium status is similarly low; nitrogen shows little improvement. 'Reserve' magnesium and potassium both well exceed the Nyalau soil levels and are possibly present in a sufficient quantity for many crops in the 'available' form. Analyses of exchangeable ions indicate that the topsoil is richest in this respect, although the concentrations are low. Because the easily available nutrients tend to be bound closely to the organic exchange complex of the topsoil it is important to prevent the surface erosion that commonly occurs. Both the cation exchange capacity and Group III levels are sufficiently high to suggest that added fertilisers will not be leached easily from this surface soil.

Soil Families  
Red-Yellow Podsollic Group

'Reserve' nutrient levels of the subsoil differ in several respects from those of the Nyalau soils (Table 10) but the overall nutrient concentration, and particularly the important phosphorus status remains low throughout. Elsewhere in Sarawak it has been shown that iron with aluminium is responsible for fixing part of the soil phosphorus in a form available to plants (Department of Agriculture, Sarawak, 1966, p.67). The indications from this area are that the iron-inorganic phosphorus ties are stronger than those between aluminium and inorganic 'reserve' phosphorus (Fig. 43) in the most iron-rich soils of the family. Pintasah Series. Phosphatic fertilisers are therefore important in considering the manurial requirements of crops on these soils (see also Bailey, 1966b). Only 'reserve' potassium and magnesium levels are sufficiently high to suggest that 'available' levels may be sufficient for most crops, particularly in the deep subsoil, although analyses are required to confirm this. Exchangeable cation levels in the subsoil are uniformly low, although calcium and potassium levels, and to lesser extent magnesium, tend to be somewhat higher in the lower B and C horizons.

Provided adequate fertilisers of the right combination are added, Merit soils are suitable for a wide range of crops. Rubber grows well, also most local fruit trees including citrus; oil palm has been seen growing well on Merit soils to the east of this area and sisal, coffee, tea and cocoa might thrive although the rooting space may be restricted for some. Bananas and sugar cane grow satisfactorily on these soils in places, and shallower rooted crops such as groundnuts, tobacco and various tubers and cereals are popular in Chinese-farmed areas, as at Batu Niah. Pepper, if cultivated carefully, is a lucrative crop on Merit soils although it is susceptible to disease in poorly drained sites and to physiological drought in some periods of the year (p.29 ). Grasses, such as citronella which contains essential oils, should have little difficulty in becoming established.

Agricultural Value of Bekenu Family Soils

In many respects Bekenu Family soils have properties intermediate between those of the Nyalau and Merit Families. Physically, the topsoil and upper subsoils are like those of Nyalau soils in being light-textured, weakly structured and permeable. Beneath, however, the subsoils are clayey, have a better structure and are rather sticky and intractable when wet. They are moderately well-drained but commonly tend to be shallow (less than 24 inches to weathering rock) and somewhat stony in the lower subsoil. As the topsoil is susceptible to gully erosion it is recommended that cultivation be restricted to slopes of less than about 20°.

Table 10. Analyses of Merit Family profiles by Genetic horizons.

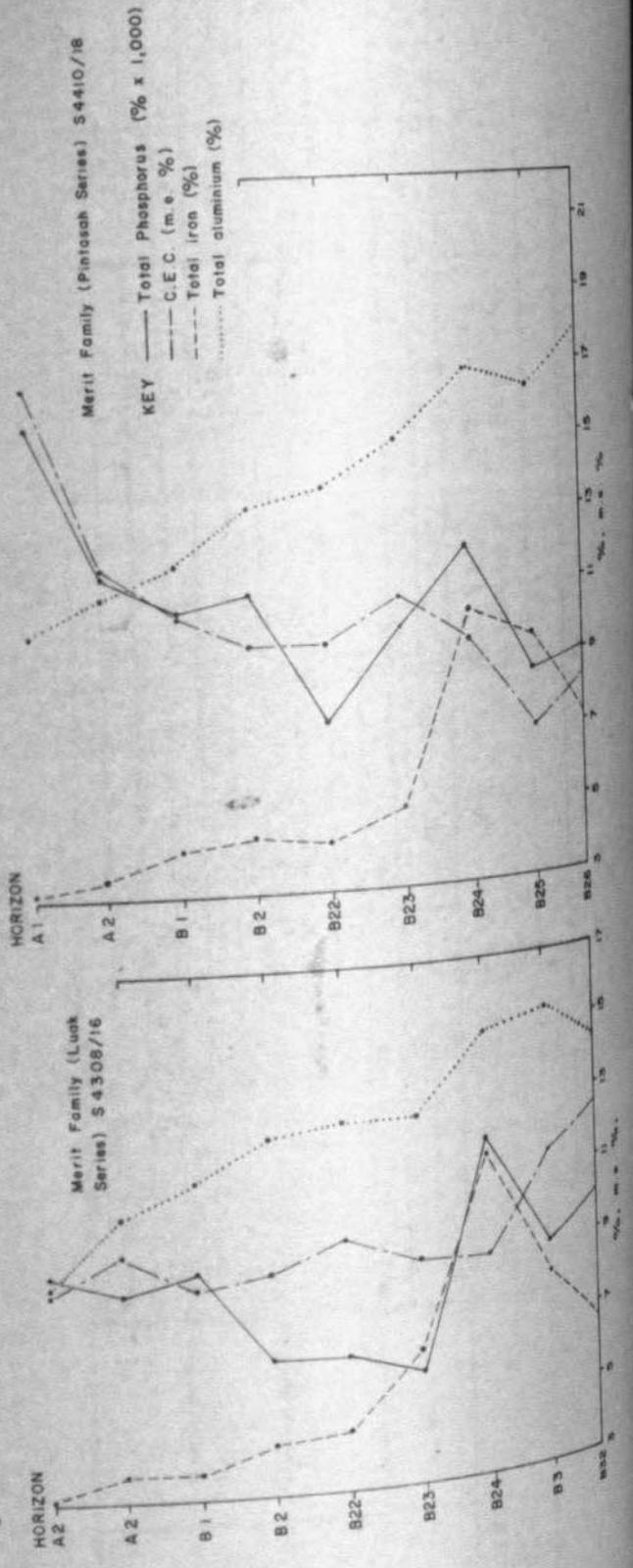
No. of samples	Horizon	Level	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' K (%)	Gr. III (%)	C.E.C (m.e.%)
11	A1	Lowest	0.008	0.005	0.02	0.15	4.6	8.5
		Highest	0.03	0.14	0.19	0.41	10.2	38.9
		Average	0.01	0.05	0.14	0.31	6.9	20.0
10	A2	Lowest	0.005	0.01	0.07	0.12	4.0	5.3
		Highest	0.02	0.09	0.32	0.48	16.0	16.0
		Average	0.01	0.03	0.15	0.32	9.0	11.3
25	B2	Lowest	0.005	0.003	0.04	0.21	6.9	5.3
		Highest	0.02	0.04	0.30	0.78	17.5	25.5
		Average	0.01	0.02	0.18	0.47	11.4	14.6
9	C	Lowest	0.01	0.01	0.21	0.35	11.9	11.1
		Highest	0.02	0.07	0.47	0.79	15.4	16.9
		Average	0.01	0.03	0.33	0.64	12.8	13.7

10 samples; \*\* 9 samples; + 8 samples; ++ 19 samples; +++ 21 samples; " 3 samples;

Note:- If more than one A1 or B or C horizon is present in a profile, all are included for the purpose of compiling this Table.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Figure 43. Showing the relationship between total phosphorus, and total iron and aluminium and C.E.C in Red-Yellow Podsolc soils



Soil Families  
Red-Yellow Podsollic Group

The topsoil fertility varies widely within small areas. (Table 11).

Table 11. Analyses of the top six inches of Bekenu Family soils from Luak Experiment Station (a and b), and from the A1 horizon of Bekenu Family, profiles elsewhere in the Bekenu-Niah-Suai area.

No. of samples	Level	Total P (%)	'Res.' Ca (%)	'Res.' Mg (%)	'Res.' K (%)	Total N (%)
a) 8 samples from a one tenth acre site collected on a grid pattern.	Lowest	0.02	0.07	0.25	0.47	0.41
	Highest	0.07	0.18	0.37	0.76	0.78
	Average	0.06	0.13	0.31	0.56	0.52
b) 3 composite split samples from 3 one tenth acre sites, from each of which 8 or 9 samples were collected on a grid pattern.	Lowest	0.01	0.02	0.08	0.07	-
	Highest	0.02	0.06	0.22	0.18	-
	Average	0.02	0.04	0.13	0.11	-
A1 horizons, 2 samples; primary forest.	Lowest	0.01	0.02	0.07	0.22	-
	Highest	0.01	0.02	0.09	0.25	-
	Average	0.01	0.02	0.08	0.23	-

Note:- 'Reserve' figures represent amounts between total and easily available figures.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

The phosphorus status shown in Table 11 a) appears to be better than that of either the Nyalau or Merit soils described above, but this is probably the exception rather than the rule, and the lower levels of b) are believed to be more typical, similarly the levels of the other bases. The nitrogen values from site a) are uniformly higher than is normally found in Bekenu soils elsewhere. Exchangeable ions are the highest in the topsoil but the concentrations are low. It is therefore important to conserve the topsoil against erosion to avoid any deterioration of the organic exchange complex. The surface soils are uniformly acid to strongly acid by Sarawak standards.

Soil Families  
Red-Yellow Podsollic Group

The similarity of the A2 horizon to that of the Nyalau Family soils, and of the B2 horizon to that of the Merit Family soils is shown by the analyses of 'reserve' nutrients in Table 12. The magnesium and potassium levels show a marked increase in the B2 horizon, conforming to a similar rise in the Group III compounds and to a small degree in the cation exchange capacity. Phosphorus and calcium are uniformly low throughout, and it is probable that balanced additions of fertilisers will be required for most crops, as with the Nyalau and Merit soils, particular attention being needed for phosphorus requirements. Nutrients can be expected to leach fairly rapidly through the A2 horizon but will tend to become absorbed in the B horizons. From the analyses of exchangeable cations this appears to be more true of calcium and potassium than of magnesium and sodium, although any increase in concentration with depth is slight as in Nyalau and Merit soils. The acidity decreases steadily from pH 4.7 in the upper subsoil to about pH 5.3 in the lower subsoil in one profile.

Bekenu soils are suitable for the same range of crops as Nyalau Family soils where slopes permit. They are probably more suitable for crops needing free rooting, such as bananas, than Merit soils and are better than Nyalau soils for heavy feeding crops such as pepper, owing to their superior nutrient-holding capacity.

Agricultural Value of Semilajau and Malang Families

Although the physical and some chemical properties of Semilajau and Malang Family soils are dissimilar, their agricultural usage and potential suitable crop range resemble each other. The soils of both families are deep and imperfectly to moderately well drained, and both are subject to periodic flooding; Semilajau soils predominantly by flash floods, and Malang soils by floods of rather longer duration. These soil families therefore should not be used for crops likely to be affected by this feature.

The main differences between the two families stem from their different textures. The essentially sandy Semilajau soils are poorly structured and loose and tend to be less fertile than the clayey, weakly blocky Malang soils.

Analyses of the topsoil nutrients show that the 'reserve' levels fluctuate quite widely from place to place and even within small areas (Table 13). Phosphorus is deficient in both soils, also calcium. Magnesium and potassium are present in moderately high concentrations particularly in the Malang topsoils, but it is not known what proportion of this is available to plants. In the subsoil, the 'reserve' nutrient levels are similar in both families except that potassium and magnesium tend to be higher in Malang soils (Table 13). For optimum crop yields it is probable that phosphorus will be the most required nutrient. The slightly higher clay status of Malang soils, indicated by the Group III levels in Table 13 will aid the retention of some fertilisers, while in the Semilajau soils soluble nutrients will be readily leached.

Table 14. Analyses of the Borneo Family profiles by genetic horizon.

No. of samples	Horizon	Level	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' K (%)	Group III (%)	C.E.C (m.e.%)
2	A1	Lowest	0.005	0.02	0.07	0.22	3.0	6.9
		Highest	0.006	0.02	0.09	0.25	3.2	15.1
		Average	0.005	0.02	0.03	0.23	3.1	11.0
3	A2	Lowest	0.006	0.01	0.09	0.24	4.2	5.7
		Highest	0.01	0.02	0.10	0.25	4.4	7.5
		Average	0.007	0.02	0.09	0.25	4.3	6.5
6	B2	Lowest	0.006	0.02	0.06	0.32	5.2	5.3
		Highest	0.01	0.04	0.27	0.72	12.5	10.6
		Average	0.008	0.03	0.22	0.51	8.8	6.6

Note:- If more than one A2 or B2 horizon is present in a profile, all are included for the purpose of compiling this Table.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Soil Families  
Red-Yellow Podsollic Group

Table 13. Analyses of the top six inches of Semilajau and Malang Family soils from Luak Experiment Station.

No. of samples	Level	Total P (%)	'Res.' Ca (%)	'Res.' Mg (%)	'Res.' K (%)	Total N (%)	Gr.III (%)
SEMILAJAU 8 samples from a one tenth acre site*	Lowest	0.02	0.005	0.05	0.18	0.15	1.3
	Highest	0.02	0.03	0.25	0.30	0.26	4.6
	Average	0.02	0.01	0.10	0.25	0.21	3.3
SEMILAJAU 3 composite site samples***	Lowest	0.01	0.008	0.06	0.18	-	-
	Highest	0.01	0.03	0.16	0.33	-	-
	Average	0.01	0.02	0.12	0.27	-	-
MALANG 10 samples from a one 10- th acre site*	Lowest	0.02	0.008	0.12	0.21	0.17	4.4
	Highest	0.03	0.04	0.20	0.41	0.26	8.2
	Average	0.02	0.03	0.16	0.31	0.21	5.7
MALANG 5 composite site samples**	Lowest	0.008	0.01	0.10	0.08	-	-
	Highest	0.03	0.11	0.27	0.67	-	-
	Average	0.02	0.04	0.17	0.24	-	-

\* Collected on a grid pattern.

\*\* Consisting of 8 or 9 split subsamples from each site.

Note:- 'Reserve' figures represent amounts between total and easily available figures.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

With appropriate fertilisers the most suitable crops for these soils are perennials unaffected by short floods. Rubber, oil palm, coffee, citrus, bananas, coconut and many local fruit trees all have been seen growing satisfactorily on these soils either in or near to the Bekenu-Niah-Suai area with the bare minimum of attention. It is probable that manila hemp, cocoa and possible pineapple would also be suitable.

Soil Families  
Grey-White Podsollic Group

SOIL FAMILIES OF THE GREY-WHITE PODSOLIC GREAT SOIL GROUP.

Although only the Triboh Family is mapped it is probable that other families of this group occupy small areas among the terrace landscape, as elsewhere in the country. The Triboh Family has only been found on terraces in the Nyalau-Suai and Niah areas. The main characteristics of the soils are described below, followed by an explanation of this development.

Table 14. The diagnostic features of Grey-White Podsollic soils in the Bekenu-Niah-Suar area.

ORIGIN OF PARENT MATERIAL	TEXTURE OF B HORIZON	SOIL FAMILY
Old alluvial	coarser than fine-textured	TRIBOH

Elsewhere in Sarawak three more families are separated on the basis of origin of parent materials and the texture of the B horizon.

1. TRIBOH FAMILY

The soils of the Triboh Family in the area can be summarised as being commonly shallow and imperfectly drained, with sandy upper subsoils overlying abruptly more clayey deep subsoils and developed in old marine and riverine alluvium. A brief description of a profile is given in Appendix B6; few analytical data are available from this area.

The surface organic horizon varies in thickness but is generally from one to four inches thick and overlies a distinct A1 horizon two to four inches thick. The A2 horizon is generally at least ten inches deep and changes abruptly to the B or IIC horizon.

Moist soil colours beneath the dark, organic-rich topsoil are characteristically pale, ranging from white to light greyish brown. In places there is a weak indication of dark-coloured humus accumulation in cracks and at the base of the A2 horizon. Mottles of high chroma are rare.

The soils textures are predominantly in the sand to sandy clay loam range. The surface O horizon if thick tends to be peaty. The A horizon is generally sandy loam to loamy sand, and overlies B or IIC horizon sandy clay loam. The change from A2 to B is generally abrupt. Deeper parts of the profile tend to be more clayey. Normally, there are no inclusions.

The soil in field conditions has a loose to very friable consistency in the A2 and friable, rarely firm, consistency in lower horizons. The soil is commonly wet in the deeper subsoil where plastic and slightly sticky consistencies occur. Structure has not been studied but is believed to be poorly developed. Roots are most widespread in the organic-rich topsoil. External drainage is slow, internal drainage is imperfect. Chemical analyses of Triboh soils have not been made by they are thought to be inherently of low fertility.

Soil Families  
Grey-White Podsollic Group

GENESIS OF THE TRIBOH FAMILY SOILS

The dominant soil-forming process taking place in the Grey-White Podsollic soils is podsolisation, in which clay, sesquioxides and soluble bases are leached downwards in solution and suspension. Conditions in the area are favourable for the podsolisation of Triboh soils and they show profile development midway between Red-Yellow Podsollic soils (p. 64 ) and Groundwater Podsol (p. 91 ).

The soil texture is sandy, particularly in the upper part of the profile, permeability is high and the drainage of the A horizons is unimpeded all allowing easy penetration of soil water. The soils are found on flat to gently sloping terraces favouring minimal surface run-off and maximal internal drainage.

The presence of a slightly peat O horizon in places and pale-coloured A2 horizon are typical features of strongly podsolised soils although the intensity of humus translocation from the surface downwards is not sufficient to cause the development of a humus pan, despite the textural discontinuity normally present between A2 and B horizons. Humus does, however, appear as mottles in the B horizon in places and also collects in old root channels. The pale colours of the soil are attributed to the paucity of iron compounds, as in the Groundwater Podsol, rather than to poor drainage, although in some areas the soil is periodically waterlogged and the surface organic material is slightly peaty.

The Triboh soils are believed to be bisequent where found in this area, as the textural change between A2 and B horizons is much greater than can be explained by the downward leaching of clay alone. The occurrence of thin layers of sand above more heavily textured material is typical of shallow offshore areas at the present time. With similar fine sand grade and gently sloping beaches, the thickness of surface sand off the Brunei shoreline to the north is 35 feet on the shore, 9 feet at 2,000 feet from the shore and 3 feet in a depth of waters of about 30 feet. The underlying material is described as mud (Wilford, p.303; quoting White, 1957, p.10-11). Thus it is quite possible for the horizon differentiation to be an inherited rather than an acquired feature.

DISTRIBUTION OF GREY-WHITE PODSOLIC SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Triboh Family soils are the sole representatives of the Grey-White Podsollic group mapped in the area. They occur in association with Miri soils (p. 92 ) mainly, and possibly with the Buso Family (p. 93 ), in the zone between coastal swamps and hills at the Nyalau River area, in one area of the middle Niah River close to Batu Niah bazaar, and they are inferred to exist from air photograph interpretation on the low watershed between the Saeh and Tiris Streams.

Triboh soils are developed in marine and riverine old alluvium (p. 31 ) on terraces (p. 38 ). They support Heath Forest (p. 50 ) and are not used for cultivation. Triboh soils were found to occur solely in the Terrace Photo-association (p. 18 ) where their air photograph characteristics are distinctive.

Soil Families  
Grey-White Podsollic Group

AGRICULTURAL VALUE OF THE GREY-WHITE PODSOLIC SOILS

As the Grey-White Podsollic soils have not been studied in detail in the Bekenu-Niah-Suai area the following remarks are tentative, and based as much on evidence from outside the area as within it.

The Triboh Family soils are normally deep and well to moderately well drained. In the area studied they generally have a loose, sandy upper subsoil contrasting with a loamy or clayey lower subsoil that is less permeable and has a denser appearance. The soil probably becomes temporarily waterlogged after heavy rain due to this heavier-textured subsoil and the associated gentle slopes.

The fertility of the soils as judged by analyses of parts of four profiles is low or extremely low throughout (Appendix C). Even in the organic-rich topsoil which is the most fertile part of the profile, both 'available' and 'reserve' phosphorus are low and the base exchange capacity of less than 10 m.e.% is less than 20% saturated by exchangeable cations. In the loamy or clayey lower subsoil the phosphorus status is extremely low and the levels of exchangeable nutrients minimal. By Sarawak standards the soils are moderately acid throughout. These analyses can be amplified by data on similar soils from West Sarawak (Andriess, p.102) where 'reserve' major nutrient levels are less than the 'available' low ratings (Appendix C) except for the magnesium and potassium in the lower subsoil.

Triboh soils therefore are unsuitable for cultivation in their present condition, due to their extremely low fertility. They are used successfully for market gardening adjacent to Kuching in west Sarawak, however, (op. cit., p.46) where organic fertiliser is cheap and plentiful, and where the market is assured and product prices are moderately high. These incentives are not yet present in the Bekenu-Niah-Suai area.

SOIL FAMILIES OF THE GROUNDWATER PODSOL GREAT SOIL GROUP

Three families in the area are classed as Groundwater Podsol. (Table 15). Bako soils have been seen only in a few small pockets among the hills while Miri soils are the dominant type on terraces and Buso soils occur along parts of the littoral. Closely similar podsol soils on terraces have been described from many parts of the humid tropics for example in British Guiana (Bleakley and Khan, 1963). The chief characteristics of the families are described first, followed by an account of their differentiating features and an explanation of their development.

Table 15. The diagnostic features of Groundwater Podsol soils the Bekeun-Niah-Suai area.

ORIGIN OF PARENT MATERIAL	STRENGTH OF SPODIC HORIZON	SOIL FAMILY
Residual	Strong	BAKO
Alluvial	Strong	MIRI
	Weak	BUSO

Soil Families  
Groundwater Podsol Group

Elsewhere in Sarawak another family is separated on the basis of a weakly developed spodic horizon in residual soil, and another is differentiated by its different type of spodic horizon.

### 1. BAKO FAMILY

The diagnostic features of the Bako Family are shown in Table 15. From the few descriptions of these soils in this area they can be termed shallow, very poorly drained, podsolised sands developed from thick sandstone beds. No analytical data are available from this area.

The surface organic horizon is from one to five inches thick and rests on a distinct A1 horizon two to six inches thick. Beneath, the prominent A2 horizon ranges in thickness from a few inches to more than two feet, and gives way abruptly to the B2. This horizon is predominantly well expressed, although in places it is less clear, where the soil more closely resembles those of the Silantek Family (weakly developed spodic horizon, not mapped in this area). The change to the C horizon beneath is gradual in some places and abrupt in others.

The moist soil colours characteristically are almost void of chroma, the colour range being from dark greyish- to dark reddish brown O and A1 horizons, to a light grey or white A2 horizon, mottled light brownish grey, over a very dark brown to black B2 horizon. Pale brown to brown shades are typical of the lower A and B horizons in some instances.

The texture of Bako soils is predominantly sandy with the exception of the raw, root-matted mor of the O horizon. The whole mineral part of the profile is classed under sand or loamy sand textures although the Bh horizon in some places increases in clay content to sandy clay loam. The C horizon generally shows a higher proportion of clay than elsewhere in the profile, except where it consists of hard rock. There are normally no inclusions.

The field consistence of the A1 and A2 is loose to very friable. The Bh varies from being too hard to auger (very firm) to being wet and therefore impracticable to auger. Structure is absent from the profile above the B horizon apart from weak fine crumb in the A1 or a weak blockiness in the A2. The B horizon has not been studied in pit profiles in this area, but elsewhere is known to be rather blocky.

Roots are restricted almost entirely to the organic rich topsoil. External drainage is slow and except for periodic dry spells internal drainage is very poor giving waterlogged subsoil. There is thought to be medium to slow lateral movement of the groundwater downslope. It has been noted in one area that deep profiles appear to be correlated with drier subsoil conditions. Chemical analyses are not available but the soils are thought to resemble those of the Miri Family in this respect.

### 2. MIRI FAMILY

The diagnostic features of the Miri Family can be found in Table 15. The family broadly consists of shallow to deep, excessively to very poorly drained, strongly podsolised soils developed in Pleistocene or Holocene quartz sand. Detailed descriptions and analyses of typical series in the family are given in Appendix B7.

Soil Families  
Groundwater Podsol Group

Where undisturbed the surface organic layer is from one to ten inches deep. The A1 horizon is distinct but gives way after three to six inches to the shallow to deep A2 horizon. The B2 contrasts strongly with the horizon above it and varies greatly in depth from a few inches to several feet.

**Moist soil colours are characteristically low in chroma.** The O and A1 horizons are dark reddish to dark greyish brown, the A2 horizon light grey to white and the Bh, olive brown to black. C horizons are generally pale coloured due to gleying.

Textures below the raw, root-matted mor or peaty O horizon range from sands, to loamy sands found mainly in the B horizon. There may be a clayey IIC horizon in the lower subsoil in places. The soils mainly have loose field consistence as deep as the B horizon which is sufficiently cemented by humus to be too hard to auger through, particularly where there is a fine-textured IIC horizon beneath. In the Beraya area (Sample Area I, Appendix A) the lower A2 or A3 horizon is also cemented but with silica. The soils are almost structureless above the slightly blocky B horizon although weak crumb structure may be detectable in the A1 and an extremely weak blockiness in the A2 horizon. Permeability is high above the B2h horizon.

External drainage is very slow. Internally there is excessive drainage to the B horizon, which in most cases lies where the perched watertable or groundwater can be found. The groundwater is more or less stagnant, although after prolonged rain there may be lateral seepage. Roots are almost entirely restricted to the O and A1 horizons.

Chemical analyses show the soils to be extremely low in exchangeable and reserve nutrients except in the topsoil. Total fine earth analyses give figures of more than 95% silica below the A1 horizon in one example. There is a peak in the cation exchange capacity and in carbon in the B horizon and the acidity levels typically rise in the unbuffered A2 horizon.

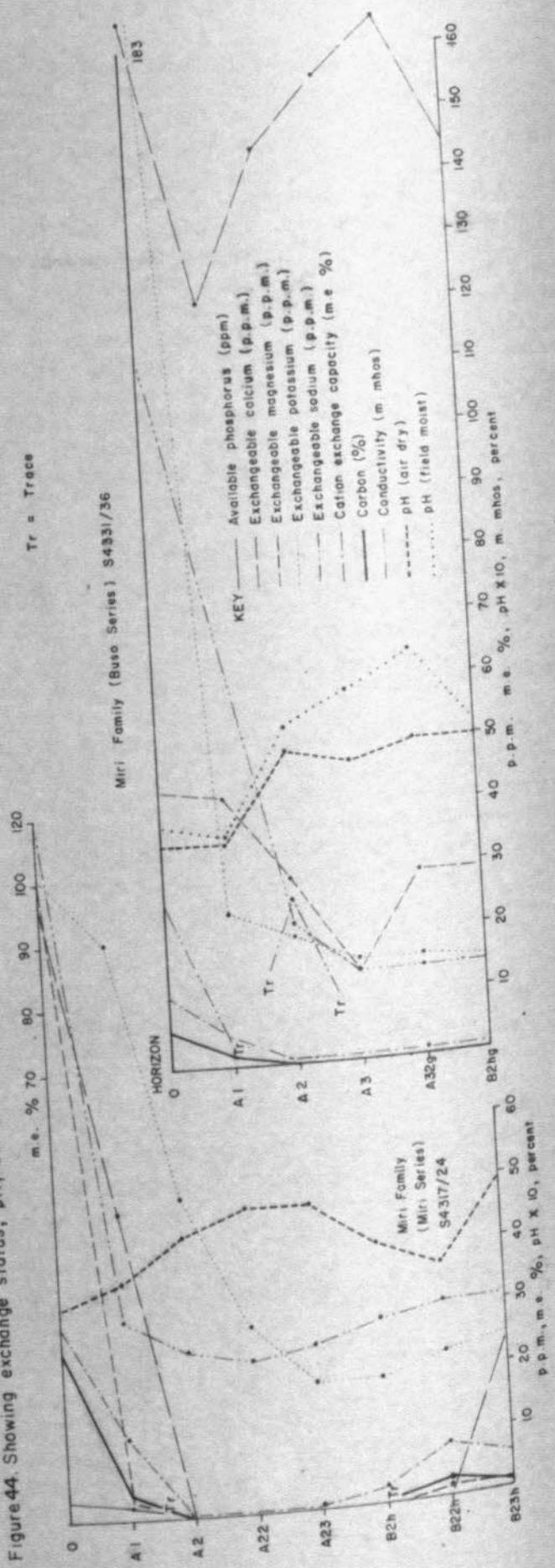
### 3. BUSO FAMILY

The features defining the Buso Family are shown in Table 15. The soils can be described broadly as being shallow to deep, very poorly to excessively drained, weakly podsolised soil developed in Pleistocene or Holocene quartz sand. Detailed descriptions and analyses of a typical series are given in Appendix B8.

The surface organic horizons are generally up to ten inches thick and overlies a distinct A1 horizon. The A2 varies in distinctness and depth but contrasts with the underlying weakly developed Bh horizon. The boundary between the A and B horizons is moderately clear and smooth to faint and broken. It is possible in places to detect gleyed Cg horizon material beneath.

The moist soil colours characteristically are low in chroma. The organic topsoil is invariably dark-coloured in contrast with the light grey to greyish brown A2 horizon, which may be mottled patchily with darker topsoil colours. The Bh horizon ranges from being very dark brown to olive brown in bands and patches; lighter coloured coarse mottles are common. The C horizon, where visible, is gleyed a pale brown or light olive grey colour.

Figure 44. Showing exchange status, pH, carbon and conductivity of two Groundwater Podsol soils.



Soil Families  
Groundwater Podsol Group

The textures are confined to sand or loamy sand grades. The moist consistence of the A horizons is loose, and the wet B and C horizons are non sticky and non plastic; there is no, or only weak, cementation of the Bh. The soils are structureless (single grain) except for weak crumb development in the A1 horizon. Permeability is high.

External drainage is very slow. Internally the soils are excessively to very poorly drained. The watertable depth commonly coincides with that of the B horizon. The watertable is thought to be stagnant except for slight lateral seepage after heavy rain. Rooting is confined to the organic rich A1 and B horizons.

Chemical analyses show that the soils are low in exchangeable and 'reserve' cations except 'reserve' calcium, the topsoil being the richest part of the profile. There is a clear tendency for the cation exchange capacity and the organic carbon level to increase in the B horizon, where the pH level is highest.

DIFFERENTIATING FEATURES BETWEEN GROUNDWATER PODSOL SOIL FAMILIES

Apart from their contrasting topography and their derivation from different materials the main difference between the three families is in their degree of development, as judged by the continuity and hardness of the Bh horizon (Table 16). A practical means of measuring this in the field is the ease with which the horizon can be augered through. Well developed Bh horizons of Miri and to some extent Bako soils are extremely hard to penetrate compared with those of the Buso soils. Bh horizons in the latter family, however, invariably lie within the zone of the groundwater

Table 16. The dominant range of important features of soil families in the Groundwater Podsol group.

Generalised features		BAKO	MIRI	BUSO
Moist colour	A2	pale brown to white	light grey to white	pale brown to white
	Bh	brown to black	very dark brown to black	olive brown to drak brown
Texture	A2	sand	sand	sand
	Bh	sandy to sandy loam	sandy to loamy sand	sand to loamy sand
Cementation	Bh	moderately strong	strong	weak
Parent material		quartzose sandstone	old alluvial quartz sand	young-old alluvial quartz sand
Topography		flat to gently sloping hills	terraces	terraces and beaches
Water table movement		moderate to slow lateral	stagnant to slow lateral	stagnant to slow lateral

table, and it is not generally possible to determine whether or not harder, cemented material lies beneath the upper uncemented part, due to the difficulties of digging in wet sand. In the Beraya area (Sample Area I, Appendix A) the poorly and very poorly drained soils

Soil Families  
Groundwater Podsol Group

with soft upper Bh in the centre of the terrace are mapped as Miri and not Buso Family members. There are known exposures of Miri soils on the terrace margins, and it is assumed that the Bh is harder at lower levels.

The Bako Family soils have been examined only in a few parts of this and adjacent areas. The available field evidence suggests a less uniform texture range, a greater variation in the B horizon qualities and probably a slightly different mineralogical and chemical composition than the other families since there appears to be an admixture with Semadoh Family soils in places (p. ). In addition, the groundwater is thought to be constantly moving laterally due to the gentle slopes compared to the more stagnant watertables of the Miri and Buso Families.

GENESIS OF GROUNDWATER PODSOLS

Table 17. Selected analyses of Miri and Buso Family soils.

BUSO FAMILY

Lab. No.	Horizon	pH (H <sub>2</sub> O)	Total Ca(%)	Exch. Ca (ppm)	C.E.C. m.e.%	Org. C (%)	% oven-dry soil			
							SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>3</sub>
84331	O	3.5	0.06	168	11.40	5.72	82.78	0.09	0.26	n.d.
4332	A1	3.5	0.05	120	4.70	2.29	95.46	0.05	0.26	n.d.
4333	A2	4.9	0.10	144	0.40	0.09	94.12	0.05	0.19	n.d.
4334	A3	4.7	0.07	156	1.00	0.04	99.00	0.33	0.19	n.d.
4335	A32g	5.0	0.05	168	1.10	0.01	93.89	0.14	0.52	n.d.
4336	B2hg	5.0	0.06	144	0.75	0.20	98.79	0.14	0.25	n.d.
MIRI FAMILY										
84317	O	3.3	0.04	96	30.50	26.31	58.83	0.09	0.32	0.13
4318	A1	3.7	0.02	48	13.00	4.33	87.93	0.04	0.51	0.08
4319	A2	4.4	tr	0	0.80	0.24	96.76	0.04	0.44	0.04
4320	A22	4.8	tr	0	0.53	0.08	94.60	0.04	0.32	0.08
4321	A23	4.8	tr	0	0.53	0.06	95.70	0.04	0.44	n.d.
4322	B2h	4.1	tr	0	3.45	0.82	97.92	0.04	0.51	0.08
4323	B22h	3.7	tr	0	8.55	1.30	98.10	0.04	0.38	0.08
4324	B23hg	4.9	tr	0	5.83	1.10	95.06	0.04	1.01	0.06

tr = trace; n.d. = not determined.

Soil analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

It is clear from analyses of Miri and Buso Family soils (Table 17) that they are being subjected to a special type of podsolisation (p. 72). The soils are so highly siliceous, with scarcely 1% sesquioxides in the Bh horizon that only humus and bases take part in the podsolisation process. The virtual absence of weatherable minerals to form clay (Table 18), the low exchange capacity and the high permeability cause rainwater leaching to be rapid and effective in transporting most soluble bases from the Buso and almost all from the Miri Family A2 horizons to the B horizons or beyond (Fig. 44). It is probable that the difference in degree of leaching can be attributed to the greater age of the Miri soils since they are found only on Quaternary terraces except for a small area at the Niah River mouth while Buso soils are found almost entirely on the recent beaches.

Table 18. Mineralogical analyses of a Miri Family soil in the Semilajau area, ten miles southwest of the Nyalau River.

Lab. No.	Horizon	Opaque	HEAVY FRACTION %										LIGHT FRACTION %					Ore					
			Alterite inc. Leucokene	Tourmaline	Zircon	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Andalusite	Sillimanite	Saussurite	Hornblende	Hypersthene	Picotite		Corundum	Quartz	Tourmaline	Zircon	Undetermined rock
5681	A1	34	28	25	49	3	15	4				1	1	2				1	98			2	pr
5682	A2	34	35	24	50	2	14	3	1			1	1	4					95	pr	pr	5	pr
5683	A22	24	36	41	40	1	4	5			1	1	1	1	1	1			100				
5684	A3	15	47	57	25		6	7			1	1	3			1			99	1			
5685	B2h	13	50	51	33	1	8	5			1	1	1						100	pr			pr
5686	C6	23	33	48	31		8	8			1	1	3	1					100				

Differential Thermal Analysis of Clays. All samples have a type of kaolinite as the main clay mineral giving exothermic peaks from 880° - 980°C, and all samples contain carbonaceous material giving exothermic peaks between 200° - 500°C. Distinct endothermic peaks typical of limonite are found in all samples.

pr = present. Analyses by Royal Tropical Institute, Amsterdam.

Soil Families  
Groundwater Podsol Group

Humus is the main constituent leached from the O and A1 horizons in rainy periods, and transported in solution or suspension to the saturated B2 horizon, where it is deposited as amorphous films around sand grains. The degree of hardness of the Bh is attributed to the degree of drying experienced in rainless periods. All profiles examined with a hard humus pan (Miri, Bako Families) are situated where the drying of at least upper B horizon can be expected to take place periodically, as on terrace margins, while those with a soft Bh (Buso Family) are situated within the permanent groundwater zone (Sample Areas II and III) or possibly in the centres of large terraces. Soil thin sections of a hard pan show almost complete infilling of grain interstices by amorphous black humus. The cementation by humus is unstable, however, as on exposure to the air the pan crumbles and disintegrates into single grain, humus-coated sand, presumably due to intense humus oxidation, and consequent reduction of volume.

It has been suggested that podsoles on the terraces developed in the absence of groundwater after the formation of terraces. While this cannot be entirely disproved it is considered to be more reasonable for the podsol formation to pre-date that of the terraces, since it can be shown that podsoles develop in very recent beach sand (Sample Areas II and III, Appendix A). It is believed that the presence of rock platforms beneath all the examined podsolised terrace sand maintained a high water table initially after terrace formation until periodic drying hardened the Bh horizon sufficiently for it to form its own watertable. Subsequently, the Bh has developed upwards, and as seen in one road cutting near Beraya, is at least eleven feet thick in places (Plate 46).

DISTRIBUTION OF THE GROUNDWATER PODSOLS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Groundwater Podsoles in the Bekenu-Niah-Suai area are moderately widespread, particularly in parts within and adjacent to outcrops of arenaceous rocks, as in the Lambir Hills in the north the upper Bakong Hills in the southeast and the lowlying country in the southwest between the Suai and Nyalau rivers.

The Miri Family, associated in places with small patches of Buso Family soils and Gley soils, (p.100) was found to coincide in distribution with the Terrace Photo-association (p. 18) and the terrace topographic unit (p. 38; - Sample Area I, Appendix A). The soils have developed on quartzose Pleistocene sediments (p. 31) and support Heath Forest (p. 50) that is rarely cleared for cultivation.

Along parts of the coastline north of Cape Batu the Miri Family is associated with Red-Yellow Podsollic soils and small areas of Gley, Recent Alluvial and Peat soils (Sample Area I). These areas were found to have the same distribution as the Dissected Terrace Photo-association (p.19). Merit Family soils (p.68) occur on the terrace flanks and other low hills stripped of the terrace cover; Bekenu and Nyalau soils (p. 67 and p. 66) are also found in similar locations in some areas. The terrace remnants are small and the soils on them are of the Miri and possibly Buso soil families, the former being most extensive. Narrow valleys penetrating the dissected terraces contain a variety of soils

Soil Families  
Groundwater Podsol Group

ranging from poorly sorted, colluvial/alluvial deposits mainly of the Kayan Family (p.146), gleyed clayey Bijat soils (p.101) and shallow and deep peats of the Mukah (p.126) and Anderson (p.127) families respectively. The parent materials, topography and vegetation of the unit are as varied as the soils. The parent materials (p. 30) range from argillaceous, arenaceous and mixed argillaceous/arenaceous rocks to sandy and clayey Pleistocene and Holocene sediments and peat. The topography (p.36) comprises small terraces, low hills and narrow valleys and the vegetation (p.47) includes Heath, Lowland Dipterocarp, Freshwater Swamp, Peat Swamp and Secondary Forests.

The Buso Family has a predominantly coastal distribution. Associated are small areas of Recent Alluvial (p.142), Gley, Peat (p.126) and Saline Gley (p.116) soils; each of the subsidiary soils may be dominant locally (Sample Area II, Appendix A). The unit was found to have a similar distribution to the Beach Photo-association (p.16). Buso soils occupy old strand lines and some swales between while Tatau soils (p.105) of the Gley soil group are found in many swales and on younger strand lines. Featureless Kabong Family (p.147) sands occur on the most recent beaches while Igan Family (p.126) shallow peat and Anderson Family (p.127) deep peat become increasingly common in swales on the landward margin (Sample Area III, Appendix A). Rajang Family (p.116) soils subject to saltwater flooding occur in swales between the Niah and Nyalau rivers mainly. The parent materials are predominantly Pleistocene sands and peat (p.36) the topography is young and old beaches (p.36) and the vegetation consists of Littoral (p.47) and Peat Swamp (p.49) forests with secondary forest at main river mouths and Saltwater Forest (p.48) in some swales.

The Bako Family occupies only small areas and its distribution was found to be entirely within that of the Cuesta Photo-association (p.21). The only associated soils are believed to be those of the Nyalau and Semadoh Families. Nyalau (p.66) soils occur on the steeper slopes of the cuestas, while Bako or Semadoh soils occupy the least steeply sloping sites particularly towards the summits. The soils are derived from gently dipping thick sandstone (p.30) which forms cuesta topography (p.39). They support a poor type of Lowland Dipterocarp Forest (p.50), rarely removed for cultivation.

AGRICULTURAL VALUE OF THE GROUNDWATER PODSOL SOILS

Throughout Sarawak these soils are known as 'kerangas', or soils on which hill rice will not grow. This notorious reputation is well founded as, with the exception of the organic-rich topsoil, they are nutritionally the least fertile soils in the country. In addition, their drainage properties are unfavourable for crop growth as in most places they readily become waterlogged after rain because of the flat topography, very slow external drainage and the perched watertable within the profile, and in addition they are equally susceptible in many places to drying out rapidly after rain because of the excessive internal drainage. Although analyses of Bako soils have not been made from this area, they are known to resemble Miri soils elsewhere both chemically and physically.

Soil Families  
Gley Group

Analyses of Bijat soils show acidity levels between pH 2.6 and 4.6, cation exchange capacities of 15-25 m.e.% in mineral soils and moderate levels of exchangeable and 'reserve' mineral nutrients. The base saturation is low to moderate and the carbon/nitrogen ratio wide with a strong tendency to be widest in the A1 horizon and in the deepest subsoil. The presence of subsurface limestone in some areas is thought to account for the unusually high levels of calcium and magnesium in some profiles.

It is known from studies elsewhere in Sarawak that Bijat soils have a slight tendency to form the notorious 'catclay' when drained. This phenomenon is explained in describing the genesis of Saline Gley soils (p. 120) which are particularly prone to its formation. The characteristic features of 'catclay', that is of dark grey clay high in organic matter, and low pH and high sulphate content of dried soil, are present to a small extent in some Bijat soils, particularly in those nearest tidal rivers.

Mineralogical analyses of a Bijat Family soil in the nearby Semilajau area show high concentrations of resistant minerals such as tourmaline, zircon and quartz. Kaolinite is the main clay mineral. (Table 21).

### 3. PLAN FAMILY

Features defining the Plan Family are shown in Table 20. The family can be described as comprising poorly drained, pale-coloured, sandy soils developed in recent sandy riverine alluvium in a hydromorphic environment (Appendix B11). The characteristic features of the soils found in this area are as follows:

As in the Bijat Family, the topsoil usually consists of a thin organic-mineral A1 horizon two or three inches thick. Beneath is a deep Bg or Cg horizon, within which the groundwater is present periodically.

Colours in the Plan Family are subdued. The A1 horizon is commonly rich in organic matter and dark-coloured. Yellowish and brownish shades mottled with reddish brown and light grey are more typical of the A1 horizon but these give way to the characteristic pale colours of the subsoil within a few inches of the surface. Bg horizons with prominent reddish brown mottles are rare, the Cg light grey to pale brown colours being dominant.

Textures are predominantly sands to sandy clay loam beneath the organic rich topsoil in at least the upper 20 inches of mineral soil. It is permissible for the lower parts of the profile to contain more clayey soil, but this is unusual. Peat or muck lenses may occur within the profile but should not amount to more than 35% of the total thickness of mineral soil in the upper 20 inches of soil. Greater percentages qualify for Peat soils.

The wet consistencies are non- to slightly plastic and non- to slightly sticky. Structure cannot be recognised. Roots form a thick mat in the A1 horizon; few penetrate the Bg or Cg horizons.

No chemical analyses have been made of Plan Family soils but they are not thought to differ much in this respect from the Tatau family soils described below.

Table 21. Mineralogical analyses of a Bijlat Family soil in the Semilajau area, 10 miles southwest of the Nyalau river.

Lab. No.	Sand .05-mm	HEAVY FRACTION %										LIGHT FRACTION %										
		Horizon	Opaque	Alterite Inc	Leucoxene	Tourmaline	Zircon	Rutile	Anatase	Brookite	Andalusite	Picotite	Corundum	Potash Feldspar	Quartz	Tourmaline	Zircon	Rutile	Anatase	Undetermined rock	Ore	Organic SiO <sub>2</sub>
5639	A1	13	36	30	41	16	11	1	1	1				91	pr	1	pr			7	1	
5640	CG	14	49	13	44	22	15	1	1				pr	97	pr	2	pr	1	pr	1	pr	
5641	CG2	5	25	38	40	12	10							96	1	1				2	pr	
5642	IIC3	4	21	21	52	12	14				1			92	1	3						2

Differential Thermal Analysis of clays. All samples have a type of kaolinite as the main clay mineral giving exothermic peaks from 880° - 920°C. All samples contain carbonaceous material giving exothermic peaks between 200° and 500°C., except sample 5641 at 840°C. Distinct endothermic peaks typical of limonite are found in all samples and there are indications of goethite in most.

pr = present.

Analyses by Royal Tropical Institute, Amsterdam.

SOIL FAMILIES OF THE GLEY GREAT SOIL GROUP

Seven families in the area are classed in the Gley group of soils (Table 20). The Semadoh Family is residual in origin and is thought to occupy small areas, while the remaining six are developed in alluvium and together occupy large tracts of low lying land. The main characteristics of each family are described, an account is given of how they differ from each other and the broad lines of their genesis are outlined.

Table 20. The diagnostic features of Gley soils in the Benua-Niah-Suai area.

ORIGINAL OF PARENT MATERIAL	PEATY O HORIZON LESS THAN 10 INCHES THICK	TEXTURE OF TOP 20 INS. MINERAL SOIL	SOIL FAMILY
Residual	Absent	Heavy	SEMADOH
		Heavy	BIJAT
Recent riverine	Present	Light	PLAN
		Heavy	SEBANDI
Old riverine	Absent	Light	GONG
Recent marine			TATAU
	Present		MATU

Elsewhere in Sarawak four other families are separated in the group on the same diagnostic features headed above.

1. SEMADOH FAMILY

The features used to define the Semadoh Family are given in Table 20. The soils are thought to occur in a few places on the Niah-Bakong watershed in association with Bako Family soils mainly on the basis of air photograph interpretation, and the fact that Semadoh soils are known to occur on a closely similar environment a few miles to the southeast. The descriptions given below are probably incomplete and are based as much on soils examined outside this area as within it. Broadly the soils can be described as poorly drained, gleyed clays and sandy clays developed over sedimentary rocks in a hydromorphic environment. No analyses of the soils are available. An augering description is given in Appendix B9.

The surface O horizon consists of thin slightly peaty or mucky humus as much as ten inches deep, including a scattering of fresh leaves. Beneath, the A1 horizon is moderately well developed; it gives way to Bg or Cg horizons that may be deep or may lie on hard rock at shallow depths.

The moist or wet soil colours are predominantly low in chroma. The surface organic and A1 horizons are dark reddish brown and dark greyish brown respectively. The underlying soil has a matrix colour ranging from light grey to yellow, with prominent reddish brown root mottles that decrease in number with depth. The deeper the soil the more pronounced the light grey colour becomes in lower parts of the profile. Bluish and greenish shades have been noted in places.

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Soil textures in the family are by definition restricted to the clays and clay loam. From the few auger descriptions made in the area it would appear that these textures are dominant, but that sandy clay loam and sandy loam upper subsoil horizons also occur. There is insufficient evidence available however to warrant establishing a new family of residual Gley soils with light textures.

The field consistence is slightly sticky to sticky and slightly plastic to plastic. Structures have not been examined. Roots form a thick mat in the O horizon and penetrate the A1 and to a small extent the underlying gleyed soil. External drainage appears to be medium to slow; internal drainage, by definition, is poor and very poor with slow lateral drainage. Although analyses are not available it is unlikely that Semadoh soils are unusually fertile.

2. BIJAT FAMILY

The diagnostic features of the Bijat Family are shown in Table 20. These soils can be described as being poorly to very poorly drained, light-coloured, gleyed clays developed in recent riverine clayey alluvium in a hydromorphic environment. The main features of the soils are described below, detailed profile descriptions and analyses are given in Appendix B10.

Surface O horizons are absent by definition and a shallow organic-mineral A1 horizon forms the topsoil. This gives way after a few inches to deep Bg or Cg horizons, of which the lowest parts at least lie within the groundwater zone.

The A1 horizon is in places dark greyish brown, but may be yellow to dark yellowish brown with light grey and reddish brown mottles where the soils are slightly better drained. The Bg horizon has a light grey matrix colour but contains abundant, prominent, coarse, strong brown root mottles. The Cg horizon has the same matrix colour but is mottled if at all, by olive shades. Some soils tend to contain admixtures of dark organic matter as finely divided material in patches or as thin lenses or bands, and it is fairly common to find a dark grey lower subsoil horizon coloured by fine organic matter.

The textures by definition are confined to the clays and clay loam in at least the upper 20 inches of soil. Sandy horizons are permitted in the lower subsoil but this is unusual, there rarely being any marked textural difference between subsoil and topsoil. Peat or muck lenses may occur within the soil but together should not constitute more than 35 percent of the total thickness in the upper 20 inches of mineral soil. A greater percentage qualifies for Peat soils.

The soils are predominantly wet, and plastic and sticky where clayey. Any sand or coarse peat contamination reduces the stickiness and plasticity. Structure is not apparent. The topsoil contains most roots, but the subsoil mottling is a good indication of the presence of at least a few fine roots. External drainage is slow due to the low gradient; internal drainage is poor.

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4. SEBANDI FAMILY

Diagnostic features of the Sebandi Family are shown in Table 20. The soils are very poorly drained clays with a thin surface peat horizon, developed in recent riverine clay in a hydromorphic environment. The main characteristics are described below; detailed descriptions and soil analyses of a common soil series are given in Appendix B12.

There is a thin, surface, peaty O horizon up to 10 inches thick which directly overlies Cg horizon material. The groundwater table lies permanently close to the surface.

Colours of the soils are confined to very dark greyish brown to black peat and light grey to brownish grey mineral soil. Mottles of any description are rare. The texture of the O horizon is peat, but in contrast to the deeper Peat soils (p.126) it is more fibrous and better decomposed and contains more inorganic matter. The Cg horizon consists of clay, rarely containing lenses of sand, and is plastic, sticky and structureless. Roots are restricted to the upper organic soil and a few inches within the mineral soil.

Chemical analyses of Sebandi soils are similar to those of Bijat Family soils, except that the surface organic matter is strongly acid, raw, and has a high exchange capacity and low base saturation. The problems of 'catclay' formation after draining are potentially as great in these soils as in the Bijat Family.

5. GONG FAMILY

The diagnostic features of the Gong Family are given in Table 20. The soils have been examined only in one small area near Sibuti, but are suspected to have a wider distribution among some terrace areas, notably where similar Triboh soils (p.89) occur in the Niah and Suai-Nyalau areas. In the location examined the soils are believed to be mainly poorly drained sandy clay loams developed in old marine alluvium in a hydromorphic environment. A brief description of the most common soil is given in Appendix B13. No analyses are available.

There is a thin, dark-coloured A1 horizon overlying pale coloured sandy loam, increasing to sandy clay loam with depth. Strong brown mottles are common in the upper subsoil. The soil consistence is slightly sticky and slightly plastic; structure was not examined. Roots are confined to the A1 and the upper part of the Bg horizon. Although the profile has features characteristic of poor drainage, such as pale colours, the water table was not within auger depth at the time examined. It is possible therefore that the soils could be considered as imperfectly drained members of the Triboh Family. - (p. 89)

The mineralogy of the soil is probably dominated by kaolin in the clay fraction and by quartz or other resistant minerals in the sand-fraction, to judge by other nearby terrace soils.

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6. TATAU FAMILY

Diagnostic features of the Tatau Family are shown in Table 20. The soils can be described broadly as poorly drained sands developed in recent marine alluvium in a hydromorphic environment. The main characteristics are described below while a profile description of a common soil series is given in Appendix B14.

The A1 horizon varies from three to six inches deep. Beneath, the profile is generally too wet to examine beyond one or two feet into the Cg horizon, which lies within the range of the groundwater table.

The colours of Tatau Family topsoils are dark due to the high organic content: the colours of the gleyed subsoil range from light grey to light brownish grey or pale yellow: mottling is rarely present. Textures of the mineral soil are confined almost entirely to sand or loamy sand. The consistence is wet, non-sticky, non-plastic; structure is absent. Roots are restricted to the A1 and upper Cg horizons.

Analyses of Tatau soils indicate an acidity ranging from pH 3.3 to 4.5 in locations well inland, to pH 6.8 to 8.0 in profiles close to the coast. The exchange capacity is extremely low and exchangeable, and probably 'reserve', mineral nutrient levels are invariably low except in places near the coast where the persistence of shell fragments gives high calcium and medium magnesium levels. Both carbon and nitrogen levels are low beneath the topsoil.

7. MATU FAMILY

Table 20 gives the diagnostic features of the Matu Family, whose soils are similar to the Tatau Family except that there is a thin surface peat horizon of a maximum thickness of 10 inches. Beneath, the soils are sands derived from recent marine sediments. They are very poorly drained. An augering description of typical series is given in Appendix B15.

At the surface peat occurs, as in the Sebandi Family. It is similarly raw, rather fibrous, non woody but contains little inorganic material. The sand beneath is waterlogged, light grey to olive grey and difficult to examine by auger. Structure is not present, consistency is non sticky and non to very slightly plastic. Roots are present largely in the surface O horizon.

Chemical analyses of Sebandi soils resemble those of the Tatau Family except that the surface peat is strongly acid has a high exchange capacity, low base saturation, and is in all nutritional respects the richest part of the profile.

DIFFERENTIATING FEATURES BETWEEN GLEY SOIL FAMILIES.

The families can be differentiated satisfactorily in the field by their site characteristics, and to a large degree by their morphology (Table 22). The Tatau and Plan Families are the most similar, but the Plan Family present materials are commonly poorly sorted with the result that texture gradation down the profile is uneven, while Tatau soils are well sorted and predominantly consist of loose sand. In addition the river sediments that Plan soils develop in can be expected to be comparatively much richer in 'reserve'

Table 22. The dominant range of important features of soil families in the Gley Group.

Generalized features	SEMADOH	BIJAT	PLAN	TATAU	MATU	SEBANDI
Moist colour B <sub>g</sub> or C <sub>g</sub>	pale brown	light grey	light greyish brown	light grey	light grey	light grey
Texture B <sub>g</sub> or C <sub>g</sub>	sandy clay loam to cl.	clay to silty clay	sandy loam to sandy clay lo.	sand	sand	clay to silty clay
C.E.C. B <sub>g</sub> or C <sub>g</sub>	< 15?	15 - 25	5	4	4	15 - 25
Exch. Ca(m.e.%) B <sub>g</sub> or C <sub>g</sub>	low?	0.5 - 12	0.2 - 1.0	0.2 - 3.5	0.2 - 3	0.5 - 12
Parent materials	sedimentary rocks	river alluvium (clayey)	river alluvium (sandy)	marine alluvium (sandy)	marine alluvium (sandy)	riverine alluvium (clayey)
Topography	flat to gently sloping hills	riverine basins	low river levees	old coastal beaches	old coastal beaches	riverine basins
Water table movement	moderate to slow lateral	almost stagnant	almost stagnant	almost stagnant	almost stagnant	almost stagnant
Surface O horizon	thin in places	absent	absent	absent	up to 10"	up to 10"

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mineral nutrients (except perhaps calcium) than the marine quartz sands forming Tatau soils, to judge by analyses of related Semilajau Family soil (p. 69) as against poorly drained Miri Family soil. (p. 92).

GENESIS OF GLEY SOILS

The Gley soils are characterised by poor or very poor internal drainage resulting from their situation in low lying basins or on gently sloping hills, where the dense nature of the soil itself, combined with that of the underlying rocks, impede groundwater movement. The presence of thin peaty topsoil testifies to the very poor internal drainage and the gleyed subsoil implies the presence of groundwater for lengthy periods during the year.

With strongly acid, hydrocorphic conditions soil genesis consists almost entirely of the weathering of minerals by solution and hydrolysis: soluble compounds, particularly bases, are dissolved and lost by slow water seepage. Reducible from compounds give dark grey, greenish or bluish subsoil colours; or if iron has been moved, or if there was little there initially to be moved, the soils are coloured light grey.

Periodic floods in the riverine alluvial areas add silt and clay to the Bijat Family soils and mainly sand to the Plan Family soils. Little, if any fresh material accumulates over Tatau and Matu soils, except peat, and the Semadoh soils can be expected to be subject to very slow surface erosion and possibly colluviation. Peat layers within the alluvial soils are buried topsoils. The dark grey layer at the base of Bijat soils is thought to be connected with the presence of old estuarine alluvium (Pendam Family; p. 117).

DISTRIBUTION OF GLEY SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Gley soils are widespread throughout riverine areas, and along many coastal tracts, mainly in association with Peat soils.

The Semadoh Family has a small distribution and is mapped in association with Bako soils in the upper Niah-Bakong area. The areas are small in extent and are confined to the dip slopes of well-developed cuestas. The distribution is therefore closely similar to that of parts of the Cuesta Photo-association (p. 21). Bako soils (p. 92) are probably dominant, in this association, the poorly drained Semadoh soils occupying the flattest parts of the cuestas. Nyalau Family (p.66) soils may occur in places. The parent rocks are gently dipping thick sandstones (p. 30) giving arcuate cuestas (p.39) and supporting poor Lowland Dipterocarp Forest. (p. 50).

The Bijat Family is mapped in association with Pendam soils mainly in the lower Sibuti and Niah valleys in those areas where it is known that both old estuarine and present day marine sediments occur. It is probable that Bijat soils are most extensive in parts furthest from rivers and from the areas of mapped Saline Gley soils (p.116). Also in this association are Sebandi soils and small areas of shallow and deep peat, of the Mukah (p.126) and Anderson (p. 127) families respectively, towards peat swamp margins. The distribution of the Bijat-Pendam Association lies mainly within that area mapped as the Flood plain Photo-association (p. 17), with Pleistocene and Holocene fine-textured sediments (p. 31), flat flood-plain topography (p. 37), and Freshwater Swamp (p. 48), and small areas of Saltwater Swamp (p. 48) forests, commonly cleared for wet rice cultivation.

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The Bijat Family is also mapped in association with the Mukah Family, mainly in the flood-plain areas of the lower Sibuti River. This distribution has been confirmed by subsequent small surveys by the Drainage and Irrigation branch of the Public Works Department. Bijat soils are believed to be dominant, occupying the parts closest to rivers and hills while the shallow peats of the Sebandi and Mukah Families occur in the central parts. Anderson Family (p. 127) deep peats occur patchily. The environment closely resembles that of the Bijat-Pendam Association except that the shallow peat areas support Mixed Peat Swamp Forest (p.49). The unit was found to occur partly in the Flood-plain (p. 17) and partly in the Peat (p.17) photo-associations.

The middle reaches of large streams are commonly mapped as the Bijat-Malang Association. In addition to the soils naming the association there are large areas of Sebandi soils and generally small inclusions of residual Red-Yellow Podsolc soils (p.64), mainly of the Merit Family. Malang soils (p.70) are found as wide, high levees. The unit forms part of the Flood-plain Photo-association (p.17). The parent materials consist predominantly of recent, clayey alluvium (p.31) and the land is generally cultivated for wet rice, rubber or fruit trees.

Tatau Family soils, and the related Matu soils have a coastal distribution, occupying the low lying, moderately recent sandy swales: soils of the Buso (p. 93) and Kabong (p.147) families are found in association on old and young strand lines respectively. Small areas of Peat (p.126) soils also occur and Saline Gley soils (p.116) occupy some swales drained by small tidal streams. The parent materials are predominantly recent sands (p.31), forming strand lines and swales (p.36). The soils support mainly Littoral Forest (p.47), cleared for grazing and villages near main river mouths.

Plan Family soils form a small part of the Kayan-Plan Association and of the Semilajau-Malang, Semilajau-Bijat and Bijat-Kayan associations. They occur as narrow strips on the backslopes of sandy levees in the flood-plains of rivers draining areas of sandy soils, such as in the valleys fringing the Lambir Hills and in the Suai-Nyalau area. They form part of the Flood-plain photo-association (p.17), the parent materials consist predominantly of recent, sandy alluvium (p.31), and the forest type is Fresh-water Swamp or Riparian Forest. (p.48).

AGRICULTURAL VALUE OF THE GLEY SOILS

Gley soils, in conjunction with those of the Red-Yellow Podsolc group are probably the most important for agriculture in the Bekenu-Niah-Suai area. While the latter are used entirely for dry land crops, the soils of the Gley group are used mainly for wet rice cultivation, or for crops that can withstand periodic flooding or moderately high water tables. They range in fertility from poor to moderately rich, and from soils that can be drained easily to those whose drainage status would be difficult to improve. In their natural state, all are subject to flooding by freshwater or slightly brackish water several times a year. The soils are grouped together below by texture classes, as this has been found to agree most closely with agricultural usage.

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Agricultural Value of Semadoh, Bijat and Sebandi Families

Analyses are not available of the Semadoh Family soils, and as little is known of them except that they are commonly shallow, poorly drained, and that they are said to be unsuitable for hill rice cultivation (Wall, 1962, p.8), no suggestions are made for suitable crops. It is clear, however, that if they are to be used, drainage improvements will be essential.

Bijat and Sebandi Family soils have similar physical and chemical properties except that up to ten inches of surface peat may be present on the Sebandi soils and they are very poorly drained rather than poorly drained. Both soils are subject to periodic flooding by fresh river water, and the water may stand for several days at a time at depths of two or three feet commonly. In the Subis area where the flooding is known to be severe, depths of twelve feet have been recorded at the Sekaloh river and are said to occur often (Wall, 1962, p.18). It is suspected that similar severe flooding occurs throughout the alluvial land surrounding the Subis karst land, which is far too drastic to attempt to curb ordinarily. Cropping in this area would entail a great risk of failure. Elsewhere, however, it should be possible to build low dykes two feet or so high which could keep out most floods.

Light gravity drainage of Bijat and Sebandi soils has not proved difficult in several places although there may be a risk of brackish water entry into ditches in downstream areas close to where Pendam and Rajang soils occur. In such places sluice gates are necessary. This problem is best assessed by detailed level investigations in all cases.

The topsoil fertility of Bijat soils fluctuates widely within small areas and from area to area, as shown in Table 23. The few available analyses of Sebandi Family topsoils show that nutrient levels tend to be higher, particularly of phosphorus and calcium, but not when expressed as percent of wet matter, which is the state the organic soil is in the field.

The exchangeable calcium concentration in topsoil increase markedly close to limestone outcrops as shown by analyses of a series of three Bijat Family topsoils from the Subis area (Table 24) for comparison figures are also shown of topsoil samples of the same family from nearby locations. Number 3842 is located on the low bank of a stream draining limestone, number 1240 lies close to a stream draining sandstone and shale, and the other samples were taken from alluvial basins containing limestone. There is a clear difference between areas upstream of and downstream of the limestone outcrops.

Table 23. Analyses of the top six inches of Bilat Family soils from Luak Experiment Station and from the A1 horizon of profiles elsewhere in the Bekenu-Niah-Suai area.

Number of samples	Level	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' K (%)	Total N (%)
5 samples from a one tenth acre site, taken on a grid pattern.	Lowest	0.01	0.02	0.08	0.22	-
	Highest	0.08	0.23	0.46	0.89	-
	Average	0.05	0.12	0.31	0.65	-
5 composite split samples from 5 one tenth acre sites, from each of which 8 or 9 subsamples were collected on a grid pattern.	Lowest	0.01	0.002	0.03	0.19	0.11
	Highest	0.01	0.01	0.08	0.27	0.15
	Average	0.01	0.01	0.06	0.22	0.13
A1 horizons; 6 samples	Lowest	0.02	0.02	0.15	0.39	-
	Highest	0.06	0.16	0.49	0.98	-
	Average	0.04	0.07	0.32	0.66	-

Note:- 'Reserve' figures represent amounts between total and easily available figures.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

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Table 24. Topsoil analyses of Bijat Family soils adjacent to a limestone outcrop, Sekaloh (Subis), and from nearby sites. No. 3846 is slightly peaty.

Lab. No.	Distance from limestone	C.E.C. milli	Exchangeable				Base sat'n (%)	pH (H <sub>2</sub> O)
			Ca	Mg	K	Na		
			equivalent percent					
S1319	Immediately adjacent	23.1	13.7	0.9	0.3	0.2	66	5.8
S1320	Three feet	28.9	9.4	2.1	0.2	0.3	41	4.8
S1321	Ten feet	17.2	7.5	1.5	0.3	0.2	55	4.9
S1240	Approx. one mile upstream	8.2	0.8	1.6	0.2	nil	29	4.2
S3842	Approx. 15 feet downstream	23.8	16.4	0.3	0.2	0.2	72	4.9
S3846	Approx. one mile downstream	43.7	7.4	3.2	0.2	0.1	25	4.0

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

The subsoils of both Bijat and Sebandi Family soils have a wide range in nutrient values, but as much within a profile as from area to area. This feature depending on the organic content and soil texture primarily, although there is a marked increase in calcium and magnesium concentrations, in places coupled with low pH and high sulphate in areas close to Saline Gley soils. For comparison analyses of two profiles are shown in Table 25. 'Reserve' analyses of four other profiles all lie within or close to this range. Some other Bijat Family soils found close to limestone outcrops have a high concentration of calcium. The subsoil of one profile in the Mulis (Suai) valley had an exchange capacity of 11-22 m.e.% that was 48-88% saturated with calcium. Levels of exchangeable cations in the subsoil are as variable as the 'reserve' concentrations: generally, however, the upriver alluvium levels are low, with cation exchange capacities of 10-15 m.e.% typically being less than 5% saturated, while downriver alluvium with a similar exchange capacity may be 20-50% saturated, with calcium and magnesium mainly.

In view of the rather variable nature of the calcium and magnesium ions in particular in Bijat and Sebandi soils it is advisable where applying fertilisers that soil samples be analysed from all locations where crops sensitive to these two nutrients are to be cultivated. The cation exchange capacity is sufficiently high for the soils to be able to retain added fertilisers.

Table 25. Showing some physical and chemical differences within Bijal Family soils. S.1092/96 from the lower Sibuti near Saline Gley soils. S.1039/42 from the upper Sibuti. S.1096 is 'catclay' see ( ).

Lab.No.	Depth in (ins.)	Colour	Texture	pH (H <sub>2</sub> O)	Total P (%)	'Reserve' Ca (%)	'Reserve' Mg (%)	'Reserve' K (%)
S.1092	0 - 10	dark grey	silty clay	4.6	0.05	0.16	0.49	0.76
S.1093	10 - 16	light grey	silty clay	3.8	0.01	0.12	0.52	0.83
S.1094	16 - 38	green grey	silty clay	3.9	0.02	0.20	0.51	0.85
S.1095	38 - 65	grey	fi. sandy clay	4.4	0.006	0.07	0.19	0.38
S.1096	65+	dark grey	clay	2.3	0.005	0.09	0.23	0.40
S.1039	0 - 7	brown	silty loam	4.3	0.04	0.05	0.28	0.56
S.1040	7 - 15	yellowish brown	silty clay loam	4.1	0.03	0.02	0.25	0.52
S.1041	15 - 30	yellowish brown, light grey	clay	4.0	0.02	0.01	0.22	0.46
S.1042	30 - 49	yellowish brown, light grey	clay	4.0	0.02	0.02	0.25	0.65

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

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The natural crop choice for Bijat and Sebandi Family soils is wet rice as both are inherently badly drained and can be flooded easily, yet can probably be drained without too much difficulty in most places. Fish can be reared in the flooded fields during the growing season. After draining for crop ripening and harvesting the fields can be planted with catch crops such as groundnuts, maize and various vegetables, although there is an unavoidable risk that they will be destroyed by flooding. Coconuts, bananas, and small fruit trees can be grown on the largest ditch banks. If it is preferred the soils could be deep-drained, preferably in large blocks to make the drainage more effective for coconut, banana, oil palm, citrus, rubber or other crops. The feasibility of deep drainage should be checked by levelling first however as it is possible that back-flooding will occur in the lower tidal reaches. If flooding tends to be common the heaping of soil into large mounds can be used as a counter measure, as by the citrus farmers in the Sarikei area of Third Division.

At the present time there seems to be little inclination to grow anything but wet rice on these soils, apart from a few small areas where the natural drainage has been improved sufficiently to plant a few coconuts. It is wasteful to use such potentially productive soils for buffalo grazing as in the Sibuti and Niah areas.

Agricultural Value of Plan, Gong, Tatau and Matu Families.

Little is known of the Gong Family of soils in the area, but in other parts of Sarawak where they are widespread they are considered to be cultivable for hardy crops, although they are probably infertile. It is suspected that during wet weather the soils become waterlogged readily, due to the slow external drainage, and that in dry weather they contain insufficient moisture for some crops. With appropriate, regular manuring and improved drainage they can probably be used for cultivation.

The Plan, Tatau and Matu Families have similar agricultural potential. Flooding is a limitation that occurs more on the Plan soils than the others, and although the water may not be deep it is faster moving than, for example, on the associated Bijat soils. While flooding also occurs on the Tatau and Matu coastal sands, it is caused directly by the slow surface drainage during heavy rainstorms and not indirectly by river flooding. Drainage will be a prior requisite therefore for most crops. This should not be a difficult problem in the case of Plan soils, but may be impossible without pumping for the other two families as they lie at or close to sea level. Elsewhere in Sarawak attempts have been made to cut drains across the grain of the beach ridge-swale landscape directly to the sea, but the mouths of the drains have rapidly become blocked by longshore drift, just as most of the natural stream mouths have in this area. Because of this it is suggested that, where practicable, drainage of Tatau and Matu soils should be effected by improving the natural drainage lines, roughly parallel to the coast, and that existing unblocked large stream outlets, such as that of the Sabubok stream, should be used in preference to constructing new outlets. The construction and maintenance of ditches will be much more difficult in these wet, loose, structureless sandy soils than in the more coherent clayey soils of the group.

Soil Families  
Gley Group

The fertility of the Plan, Tatau and Matu Families is inferior to the other Gley soils basically because of the high ratio of sterile quartz to the exchange complex. Where the exchange complex is low there is little chance of easily available nutrients being present, nor of aided fertilisers being maintained in the soil because the complex readily becomes saturated. In addition to the preponderance of quartz there are known to be virtually no weatherable minerals in the soil, apart from the organic shell remnants present in some places.

The topsoil of the three families is the richest part of the profile. That of the Matu Family consists of peat and is raw, to judge by the wide carbon/nitrogen ratio generally exceeding 24, while the Tatau and, it is thought, the Plan soils have more humified organic matter in the Al horizon with a ratio between 13 and 20; the Al is however absent in many places especially in grazed areas. Analyses of 'reserve' nutrients and total phosphorus have not been made for these soils, but extrapolating from nearby Recent Alluvial (Oya Family) and shallow Peat (Igan Family) soils, it may be inferred that the total phosphorus is extremely low throughout the mineral soil and up to 0.6 - 0.7% in the O horizons. 'Reserve' mineral nutrients are as low as in the depleted Podsol soils (p. 98) except that calcium and magnesium tend to be higher in the Al and O horizons.

Analyses of the exchange complex of the Matu and Tatau soils are given in Table 26. They indicate that the levels of exchangeable calcium and magnesium increase distinctly wherever the organic matter increases as shown by the cation exchange capacity (there is virtually no clay exchange complex in these soils). These higher levels possibly indicate additions from sea spray. Plan Family soils are thought to have a slightly better exchange capacity, but since they are located inland there is unlikely to be any addition of sea spray-derived ions.

In their undrained state the Tatau, Matu and Plan soils are unsuitable even for rice cultivation. If they can be lightly drained, however, they can be planted with vegetables, maize and shallow-rooted crops such as chilli, groundnut, coconut, banana, pineapple and gourds, although applications of fertiliser will be essential for optimum yields. Because of the poor organic status of the subsoil the application should be on the basis of a little and often, rather than infrequently as heavy doses. Elsewhere in the world, such as in Holland and the English Fens, similar sandy soils to these are ameliorated by mixing in organic matter, such as peat. This is achieved unintentionally in other parts of coastal Sarawak (Wall, 1961, p.11) where Matu soils are drained and patchily cultivated by hoe, but peat is not transported from adjacent swamps to mix with the Tatau soils. If a similar textural amelioration of Plan soils is required there should be suitable loamy soil available in adjacent basins, but the cost and effort involved in transportation and labour in either case would probably be prohibitive except for intensive market gardening.

Table 26. Showing analyses of 1. Matu Family soils and 2. a Tatau Family profile

Horizon	No. Samples	Level	pH (H <sub>2</sub> O)	C.E.C. (m.e.%)	Base saturation (%)	Exchangeable ions (Milli equiv. %)			
						Ca	Mg	Na	
1. O	3	Lowest	3.3	18.5	13.0	1.8	1.1	0.4	0.3
		Highest	4.4	72.5	38.0	4.7	7.1	0.7	0.8
		Average	3.7	36.8	21.8	2.3	3.2	0.5	0.5
1. C <sub>1</sub>	3	Lowest	3.6	2.1	18.0	0.4	0.0	0.07	0.1
		Highest	4.8	4.5	47.0	0.9	0.3	0.1	0.3
		Average	4.1	3.3	30.0	0.6	0.1	0.1	0.3
1. C <sub>2</sub>	3	Lowest	4.0	2.1	18.6	0.4	0.0	0.02	0.1
		Highest	5.6	2.9	96.0	0.9	0.7	0.1	0.3
		Average	4.7	2.6	46.0	0.6	0.2	0.1	0.2
2. A <sub>1</sub>	1		5.3	6.0	28.6	1.1	0.23	0.1	0.3
2. C <sub>1</sub>	1		5.7	0.9	73.6	0.4	0.0	0.04	0.2
2. C <sub>2</sub>	1		5.4	0.9	66.3	0.4	0.0	0.03	0.1

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

SOIL FAMILIES OF THE SALINE GLEY GREAT SOIL GROUP

Four soil families of the Saline Gley group occur in the Bekenu-Niah-Suai area, together totalling 5% of the area, or about 10% of the flat land. The characteristics of each family are described first, followed by discussions of the differences between them, and their genesis.

Table 27. The diagnostic features of Saline Gley soils in the Bekenu-Niah-Suai area.

TYPE OF PARENT MATERIAL	TEXTURE OF MINERAL SOIL	SALINITY	SOIL FAMILY
Mineral	Heavy-textured	Strongly saline	RAJANG
	Light-textured	Weakly saline	PENDAM
Organic	Organic and more than 10 inches deep		Undifferentiated
		LIMBANG	

Only one other family is differentiated in this group elsewhere in Sarawak (on the same diagnostic features headed above).

1. RAJANG FAMILY

The Rajang Family soils occupy small areas, mainly at the mouths of the three largest rivers; they consist of poorly and very poorly drained, greyish, strongly saline clays locally containing moderate amounts of organic matter. An augering example of a common soil series is given in Appendix B16.

The ground surface is broken by large mounds produced by burrowing lobsters (*Thalassima anomala*). In the hollows between there are commonly shallow accumulations of organic debris, comprising both litter from nearby mangrove and *Nypa* and from tidal detritus. This material is poorly decomposed and rests abruptly on inorganic soil. In the least disturbed parts there is a weak A1 horizon development beneath which are Cg horizons. The lobster mounds consist of a heterogenous mixture of former topsoil, organic matter and subsoil.

Moist or wet soil colours characteristically have low matrix chromas. The O horizon if present is generally very dark brown, or dark greyish brown admixed with lighter coloured coatings of mineral soil. Where the A1 horizon occurs it is greyish brown with strong brown or reddish brown root-channel mottles. The main Cg horizon is generally light grey or light greyish brown, in places with a greenish or bluish cast, and mottled with reddish brown colours along root channels. Deep Cg horizon material commonly deepens to grey or dark grey with olive coloured mottles, the matrix colour being in part due to abundant, soft, finely comminuted black organic particles. In some locations there is common, rather coarse organic matter throughout the profile. The lobster mounds exhibit varied colours ranging from those described above when moist or wet, to yellows and white on dried surfaces. The last two colours are those of salt crusts. (p. 121).

Soil Families  
Saline Gley Group

Soil textures range from heavy loams to fine textures, sandy clay loams or sandy clays being rare except close to coastal sand bars. There is commonly a higher amount of silt than in similar upriver soils. Peaty or mucky loams are locally common at all depths in the profile, notably adjacent to deep peat swamps such as in the Lower Sibuti basin. Fresh deposits of inorganic soil are frequently made at high tides.

The wet consistence of the gleyed soil is sticky and plastic; structure has not been determined. The lobster mounds bake hard on the outer surface if sufficiently high above the daily tidal incursions. Rooting of Nypa is shallow and concentrated in a small radius from the palm, while that of the various types of mangrove is thought to be deeper and more extensive. Soil drainage is very slow externally and poor or very poor internally. Permeability is thought to be low.

Only one profile of Rajang Family soils has been analysed in this area. This showed the soil to have a high cation exchange capacity, probably due mainly to incorporated organic matter, that was saturated with sodium, magnesium and calcium in the lower subsoil. The acidity level on air drying fell to pH 3.3, denoting the production of acid anions on oxidation (c.f. Pendam Family below). The clay mineralogy is probably dominated by kaolin with subordinate amounts of illite.

## 2. PENDAM FAMILY

Soils of the Pendam Family are common in the lower main river basins. They are transitional in character between the Rajang Family and the Bijat Family (p.101), and consist of poorly or very poorly drained, weakly saline greyish clays. Detailed descriptions and analyses of a typical profile are given in Appendix B17.

Surface O horizon peaty litter or humus is locally present but generally less than two inches thick. The A1 horizon is normally moderately well developed and may extend downwards two to four inches before giving way to the underlying Cg horizon, which forms the major part of the profile.

Moist or wet soil colours have low chroma as in most hydro-morphic soils. The surface peaty layer where present is very dark greyish brown and rests on similarly coloured A1 material. Where peaty material is absent the A1 horizon is generally dark yellowish brown and contains prominent reddish brown and light grey mottles. The gleyed soil beneath is predominantly light grey, mottled reddish brown down root channels, and commonly grades with depth to grey or dark grey soil with olive brown mottles. Light bluish or greenish hues are also locally common in the lower subsoil. If the dark grey lower subsoil is dried it may develop yellow and white crystalline crusts.

Textures range from clay loam to clay or silty clay; sandy varieties are excluded by definition. Peat or muck topsoils are in places common and it is not unusual to find peaty lenses at any depth within the profile. The dark grey subsoil, and to a lesser extent the whole Cg horizon, may contain abundant finely comminuted black organic particles (c.f. Rajang Family above). The wet consistence is sticky and plastic, the structure of partly dried soil appears to be coarse angular blocky in the few ditch profiles seen with the structural faces marked by reddish brown colours.

Soil Families  
Saline Gley Group

Roots are concentrated in the A1 horizon but to judge by the presence of mottles deep within the subsoil some fine roots are capable of penetrating the gley horizon. External drainage is very slow, internal drainage is poor or very poor.

Chemical analyses of Pendam soils give high cation exchange capacity in the organic topsoil decreasing to medium levels with depth. Exchangeable cations are low to moderate. Calcium and magnesium levels tend to be highest; sodium is normally low.

A feature of the dark grey subsoil of some Saline Gley soils is that on drying out they develop extremely strong acidity coupled with the production of yellow and white sulphates. This type of soil, toxic to plants, is termed 'catclay' and was originally noted in Holland. (Van Beers, 1962).

### 3. NONOK FAMILY

Soils of this family are restricted to coastal swales between beaches. They are essentially loose, poorly drained sands made weakly saline by occasional salt water flooding. Nonok soils are probably mixed with small patches of strongly saline sands of the related Belat Family on the coastline at mouths of streams. Since these areas are small however they have not been mapped. An augering description of a Nonok soil is given in Appendix B18.

In places there is a thin O horizon and a weakly developed A1. Beneath, are Cg horizons forming the major part of the profile. The organic-rich layers are dark-coloured. The moist or wet subsoil is predominantly pale with olive, yellow and brown shades; mottling is weakly developed. The texture ranges from sands to sandy loams in this area, with peaty lenses being locally common. The consistence is non- or slightly sticky and non- or slightly plastic; structure is not apparent. At most times of the year the water table is close to surface and is weakly saline to judge by the character of the vegetation; flooding by brackish water or salt water occurs periodically.

Analyses of Nonok soils are not available from this area, but elsewhere in Sarawak they are known to contain medium levels of calcium, magnesium and sodium despite a low cation exchange capacity. The sands are probably quartzose in this area judging by the high quartz levels of associated Kabong (p.147) and Buso soils. (p. 93).

### 4. LIMBANG FAMILY

A few acres of Limbang Family soils are known to occur in the lower Sibuti River basin and they are probably present also in the lower Hiah and Suai River basins where peat swamps about onto land flooded by saline water. The soils consist simply of deposits of saline organic debris more than 10 inches deep. A description of a typical profile is given in Appendix B19.

The soils are predominantly organic but may contain inorganic clayey material as thin lenses. Clayey horizons are most common in the basal layers. The depth of the material where examined in the lower Sibuti is largely between 8 and 15 feet. The material is coloured very dark greyish brown or very dark brown to black except where light-coloured clay is admixed. The peat consists of debris

Soil Families  
Saline Gley Group

of both Freshwater and Saltwater Swamp forests, but mainly of the former. The peat tends to be rather less woody than that of the Anderson Family (p.127) and in the top few inches has a coarse crumbly appearance. The watertable is high and flooding by salt or brackish tidal water is frequent.

Chemical analyses of the peat show its cation exchange capacity to be high, and that it is saturated by calcium, magnesium and sodium ions. Air dried acidity of the peat is pH 3.0 to 3.6 and the conductivity of soil water exceeds 500 micro mhos, commonly reaching 15,000 micro mhos. Table 28 shows the rapidity with which soil water conductivity decreases from the Sibuti river bank inland in Sirik and then Anderson Family soils. The cause of this is possibly due to peat doming which prevents the ingress of tidal water.

Table 28. Groundwater salinity levels with increasing distance from the bank of the lower Sibuti River inland. Lines 200 feet apart.

		DISTANCE FEET							
		0	200	400	600	800	1000	1200	
Salinity micro mhos per cm. at 25°C.	LINE 1	<u>21,300</u>	<u>21,300</u>	<u>1,300</u>	<u>260</u>	<u>1,000</u>	<u>560</u>	320	
	LINE 2	<u>23,500</u>	<u>610</u>	<u>560</u>	270	100	120	120	
	LINE 3	<u>26,000</u>	<u>14,500</u>	450	310	260	340	220	
	LINE 4	<u>22,000</u>	<u>2,000</u>	150	80	80	80	20	

Underlined figures are those of the Limbang Family. Readings by portable Pye conductivity meter.

DIFFERENTIATING FEATURES BETWEEN SALINE GLEY SOIL FAMILIES

The Limbang Family is easily differentiated from the three other families by its organic nature and allied properties (Table 29). The Rajang and Pendam Families are separated in the field less by profile characteristics, which may be similar, than by indicators of degree of salinity such as the number of lobster mounds, flooding, vegetation and cultivation. The presence of many lobster mounds on the soil surface has been established as an indicator of Rajang Family soils: they are less common on Pendam soils. Apparently the lobster (*Thalassima anomala*) prefers the environment of strongly saline to that of weakly saline soil. The absence of lobster mounds is not necessarily indicative of freshwater soils, however, as they are by no means ubiquitous in the saline soil areas. Nonok soils are distinguished easily by their markedly different texture. Nonok soils are, however, difficult to separate from the similar Tatau Family Gley soils without the aid of vegetation indicators.

The type of flood water, also the soil groundwater, can be tested qualitatively in the field by tasting. To some extent this can be correlated with the laboratory conductivity readings of soil water used to differentiate the families. Conductivity meters are also used in the field in semi-detailed surveys, as for example in the lower Sibuti River area, to help distinguish between saline, weakly saline and non saline soils. The disadvantage of this, as with all other single determinations, is that it cannot be used as a

Soil Families  
Saline Gley Group

valid measure of such a varying characteristic as salinity. Salt levels reflect a balance between the duration and intensity of flooding, the level of salts in the floodwater and rainwater leaching, which to some extent has a seasonal rythm.

Table 29. The dominant range of important features of soil families in the Saline Gley Group.

Generalised features	RAJANG	PENDAM	NONOK	LIMBANG
Texture Cg horizon	clay loam-silty clay	clay loam-silty clay	sand	peat
C.E.C. Cg horizon (m.e.%)	10-20	10-20	<10?	>75
Conductivity of groundwater (micro mhos/cm. at 25°C)	1000-15000	200-1000	200-1000	500-15000
pH a) wet, b) air dried of Cg horizon	a) 6.5 to 7.8 b) 3.8 to 8.0	a) 4.5 to 7.4 b) 2.0 to 6.6	- -	a) 6.5 to 8.0 b) 3.0 to 3.6
Sulphate content Cg horizon (%)	0 - 5	0 - 5	-	0 - 3

Primary vegetation is a fairly reliable indicator of the degree of salinity of soils. Mangrove species and Nypa are easily recognised and are only found on Rajang Family soils, while Oncosperma filamentosa and Heritiera globosa, for example, are indicative of the Pendam Family. Normally, the strongly saline soils of the Rajang Family are not cultivated. The exception to this rule, however, is in the lower Sibuti basin at the Kalulit River mouth where Rajang and Sirik Family soils are being reclaimed from mangrove swamp for coconut cultivation. Crop growth is poor however and it is felt that this land will be abandoned before long.

Laboratory analyses for conductivity and cation levels, sodium in particular, are used to separate Rajang from Pendam soils in areas difficult to map in the field. Similarly, analyses are used to demarcate Pendam soils from the morphologically similar Bijat Family soils (p.101) of the Gley group, and in this area only a tentative boundary between the two can be mapped as the natural vegetation has been removed and land use is similar.

#### GENESIS OF SALINE GLEY SOILS

The Saline Gley soils of the Bekenu-Niah-Suai are have developed under almost permanent hydromorphic conditions as in the case of Gley soils (p. 107) but the groundwater differs in being saline for at least part of the year. Periodic salt or brackish water floods maintain the salinity levels.

Soil Families  
Saline Gley Group

The Rajang and Pendam Families differ principally in degree of salinity and these levels under natural conditions directly reflect the frequency of tidal flooding, the quality of the water, and the weather. It is clear that the frequency of flooding and the salinity of flood water will concentrate or dilute salt levels in the soil and groundwater directly, the greatest amounts of salt being added when spring tides coincide with dry weather and hence low river flow. The effect of weather is marked, as it is known from work elsewhere in Sarawak (Department of Agriculture, Sarawak, 1966) that during prolonged dry periods the conductivity levels of the soil water rises, while during the wet season the levels fall markedly, in the topsoil at least, due to dilution and/or leaching. Similarly the lobster mounds in the Rajang Family soils commonly stand above flood levels and therefore can be quite strongly leached of soluble salts.

The salts in the soils are dominated by sodium only in Limbang and Rajang Family soils that are most frequently inundated by salt water. Elsewhere in the group excessive sodium is leached out fairly rapidly to leave mainly calcium and magnesium. These salts are not deleterious to soil structure as sodium can be.

The Limbang Family soils are similarly affected by the conditions outlined above, but due to their low bulk density they react differently from the inorganic soils when drained. Drainage reverses the normal reduction processes into oxidation and results in a gradual lowering of the peat surface as it dries, compacts and humifies. This eventually causes difficulties in controlling tidal flooding.

An important feature of the Saline Gley group is that the clayey and organic soils are potential 'catclay' formers, particularly the dark grey subsoil horizons containing much organic matter. Work elsewhere (Van Beers, 1962) has established that 'catclay' formation develops principally from estuarine alluvium containing organic debris. Sulphur in both the elemental state and as compounds in the organic matter, and to a lesser extent in the inorganic soil is released under hydromorphic conditions by micro-biological and chemical activity. If the soil containing the deep dark grey horizon with latent 'catclay' properties is drained deeply, aerobic microbiological and chemical actions begin. This results in the formation of yellow and white sulphates of iron and aluminium principally, also the production of sulphuric acid by the utilisation of soil water. The diagnostic characteristics of 'catclay', namely the distinctive yellow and white crusts on dark soil, the sulphurous smell, organic inclusions in the soil and the strong acidity and high sulphate levels, have been found in parts of the lower Sibuti and Riah river basins. From studies elsewhere in Sarawak, however, it has been established that the occurrence is sporadic areally (Wall, 1963) and that the conditions may be latent in any soils of the Saline Gley group, and in the lower subsoil of the Gley group where riverine alluvium overlies old estuarine alluvium. Drainage of these soils for cultivation therefore has to be planned carefully in order to maintain the potentially toxic horizon wet if possible. The amelioration of 'catclay' by deep drainage, liming and leaching with freshwater is both expensive and prolonged.

Soil Families  
Saline Gley Group

Nonok soils are simply sandy lagoons between old beaches that become flooded periodically with salt or brackish water. The levels of salts are lower than other soils in the group, and are readily leached.

DISTRIBUTION OF SALINE GLEY SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Saline Gley soils occupy only a small proportion of the coastal belt and the lower main river valleys in the Bekenu-Niah-Suai area as shown on Map 4.

Rajang Family soils form roughly 80% of the Rajang Association, the remaining 20% consisting mainly of Pendam and Limbang Family soils. The Pendam-Limbang and Limbang associations mostly occupy a narrow strip between peat swamps and the main rivers. The associations are mapped principally by delimiting on air photographs the occurrence of mangrove and *Nypa* vegetation (p. 48) which are known to be reliable indicators of saline soils. The distribution therefore coincides with that of the Estuary Photo-association (p. 16) and the topographic unit Estuaries (p. 36), characterised by flat macro-topography drained by many small, temporary, anastomosing creeks.

The Pendam-Bijat Association consists mainly of the named families in what is believed to be roughly equal proportions, although locally one or the other may be dominant and small areas of Peat (p. 26) soils may occur in places. The soils are mapped as an association since it is not easy to separate the morphologically similar Pendam and Bijat soils by reconnaissance work. Many soils and soil water samples need to be analysed for conductivity to be able to demarcate their boundaries accurately. This unit occupies the coastal or downriver margins of the Flood-plain Ecosystem (p. 17), the Flood-plain topographic unit (p. 37), parts of both the Freshwater and Saltwater Swamp forests (p. 48) and areas used for swamp rice cultivation. The soils have developed in Quaternary alluvial deposits. (p. 31)

Nonok soils occur only on the coast in the small swales drained by tidal streams. They are associated with strongly saline Rajang and probably Belat Family soils. They occupy parts of the Beach Photo-association (p. 16), the Beach topographic unit (p. 36) and support a specialised type of Littoral Forest or Saltwater Swamp forest. (p. 47 and p. 48).

AGRICULTURAL VALUE OF THE SALINE GLEY SOILS

All the soil families in the Saline Gley group have inherently poor or very poor drainage and are affected by flooding of varying degrees of salinity. The Rajang and Limbang Families have acquired a high degree of salinity and are not used for agriculture while the Pendam Family is only weakly saline and is used extensively for wet rice cultivation. Nonok soils only occur along the coast in small patches near stream mouths and are largely unused: they have not been studied in detail.

Soil Families  
Saline Gley Group

Agricultural Value of the Rajang Family

These soils cannot be used in their existing condition, due to the high salinity of the groundwater for at least part of the year. The salinity is caused by repeated flooding with salt- or brackish water giving high levels of calcium, magnesium, and sodium ions in particular, which combination is both deleterious to soil structure and toxic to plants. Analyses of one profile are given in Table 30, which shows the high topsoil levels of exchangeable sodium and the complete saturation of the exchange capacity with cations, probably indicating that there is much free sodium in the soil. The rather low (air dry) pH is a sign of 'catclay' formation.

Table 30. Showing analyses of a Rajang Family soil (lower Sibuti).

Lab.No.	Depth (ins)	pH (H <sub>2</sub> O)	N (%)	C.E.C. (m.e.%)	Base sat'n (%)	Exch.ions(milli equiv.%)			
						Ca	Mg	K	Na
S4372	0-25	3.4	0.73	44.6	100	10.3	27.3	0.4	40.0
S4373	25-30+	3.3	0.47	40.5	100	11.2	23.6	0.2	25.5

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

To reclaim Rajang Family soils it would be necessary to leach the excess salts (particularly of sodium) from the soil by draining, flooding and washing with fresh water, but at the same time the creation of conditions in which 'catclay' can form must be avoided. By draining and washing with comparatively fresh water the water-soluble sodium salts can be leached readily, but this would involve the construction of substantial dykes and sluice gates to keep out the salt water and would require a reliable source of fresh water. The first necessarily would be expensive, and the second impracticable, unless adjacent peat swamp water could be tapped, as in most places the soils are not situated close to large freshwater streams. In addition, the draining of Rajang soils may easily initiate 'catclay' formation (p.12), which is a more difficult feature to remedy.

In view of the smallness of the areas in relation to the difficulties involved in reclamation and in spite of their high potential, it is considered that Rajang soils should be left under their natural vegetation of mangrove and *Nypa* palm, which are extremely useful in the provision of building timber, charcoal wood and thatch (Panton, p.122).

Agricultural Value of the Limbang Family

Soils of this family have all the limitations of those described for the Rajang Family, but in addition pose more difficult drainage problems and are much more susceptible to 'catclay' formation.

Soil Families  
Saline Gley Group

Where it possible to drain Limbang soils the oxidation, humification and shrinkage of the peat could result in the lowering of the surface even further below high tide level and cause much more serious flooding. As the soils occur within the tidal range now, dykes would also be required, but would have to be built of imported clay, the peat being porous. The presence of organic matter in saline gley soils has been found to correlate well with the sulphate concentration after drying and since those soils are formed principally of organic matter the potential sulphate levels can be expected to be high.

As Limbang soils are likely to be difficult to reclaim properly they are not recommended for cultivation - despite being used for coconuts in the lower Penirak area. (p. 162).

Agricultural Value of the Pendam Family

As with the Rajang and Limbang Families the Pendam Family soils are flooded periodically, the flood water, however, is fresh or brackish and at times may last for four or five days to a depth of one or two feet. Drainage of Pendam soils may be difficult, as they occur within or close to the tidal range and back flooding of brackish water up ditches may result unless dykes and sluice gates are used. Detailed level investigations are required to verify this.

The Pendam soils are clayey, and by Sarawak standards are fertile. They have a moderately good exchange capacity, moderate levels of exchangeable calcium and magnesium, no excess sodium and are not too strongly acid. The concentration of all elements varies quite widely from area to area, however, commonly in proportion to the organic matter content and to the duration and salinity of the last flood. The soils may be deficient in phosphorus for some crops. Analyses of one soil situated close to the strongly saline Rajang soils in the lower Jangalas area (Sibuti) are thought to be fairly typical of the family. (Table 31).

The formation of sulphate in sample 4390 is typically associated with an increase in carbon and a lowering of the pH level. The sporadic tendency to 'catclay' formation in the lower subsoil is the worst limitation to the cultivation of Pendam soils but it can be avoided generally by using the soil for crops not requiring deep drainage.

Wet rice cultivation requires the least improvements to the soil and most strains of wet rice are slightly salt tolerant. Dykes and ditches will be needed, however, in order to drain and flood the crop seasonally. Stream irrigation water is present in some areas of Pendam soils. As with the similar Bijat Family soils (p.113) catch crops can be planted in the off season, although flooding is an unavoidable risk. Small fruit trees can be planted on the dyke banks.

Where drainage is possible the soils should be suitable for coconut, oil palm and citrus. It is wasteful to use these potentially high-yielding soils for buffalo grazing as, at present, in the Sibuti-Penirak area.

Table 31. Analyses of a Pendum Family soil, recently flooded by slightly brackish water.

Lab.No.	Depth (ins)	pH(H <sub>2</sub> O) air dry	Org.C (%)	N (%)	C/N ratio	C.E.C. (m.e.%)	Base sat. (%)	Exch. cations (m.e.%)			SO <sub>4</sub> %	
								Ca	Mg	K		Na
4387	0-4	3.6	2.4	0.04	60	39.2	19	1.7	2.1	0.5	2.9	nil
4388	4-16	3.6	4.0	0.17	24	23.5	14	0.8	1.4	0.1	0.8	nil
4389	20-25	3.9	4.3	0.17	25	24.1	17	0.9	2.3	0.2	0.6	nil
4390	40-56+	2.6	5.1	0.11	46	18.8	22	0.9	1.8	0.2	1.2	0.96

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Soil Families  
Saline Gley Group

Agricultural Value of the Nonok Family

Little is known of this soil family, but it is probable that the potential value is similar to that of Tatau soils (p.113). Being a sandy soil the nutrients will be easily leached if the soil is drained, and fertiliser applications may be required frequently for the best crop yields.

SOIL FAMILIES OF THE PEAT GREAT SOIL GROUP

Although Peat soils occupy approximately 23% of the Bekenu-Niah-Suai area, and about 50% of the lowlands of the area, they are remarkably uniform and only three soil families are recognised, the main characteristics and development of which are given below.

Table 32. The diagnostic features of Peat soils in the Bekenu-Niah-Suai area.

DEPTH OF O HORIZON	TEXTURE OF MINERAL SUBSOIL	SOIL FAMILY
O horizon 10 - 40 inches deep	Light-textured	IGAN
	Heavy-textured	MUKAH
O horizon more than 40" deep	Undifferentiated	ANDERSON

Only one other family in this group is separated elsewhere in Sarawak, on the basis of the origin of the peat.

1. IGAN FAMILY

Igan Family soils consist of a moderately thick accumulation of very poorly drained peat or muck overlying gleyed sandy subsoil. A description and analyses of a common Igan soil is included in Appendix B20.

The surface organic O horizon is from ten to forty inches deep. It is brown to very dark brown in colour and consists of peat or muck with up to 35 percent of the top 20 inches consisting of inorganic (sandy) lenses. The peat is raw, waterlogged, acid and low in nutrients per weight of wet soil. Roots are generally restricted to the top 18 inches of soil.

The Cg horizon is gleyed and almost invariably is a light grey to brown, loose, wet sand. The sand is commonly humus stained and of low fertility due to the low buffer capacity. The sand consists predominantly of quartz, similar to that of the Matu Family with which it commonly occurs in association.

2. MUKAH FAMILY

Mukah Family soils are very poorly drained and can be described broadly as having a moderately thick surface peat or muck horizon overlying gleyed clayey subsoil. A description of a common Mukah soil is given in Appendix B21.

Soil Families  
Peat Group

The surface O horizon varies from ten to forty inches deep. The wet colour of the organic matter ranges from brown to very dark brown depending on the admixture of inorganic material. This horizon generally consists entirely of rather woody peat or muck, but it is possible for as much as 35 percent of the top 20 inches of soil to consist of inorganic (clayey) lenses. The peat is raw, waterlogged, woody and acid with low mineral nutrients per weight of wet soil. Elsewhere in Sarawak the levels of exchangeable nutrients tend to be higher in the immediate vicinity of the coast than further inland (Wall, 1961a, p.9; 1961b, p.11). Roots are generally confined to the uppermost 18 inches of soil.

The underlying inorganic soil is gleyed and light grey to dark grey in colour, with blue or green tints in some areas. Where the soil is dark it contains finely comminuted organic matter and may smell sulphurous (p.122). The texture ranges from clay and silty clay to clay loam; peaty or mucky clay loams also occur. The material is generally plastic and sticky and is probably similar to that of Bijat (p.101) or Pendam (p.117) families in mineralogical and chemical properties depending on location. Close to tidal rivers Mukah Family clays are richer in calcium, magnesium, and potassium than those in upriver areas.

### 3. ANDERSON FAMILY

Soils of the Anderson Family consist of deep, waterlogged, raw, woody peat, or muck. Detailed chemical analyses of typical profiles are given in Appendix B22.

The peat is formed predominantly of freshwater swamp forest debris except for basal layers which are believed to consist of saltwater forest material. It is commonly more than 20 feet deep, is characteristically brown to dark reddish brown, and in places contains so much water that it is difficult to walk over. Decomposition is slow and lags behind the rate of accumulation so that there is much entrapped woody material, often encountered when probing for peat depths. Admixed clay and muck occurs close to rivers, and in basal layers. Basal peat or muck has the sulphurous smell and apparent composition of mucks forming in parts of saltwater swamps (p.122). Where the surface 20 inches of soil consists of more than 35% organic matter, it is classed as part of the Gley group (p.100). The watertable lies at or close to the surface, and, since the surface of large and possibly small swamps is convex (p. 37) the watertable is stilted; its colour is dark reddish brown, its conductivity low and acidity high.

As with the Mukah and Igan families the nutrient levels per weight of wet soil are low (Polak, 1948). There are clear indications that in coastal swamps phosphorus levels decrease both with depth and with increasing distance inland. (Table 33). The trend noticed elsewhere in deep peats of coastal Sarawak for some exchangeable nutrients to have greater concentrations than further inland is not evident in this area. (Wall, 1966c, p.8).-

Due to the marked uniformity, it was possible to map the Anderson Association as depth phases (Map 4) in most areas. The small strips of deep peat close to the Lower Sibuti River that are periodically subjected to saltwater flooding have acquired high conductivity and are therefore classed in the Limbang Family. (p. 123).

Table 33. Showing changing levels of some Peat soil elements from the coast-land. Igan and Anderson soils from Sample Area III (Appendix) 4.

ELEMENT	DISTANCE FROM COAST (FEET)					Luak - 8 miles inland (soil depth-ins.)
	1800 (soil depth-inches)	3100 (soil depth-inches)	5000 (soil depth-inches)	10000 (soil depth-inches)	15000 (soil depth-inches)	
Phosphorus (total p.p.m.)	750(0-31)	620(0-12) 270(12-24) 150(24-48+)	600(0-12) 235(12-24) 145(24-48+)	355(0-12) 210(12-24) 95(24-36) 95(36-48+)	240(0-12) 110(12-24) 60(24-36) 50(36-48+)	1160(0-12) 630(12-24) 510(24-36)
Calcium (reserve %)	0.07(0-31)	0.14(0-12) 0.08(12-24) 0.06(24-48+)	0.10(0-12) 0.07(12-24) 0.08(24-48+)	0.03(0-12) 0.02(12-24) 0.03(24-36) 0.04(36-48+)	0.07(0-12) 0.01(12-24) 0.03(24-36) 0.03(36-48+)	0.03(0-12) 0.04(12-24) 0.05(24-36)
Magnesium (reserve %)	0.06(0-31)	0.06(0-12) 0.02(12-24) 0.02(24-48+)	0.05(0-12) 0.06(12-24) 0.02(24-48+)	0.02(0-12) 0.006(12-24) 0.01(24-36) 0.04(36-48+)	0.03(0-12) 0.02(12-24) 0.02(24-36) 0.006(36-48+)	0.30(0-12) 0.28(12-24) 0.30(24-36)
Sodium (exchangeable - m. e. %)	0.25(0-31)	0.40(0-12) 0.20(12-24) 0.36(24-48+)	0.16(0-12) 0.20(12-24) 0.11(24-48+)	0.76(0-12) 0.78(12-24) 0.70(24-36) 0.83(36-48+)	1.10(0-12) 0.64(12-24) 0.73(24-36) 0.85(36-48+)	
SOIL FAMILY	IGAN	ANDERSON				MUKAH

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Soil Families  
Peat Group

DIFFERENTIATING FEATURES BETWEEN PEAT SOIL FAMILIES

The organic material is essentially similar in all three families. The Igan and Mukah soils are differentiated by their subsoil properties. Texture is the most obvious difference, and this feature can be linked with the higher fertility of Mukah Family soils. Its clays are higher in nutrients than Igan Family quartz sands and have a higher capacity to absorb and retain exchangeable nutrients, they also have higher agricultural potential after drainage. Igan Family soils are normally situated close to the coast or where old inshore sand bars occur, such as between the Lower Niah and Suai rivers, Mukah soils are found close to rivers. Anderson peat soils consist of all peats deeper than 40 inches.

GENESIS OF PEAT SOILS

The locations of all Peat soils in the area characteristically have slow impeded surface drainage associated with alluvial basins. The basins vary in size from those of the large, lower river courses to small pockets trapped between high river levees and adjacent hills; the latter are common in the middle reaches of the main rivers.

The extensive coastal and Bakong River swamps are located in the foreland between the present coastline and the middle Pleistocene coastline (p.43). This, together with the presence of salt water vegetation forming basal peats (mangrove and *Nypa* pollen occurs in basal peats of Marudi Swamp, contiguous with the Bakong Swamp; Wilford, p.119) supports the idea that these swamps originally formed on estuarine mud flats that filled-in the shallow sea between growing offshore sand bars (now at the present coast) and the former coastline (hills lining inland swamp margin). As river levees grew in the mud flats basins developed with increasingly poor drainage and existing salt water vegetation was slowly replaced by brackish, then fresh water species. Peat accumulated first with the salt to brackish water vegetation and it is to be expected that the base of all the larger swamps are of this type, and probably eutrophic, containing high levels of salts derived from brackish or salt water, at least where clay forms the subsoil. As the peat accumulated fresh water conditions became established.

The mineral subsoils have been laid down by slow-moving river flood water in the case of the Mukah Family, and by longshore drift in the Igan Family, each process giving a typically narrow textural range. The mineral soils are permanently gleyed. Reducible iron compounds in these conditions give the green and blue shades associated with Mukah Family clays. Prominent strong brown mottles are found in the clays along root channels in places, where overlying peat is shallow. This does not necessarily imply a drying out of the soil as root exudates are known to be able to oxidise iron compounds. Nutrient levels in the clays invariably exceed those in the sands. (p.132).

The margins of the swamps failed to grow as rapidly as central areas, probably due to better drainage and the periodic flooding with oxygenated, base-rich water which encouraged aerobic microbiological and chemical decomposition. The uneven growth has resulted in domed large swamps (White, 1956) with biconvex cross section (Sample Area III, Appendix A) - a development from low-moor swamps with eutrophic, topogeneous or soligenous peat to high-moor swamp with oligotrophic, ombrogenous peat.

Soil Families  
Peat Group

The development from eutrophic, nutrient-rich peat to oligotrophic, infertile peat in the central domed swamps is thought to be due partly to radial surface leaching of soluble nutrients, and partly to the decreasing ability of succeeding plant communities to take up all the nutrients available in the peat they grow on, and hence decreasing levels of nutrients in the litter of each successive generation of plants. This is reflected in the relative richness of Mukah peats compared to Igan Family peats developing over poor quartzose sands.

The coastal surface peats here, unlike elsewhere in Sarawak, do not seem to have higher levels of exchangeable calcium, magnesium and sodium than inland peats (Wall, 1961a, p.9) but this trend is apparent from the 'reserve' analyses (Table 33). Wood and Beckett (p.227), however, find that composite leaf samples of coastal trees about twenty miles to the southwest of this area have higher sodium and magnesium levels than those of composite samples further inland, and attribute it to salt spray being carried onshore by winds. Levels of 'reserve' phosphorus, probably mainly organic, clearly decrease both with increasing distance inland and with increasing depth (Table 33), and this has been confirmed by similar analyses of the Bakong Swamp peats (Wall, 1965): levels of 'available' phosphorus show the same trend but are extremely low below 24 inches. While it is not difficult to understand that the phosphorus concentration becomes progressively less towards the raised centres of swamps where the only available source of replenishment is rainwater and where lateral drainage depletes the supply, it is not so clear why the levels increase markedly towards the surface. It may be the result of a continual drawing on subsoil supplies by roots and the eventual enrichment of topsoil by litter, which suggestion is supported by the figures in Table 33, where in two profiles phosphorus levels below 24 inches are constant. The inland peat at Luak has the same vertical trend, but is richer in total amounts, presumably due to enrichment from the periodic flooding by nearby streams. Parberry (1964, Table 1) writing on South Malayan peat soils reports a similar vertical distribution.

The difference in acidity between fresh and air dried peat is between 0.9 and 2.0 in seven samples analysed, the lowest air dry level being pH 2.5 at the surface of an Igan Family soil. This great increase in acidity after drying resembles that found in Brunei peats by Blackburn and Baker (p.25) who explain the difference as being due to the same process that causes 'catclay'.(p. )

The exchange complex of peat is high, but tends to be saturated with hydrogen ions at the expense of bases (Parberry, p.132). The wide carbon-nitrogen ratio indicates the preponderance of inactive lignaceous material in the peat compared to the topsoil of mineral soils.

DISTRIBUTION OF PEAT SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

The Bijat Family is mapped in association with the Mukah Family largely in the middle Sibuti River valley and in basins drained by the Jangalas and Tiris rivers. The Mukah soils are found mainly towards the centres of the basins that the association occurs in while the Bijat soils (p.101) occupy the outer areas close to rivers. Some Anderson Family deep peat may be present in places also Sebandi Family shallow peats. The soils have developed in recent riverine

Soil Families  
Peat Group

clayey alluvium and organic accumulations (p. 31) in flat, poorly drained riverine basins (p.35 ) with both Freshwater and Peat Swamp Forest (p. 48 and p. 49) replaced in many areas by wet rice fields and secondary growth. The association occurs within the areas mapped as the Flood-plain Photo-association (p.17 ) and on the margins of the Peat (p. 17) Photo-association.

The Igan Family has an entirely coastal distribution. It is mapped principally with badly drained sandy Gley soils and with poorly drained Groundwater Podsol soils. The parent materials consist of recent marine sands and peat (p.31 ), the topography comprises peat swamp margins (p. 37) and the lower, landward parts of the beaches (p.36 ). The forest type is principally Peat Swamp Forest (p.49 ). Igan soils were found to lie largely within the area mapped as the Peat Photo-association (p. 17); - Sample Areas II and III, Appendix A).

Due to the uniformity of the Anderson Family it has been mapped in most places as three depth phases. Associated soils belong mainly to the Gley group. (p.100).

All the areas mapped as the Peat Photo-association (p.17 ) contained Anderson Family soils (Sample Area III, Appendix A); they also covered parts of the Beach (p. 16) and Flood-plain (p. 17) photo-associations. The soils consist of young Peat Swamp Forest debris (p. 31) accumulating within riverine basins (p.36 ). The forest (p. 49) is only removed for cultivation on the fringes in a few localities.

AGRICULTURAL VALUE OF THE PEAT SOILS

The value of Peat soils and their best use is a controversial issue in Sarawak that has not yet been resolved. While it is agreed by most people that the shallow peats can be reclaimed for some crops, it is debatable as to what depth the soil should be regarded as unsuitable for cultivation. The main points at issue are the fertility, drainage and rooting properties.

Agricultural Value of Igan and Mukah Families

The maximum peat depth in these two soil families is 40 inches, which, it is generally agreed, can be reduced slowly by light drainage to give a shallow, light, but cultivable soil for annual crops, and which can be penetrated by tree roots to reach underlying mineral soil. It must be expected, however, that the risk of flooding increases proportionally to the effectiveness of draining and hence peat shrinkage. Thus before a large-scale, expensive programme of drainage is embarked upon investigations must be made as to whether or not the swamps is domed, and therefore drainable, or flat and to what height local flooding can be normally expected.

Soil Families  
Peat Group

Table 34. Showing analyses of a) five Mukah and b) three Igan Family profiles from downriver or coastal locations where additions of calcium and magnesium can be expected from either flooding or from salt spray.

No. samples	Horizon	Level	pH (H <sub>2</sub> O)	C.E.C. (m.e.%)	Base sat'n (%)	Exch. cat. (m.e. %)			
						Ca	Mg	K	Na
a) 5	O	Lowest	3.4	46.6	2	0.6	0.3	0.0	0.1
		Highest	4.4	72.0	36	13.2	3.4	0.9	0.5
		Average	3.8	59.6	12	4.1	1.6	0.3	0.4
a) 6	Cg	Lowest	2.8	14.8	8	0.2	1.3	0.1	0.1
		Highest	4.0	44.9	42	6.6	4.6	0.3	0.6
		Average	3.9	31.2	20	2.3	2.7	0.1	0.2
a) 3	O	Lowest	3.3	59.3	5	0.7	1.1	0.4	0.2
		Highest	3.7	85.5	6	1.3	2.0	1.7	0.9
		Average	3.4	68.4	6	0.9	1.3	0.9	0.5
a) 5	Cg	Lowest	3.1	1.9	12	0.4	0.0	0.03	0.07
		Highest	4.4	4.5	87	0.7	0.5	0.07	0.3
		Average	3.8	3.6	38	0.5	0.1	0.05	0.1

The level survey of Sample Area III (Appendix A) showed that it would be possible to drain the Igan soils of that part of the coast, as the base of the peat is just above high tide level.

The fertility of the peat appears to vary widely from area to area to judge by available analyses (Table 34). Mukah Family peat in small swamps close to Saline Gley soils, for instance, has higher exchangeable calcium and magnesium than that of larger and deeper inland swamps (c.f. Table 35), while some Mukah peats near Subis have acquired high calcium levels in the top part of the profile, presumably due to flooding by calcium-charged stream water draining the limestone. Igan Family peat in coastal areas on the other hand has somewhat higher levels of exchangeable nutrients in places possibly due to additions from salt spray. Although some peat may appear to be moderately fertile to judge by the analyses, it should be remembered that the concentration is per oven-dry weight, and that in the field-wet condition the concentration per volume is reduced markedly. The practice of burning and periodically after drying is temporarily beneficial to subsequently planted crops as a certain amount of organic-bound mineral nutrients are released. The benefit is short-lived, however, and serves in addition to both accelerate the peat removal, and therefore heighten its susceptibility to flooding, and to destroy the important organic exchange complex. In the case of Igan soils this is doubly important, as the underlying sand is extremely infertile (p. 126) and only the peat is capable of storing nutrients.

Soil Families  
Peat Group

Undrained Mukah and Igan soils are known to support sago palm satisfactorily (Wall, 1961a, p.11). Lightly drained Mukah soils are used for wet rice in places but control of flood-water is difficult. More intensively drained shallow peat of both families grows vegetables, gourds, maize, bananas, pineapple, papaya, citrus and some taller fruit trees. All grow better on the Mukah than Igan soils where unfertilised, in the same way that the Bijat or Pendam Family clays are better for crops than the Tatau or Nonok Family sands (p.113 and p.126). The taller trees, notably rubber, will grow on the peat, but after drainage the roots tend to become exposed in the air. Igan soils are less susceptible to deep flooding than Mukah Family soils, and therefore vegetable growing is more appropriate on them.

Agricultural Value of Anderson Family

The soils of this family tend to be more strongly domed than the shallow peats (Sample Area III, Appendix A) and therefore could be gravity drained, in theory as low as the local base level. Flooding would not be a serious problem unless the peat surface was close to the local base level. The base of the coastal peats is known to be below high tide level. (op.cit.)

Anderson Family peats are less fertile than most shallow peats and recalculating the nutrient levels on a field-wet basis (loss of water on ignition 80-90%) it seems surprising that trees are able to survive at all. Inland peats to judge by the local analyses have slightly lower exchangeable nutrients than those on the coast (Table 35). Burning these deep peats periodically may be a practicable aid to improve the low fertility, although it is highly probable that most crops would require fertilisers including both major and minor nutrients. Leaching of these soils should be minimal.

Table 35. Average levels of the cation exchange complex in Peat soils, a) on the coast overlying infertile beach-sand, and b) well inland overlying more fertile clay.

Depth	pH (H <sub>2</sub> O)	C.E.C. (m.e.%)	Base sat'n (%)	Cation exch. (m.e.%)				No. Samples
				Ca	Mg	K	Na	
0-12	3.7	88.2	4	1.2	1.6	0.3	0.6	4
12-24	3.6***	70.0	3	0.6	1.1	0.3	0.4	4
24-36	3.6**	71.1	3	0.8	0.7	0.1	0.5	4
36-48	3.2*	93.2	2	0.7	0.5	0.1	0.8	2
48-60	3.6	97.9	1	0.2	0.7	0.2	0.2	2
60-72	3.6	100.0	1	0.1	0.5	0.5	0.1	2
72-84	4.1	100.0	1	0.2	0.3	0.3	0.1	2
84-96	3.5	100.0	1	0.4	1.0	0.6	0.1	2

Note:- \*\*\* three samples; \*\* two samples; \* one sample.  
Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Soil Families  
Peat Group

Undrained Anderson Family peat is used for semi-wild sago palm gardens in coastal Third Division (Wall, 1961a). Fertilisers are not used, and it is not known to what extent fertiliser applications would improve growth. The pith product can be processed as sago flour or can be used directly as pig and poultry bulk feed. Coconut and rubber are grown on drained deep peat elsewhere in Sarawak but growth tends to be slower than on more suitable soils, the fruiting and latex production is poor and the trees are highly prone to falling over when mature because of the unstable, soft foundation. In the writer's opinion neither rubber nor coconut are suitable crops for drained peat more than about two feet deep, and annuals and small fruit trees are far more appropriate. In Malaya, coffee and pineapple plantations (Parberry and Venkatachalam, p.125) are grown successfully on similar deep peats but a prime requisite for pineapple processing is an assured large water supply close to the plantation. In these areas spot fertilisation by pellets is being tried, so far with success: potassium appears to be the most deficient element in pineapple nutrition there.

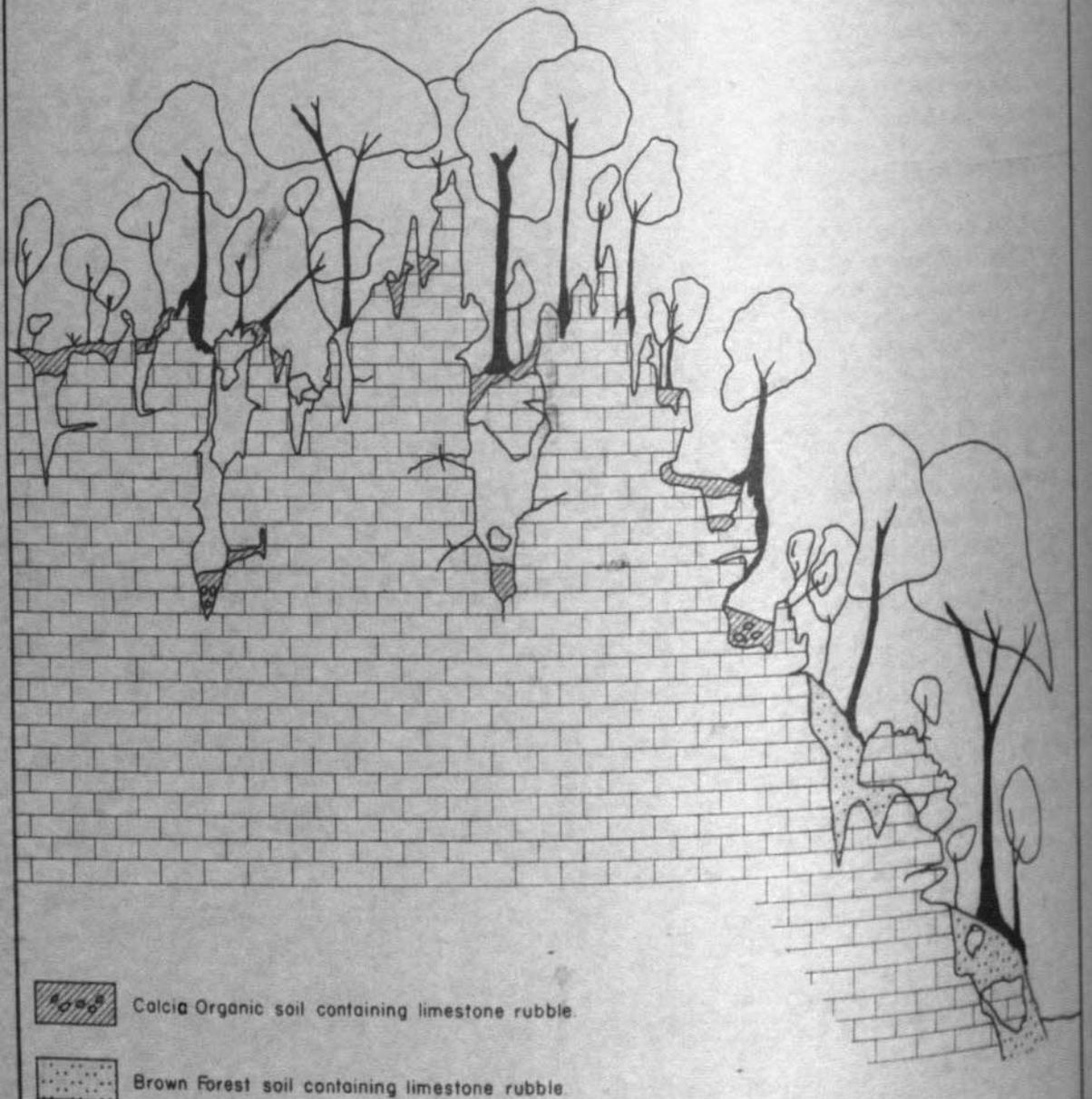
In Sarawak there has been a tacit agreement until recently that peat deeper than a rather arbitrary depth of three feet should be left under primary forest for timber exploitation, as the timber yield per acre of some swamps could reach high values, in particular with a programme of planned afforestation. The overriding benefit of this approach is that the delicate soil-water relationship of the swamp is not tampered with and swamp growth is maintained without risk of flooding. Recently, however, and it can be presumed even more so in the future, there have been vociferous demands from natives in over-farmed areas that government owned peat lands, of which there are vast areas (e.g. the Semilajau Forest Reserve - 96 square miles in this area) should be opened up for cultivation of swamp rice, rubber or coconut. This approach should be strongly resisted, for quite apart from the known poor quality of the peat for cultivating such crops, the potential damage to a large swamp by lowering the surface to the local flood level is a process that cannot be reversed easily or quickly, and once this level is reached the area becomes virtually useless for agriculture.

Small-scale cultivation on the margins of the swamps for vegetables and fruit is the only recommendation for these soils until further knowledge is available on manurial, and drainage limitations in particular. (Panton, p.122).

SOIL FAMILIES OF THE CALCIC ORGANIC GREAT SOIL GROUP

Calcic Organic Soils commonly do not exceed six to nine inches in depth, which should justify their classification as Skeletal soils (p.148). However, their other characteristics are quite different from those of the Skeletal soils, and since they only superficially resemble the Peat soils of the Anderson Family (p.127), they have been classed as a separate, locally defined soil group. Only one soil family, the Kapor Family is sufficiently widespread to be worthwhile mapping in the Bekenu-Niah-Suai area. It has a distribution limited entirely to the limestone outcrops at Subis. The main features of the family, its genesis and relationship to the environment are described below. One other family in the group has been established elsewhere in Sarawak based on the inorganic soil content.

Fig. 46 DIAGRAMMATIC SECTION SHOWING TYPICAL SOIL DEVELOPMENT ON KARST



Soil depth not to scale.

Soil Families  
Calcic Organic Group

Although it is known to occur in this area its distribution is believed to be extremely small.

1. KAPOR FAMILY

The Kapor Family soils can be described as organic accumulations, overlying limestone, that have decomposed to give shallow mull soils rich in calcium. Profile descriptions and some analyses of Kapor soils are given in Appendix B23.

The soil varies in depth from a thin, two or three inch layer to as much as three feet in favourable sites, such as in natural hollows and clefts in the limestone. It is characteristic of the soil to vary widely in depth over short distances, and to be sporadic areally due to the abundance of protruding bare limestone pinnacles, boulders and lapies. A typical feature of Kapor soils is that it may be suspended in the air by a root mat (Fig. 46) with no contact at all with limestone. Elsewhere, the soil rests abruptly on limestone rock or rubble.

The soil profile is typically uniform in morphology below the surface one or two inches of litter. It is very dark brown in colour when moist, well-decomposed, very friable and slightly crumbly. It has the appearance of mull, contains common small shell fragments, and at the base may incorporate limestone rubble. Typically the whole soil beneath the surface litter is threaded, reinforced, and fed on by abundant fine to medium roots.

No analyses have been made from Kapor soils at Subis, but several Kapor soils overlying similarly pure limestone 50 miles to the east and southeast, and in West Sarawak (Wilford and Wall, Table 3, p.61) have the following chemical characteristics. The exchange capacity ranges from 20-70 m.e.% with a mean of 44.7 m.e.% from 10 samples; the exchangeable calcium in the same samples range from 1.2-6.6 m.e.% averaging 4.7 m.e.%. Total calcium content of the humus exceeds 2% of the dry matter and commonly exceeds 5%; part of this amount is probably attributable to shell and tiny limestone fragments. Other bases normally are present in small concentrates with total phosphorus ranges from low to high. Nitrogen ranges from 1.5 to 3.0%. Acidity levels are varied; in some sites the values are as low as pH 4.8 while in others it may reach pH 8.0. Burned soil yields 5 - 15% ash.

The analyses of Calcic Organic soils have been given strong indications that two types of the soil exist, the differences between them being attributable to site and leaching effectiveness (p.136). Broadly, the two types are associated with karst hill summits and flanks respectively. The differences are principally in acidity and calcium values. The summit type is acid (pH 4.8-6.5, five samples) with total calcium values averaging 2.8% dry matter; the Kapor soil on flanks of karst hills on the other hand is slightly alkaline (mean of 13 samples pH 7.3) with total calcium averaging 5.5% of dry matter. The two types of soil, while morphologically alike, support different vegetation communities (p.51), and since both communities have been noted at Subis it is assumed that the two soil types occur there.

Soil Families  
Calcic Organic Group

GENESIS OF CALCIC ORGANIC SOILS

Calcic Organic soils in the Bekenu-Niah-Suai area occur solely above hard pure limestone and simply represent accumulations of decayed organic matter from vegetation living in this environment. The sporadic occurrence and highly variable depth of the soils are the combined result of the topography and effectiveness of root systems in trapping litter.

The topography is karstic (p. 40), in which sheer and sharply ridged lapies project from the general surface leaving natural deep hollows and clefts between. This tends to concentrate falling litter into the lower parts. The trees all have root networks that to a large extent are exposed on the surface where they commonly traverse gaps and span clefts in the rock. Once litter collects above a root layer the accumulation becomes more effective and rapid, and fine root networks begin to form and feed on the decomposing litter and new humus. In favourable sites with few lapies, the soil may spread over the entire surface as a deep, springy, organic mattress hiding deep clefts beneath, while on some sheer karst hill flanks the soil can only be found in a few water worn holes and clefts.

The chemical features of the two soil types described in the section above are explained as the result of normal rainwater leaching on hill tops and flanks respectively. On hill flanks, rainwater leaches soluble bases from the soil to lower levels. The amount removed is small however as the humus has a high cation exchange capacity and can effectively bind large quantities of bases to prevent leaching. In addition, base-enriched water seeping downhill from upslope serves to replenish the soil, and root networks feeding on the soil carry nutrients into the living system and then as litter back to the soil again. These features together result in a small overall loss of the main base, calcium, and the maintenance of an alkaline soil environment. On exposed hill summits however it is probable that rainwater leaching is more effective. There can be no replenishment of lost calcium from soil water upslope and the only replacement is from the feeding roots via the vegetation to the soil. The overall result is a more rapid and effective leaching of calcium and other soluble bases giving and acid soil environment and lower calcium levels.

The process is than self-generating; the more acid the soil water the greater the leaching power, and the more acid the soil the more acid the vegetation leachate becomes. Acidophyllous species noted on Subis summits include the conifer-like Gymnostoma nobile. Analyses of leaves and litter of Kapor soils in West Sarawak show that those of the hilltops are more acid and lower in calcium, magnesium and potassium than those of the hill flanks (Wilford and Hall, Table 3, p.61). It is probable that the Kapor soils on exposed hill summits can become strongly acid in the most favourable circumstances of heavy rainfall and level summits surrounded by cliffs, such as at parts of Subis.

DISTRIBUTION OF CALCIC ORGANIC SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

The Calcic Organic soils are mapped only at Subis as the Kapor-Rock Association as shown on Map 4. (Associations are normally named after the dominant soil family or families within them, but in this case pure limestone rock is so common that it is included in the title.)

Soil Families  
Calcic Organic Group

Kapor soils are locally common, particularly on hill summits and the least precipitous hill flanks. Elsewhere, on the marginal cliffs, lapies and on some rocky scree, bare limestone is dominant. Because of this sporadic distribution the total area is small. The association occurs only in Karst topography (p.40) formed by hard, massive, almost pure limestone (p. 31) and supports two distinctive broad vegetation types (p. 51) untouched by cultivation. The Karst Photo-association (p.21) covers all areas mapped as this association.

Agricultural Value of Calcic Organic soils

Kapor Family soils are found in such extremely jagged topography, and are generally so shallow and infertile (nutrient concentration per volume field-moist soil) that it is totally impracticable to consider them for cultivation.

SOIL FAMILIES OF THE BROWN FOREST SOIL GROUP

Brown Forest soils, originally classified in temperate latitudes, are uncommon in Sarawak and to judge from the literature are equally uncommon in South East Asia. Dudal and Moormann (pp. 62-63) describe scattered, similar '(Acid) Brown Forest Soils' derived from mica schist, andesitic ash and easily eroded calcareous rocks on steep slopes. Dames (1955, pp.101-103) writing on the soils of part of Java classifies small areas of similar soils as 'midway between light-textured, podsolised, lateritic yellow sandy loam and heavier, quartz-containing black marginalitic soil.' In New Guinea slightly more acid and somewhat less calcareous soils are called Yellow Brown Earths by Rutherford (1962), while Stephens (p.30) describes Brown Forest Soils overlying calcium rich parent materials in Australia.

One soil family of the Brown Forest soils occurs in the Bekenu-Niah-Suai area; it is distributed in a few small patches (Map 4) in direct association with outcrops of marl and limestone. The main features of the Kebuloh Family are described below, also the genesis and relationship with the environment.

1. KABULOH FAMILY

The characteristic features of the Kabuloh Family are yellowish brown colours, clay textures, an abrupt change to underlying limestone and a moderately high base exchange capacity saturated with calcium. Detailed descriptions and analyses of typical Kabuloh soils are given in Appendix B24.

Surface litter and humus are generally thin or absent and the A1 horizon, although distinct, is rarely deeper than three inches. There may be a weakly expressed A2 horizon which grades rapidly to the main B horizon. The change to C horizon material is abrupt and the total depth of soil rarely exceeds 30 inches.

Moist soil colours in the B horizon range from light yellowish brown to yellowish brown or strong brown with common, fine, very dark brown to black mottles in the lower part. The thin A1 horizon is darker coloured. Where the parent material is soft it is coloured olive to dark greyish brown; where hard it ranges from light grey to dark grey. A thin zone between lower B and upper C horizons may contain common gley mottles.

Soil Families  
Brown Forest Group

Kabuloh Family soils are characteristically clay textured, although the A1 horizon may contain sufficient sand with silt and organic matter to be classed as loam or clay loam. The bulk of the profile (B horizon) contains at least 60% clay and 30% silt with slight evidence of increasing amounts with depth. The C horizon contains a considerable amount of material soluble in acid (as much as 20%), largely as soft fragments of weathered marl or highly calcareous shale. Inclusions of hard smooth-surfaced limestones are common in some areas.

The structure of the organic rich topsoil is fine, subangular blocky to crumb, and that of the bulk of the B horizon is fine to coarse, strong blocky. At the base of the B horizon the soil may become massive particularly where overlying the softer parent rocks. Moist soil consistence is firm to very firm throughout, except in the B3 horizon where the gleyed soil that occurs in places is slightly plastic and non sticky. Despite the dense nature of Kabuloh soils roots penetrate as far as the lower B horizon. They are most plentiful in the upper six inches of soil. The internal drainage ranges from imperfect to good, and external drainage from slow to rapid.

Chemical analyses of five profiles show that the soils typically have medium to high cation exchange capacities that increase slightly with depth to peaks of 20-45 m.e.% in the B horizon. The capacity is largely saturated to levels of 40-100% by calcium and lesser amounts of magnesium. Where exchangeable calcium with magnesium m.e.% values exceed that of the exchange capacity it is assumed that free calcium in the form of calcium carbonate exists in the soil. Exchangeable phosphorus and potassium values are low beneath the topsoil as are those of nitrogen, and, in places, carbon. The pH value generally increases from pH 4.5 in the most strongly leached topsoils to pH 7.7 in the most alkaline subsoils adjacent to weathering limestone.

Mineralogical analyses of Kabuloh Family soils have not been made, but the medium to high levels of base exchange sites of the soil (not entirely due to the presence of organic matter) indicate that a part of the clay fraction at least is illitic or montmorillonitic and not kaolinitic. The small sand fraction probably consists of a mixture of quartz and probably calcite. Related soils in West Sarawak (Wall, et.al. 1962) are known from the section analyses to contain secondary, illuvial calcite in the lower subsoil.

GENESIS OF BROWN FOREST SOILS

The Brown Forest soils have been subjected to the same climatic conditions over the same period of time as the associated Red-Yellow Podsollic soils and some Podsolis described above. Their distinctively different morphology therefore has developed due to the effects of parent rocks, vegetation and topography; it is thought that the lithology and mineralogy of the parent rocks is most influential, in particular their calcareous nature.

Soil Families  
Brown Forest Group

Rocks and weathered rocks underlying the Brown Forest soils are characteristically rich in calcium carbonate and, in places, minerals that release magnesium on weathering they range from soft marls and calcareous shales to extremely hard and pure limestone. The soils developed from the marl and shale are generally shallow and stone-free, and occur on low, gently undulating topography. This is because weathering of the marl and shale is a rapid process compared to that of non calcareous shales since a large part of the rock is readily soluble in percolating acidified soil water, and is subsequently leached from the soil. Therefore, in addition to the rate of weathering being more rapid than that of adjacent shale or sandstone, the breakdown of the rock releases a much smaller amount of insoluble material for soil formation.

The soil resting on hard limestone is believed to be purely colluvial and partly residual in most instances. In the Subis Mountain area the Kabuloh Family soils have only been noted on the lower flanks and scree slopes, although it is possible that there are other occurrences among the higher limestone peaks. Because the Subis limestone is known to be extremely pure (Wilford and Wall, p.45), and because it is known that conformable shales once overlay the limestone, it is felt that the soils there are likely to represent a mixture of material derived in part from the residue of dissolved limestone, but predominantly from allocthonous, incompletely eroded weathered shale remnants. In other areas examined, such as at Luak, the upper Penirak area (Sibuti), and the upper Nulis Valley, this polygenetic origin of the Kabuloh soils is made even more probable by their occurrence as small patches of low rolling land among somewhat higher hills with Merit soils (p.68), from which colluvial material could easily become admixed with residual material from limestone.

Clay leaching from upper to lower subsoil occurs, but on a small scale as shown by mechanical analyses of one profile, and by the even spread down the profile of group III elements, which are closely related to the clay fraction. Similarly the base exchange complex increases in value only slightly to a peak in the lower B horizon (excluding the A1 horizon) then decreases markedly in weathering rock horizons. From visual observation of two profiles in the field it is likely that most clay moves down the structural faces, seen as clayskins, and not through the dense soil matrix.

It is clear that the calcium content of rocks underlying Kabuloh Family soils must range from that of the most pure limestone to that of shales only just sufficiently calcareous to give the requisite 30% base saturation level in derived soil. It is in the latter soils, which are normally deeper than the highly calcareous variety, that the downward leaching of soluble bases is most clearly seen, and in which an incipient A2 horizon is developing. The acidity of the upper B or A2 horizon is in one profile pH 4.8, compared to pH 7.6 in the lower subsoil, a condition in which podsolisation can take place.

In general, however, podsolisation is believed to be minimal and, if present, restricted to the upper subsoil; the reverse process, that of silica removal is thought to be dominant. Elemental silicon is slightly soluble at pH levels near neutral, while iron and aluminium, also manganese, become increasingly insoluble at levels exceeding pH 6.5. This possibly accounts for the dark

Soil Families  
Brown Forest Group

ferro-manganese(?) mottles commonly present in the lower B horizon, and may partially explain the decreasing amount of quartz sand with depth (one profile). No confirmatory silica/sesquioxide analyses are available. It is also possible in these conditions for illitic or montmorillonitic clay to form.

The effect of vegetation on soil formation is difficult to establish and while it is clear that the vegetation community on Brown Forest soils is different from that on the Red-Yellow Podsollic soils, for instance, it is not known whether it maintains a passive or active role. It is established, however, that the litter of the vegetation is only slightly to moderately acid, and rich in plant nutrients. It seems probable therefore that the litter helps to maintain a weakly acid soil environment aided by a microbiological population that will be quite different from that of the strongly acid, raw, mor-like humus of the podsolised soils.

DISTRIBUTION OF BROWN FOREST SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Brown Forest soils are mapped mainly at Subis as the Kabuloh-Rock Association as shown on Map 4.

In the Kabuloh-Rock Association Kabuloh soils tend to be dominant in association with small patches of bare limestone rock containing Kapor Family organic soil (p.135). At Subis the association has been examined at four sites around the mountain where it occupies foothill screes. Air photograph interpretation has been used to delimit similarly sloping foothills in the remainder of the mapping unit. The other areas mapped, at Luak, the upper Penirak Stream, the upper Mulis Valley and in the Galasah Valley are small in extent and drawn schematically as there are no distinctive air photograph features to facilitate their mapping. It is highly probable that many other small areas exist, particularly within areas underlain by the argillaceous rock formations (p.31). Thus, although small in extent the individual areas of Brown Forest soils would add up to a great deal more than the 1,100 acres mapped.

This soil association occupies areas of karst (p.40) and low hills (p.38) underlain by limestone or rocks rich in calcium (p.31). The natural vegetation is a specialised kind of Lowland Dipterocarp Forest (p.50) that has only been removed for the cultivation of hill rice in the Penirak area. The association occurs in both the Karst (p.21) and Low Hill (p.19) Photo-association.

AGRICULTURAL VALUE OF BROWN FOREST SOILS

The main limitations to cultivation of the one family in this group in the area are not serious. In places there is known to be restricted rooting depth, for example, at Subis where limestone outcrops are common, and at Mulis (Suai) where hard limestone occurs at less than 24 inches from the surface. Slope is only a limiting factor on the karst scree slopes of Subis. Physically, the Kabuloh soils resemble those of the Merit Family (p.68) and it is possible that sensitive plants may suffer from drought during prolonged dry periods. (p.29).

TABLE 36. AVERAGE ANALYSES OF SEVEN BROWN FOREST SOIL PROFILES.

Horizon	pH (H <sub>2</sub> O)	Exch. Ca (m.e. %)	'Res' Ca (%)	Exch. Mg (m.e. %)	'Res' Mg (%)	C.E.C. (m.e. %)	Base sat. (%)	Org. C (%)	CaCO <sub>3</sub> (%)
A1	5.5 <sup>7</sup>	25.7 <sup>6</sup>	0.7 <sup>1</sup>	1.5 <sup>6</sup>	0.5 <sup>1</sup>	29.9 <sup>7</sup>	74 <sup>6</sup>	4.0 <sup>5</sup>	0.14 <sup>1</sup>
A/B	5.2 <sup>7</sup>	17.9 <sup>6</sup>	0.5 <sup>1</sup>	0.8 <sup>6</sup>	0.4 <sup>1</sup>	26.5 <sup>7</sup>	69 <sup>6</sup>	1.7 <sup>3</sup>	0.16 <sup>1</sup>
B2	6.4 <sup>7</sup>	28.0 <sup>6</sup>	0.6 <sup>1</sup>	1.3 <sup>6</sup>	0.4 <sup>1</sup>	26.5 <sup>7</sup>	86 <sup>6</sup>	1.0 <sup>3</sup>	0.07 <sup>1</sup>
B22	6.8 <sup>5</sup>	29.6 <sup>4</sup>	0.5 <sup>1</sup>	0.4 <sup>3</sup>	0.4 <sup>1</sup>	25.0 <sup>5</sup>	89 <sup>6</sup>	0.8 <sup>3</sup>	0.6 <sup>1</sup>
B3	7.5 <sup>1</sup>		2.7 <sup>1</sup>		0.5 <sup>1</sup>	39.1 <sup>1</sup>		0.4 <sup>1</sup>	
C1	7.7 <sup>1</sup>		9.8 <sup>1</sup>		0.7 <sup>1</sup>	20.4 <sup>1</sup>			
C2	7.4 <sup>1</sup>		9.6 <sup>1</sup>		1.0 <sup>1</sup>	15.6 <sup>1</sup>			

Note:- C.E.C. values may be too low in A1 to B22 horizons.  
 Number of samples shown by elevated numbers.  
 Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Soil Families  
Brown Forest Group

The topsoil, in some places at least, is superior nutritionally to most Merit Family soils (c.f. Table 37 and Table 9, p. ), in that it is less strongly acid and, despite a rather weakly developed Al horizon contains high concentrations of 'reserve' calcium, magnesium and potassium. It is probable that there is more than sufficient available calcium for most plants and possibly of magnesium. Nitrogen values are medium and also phosphorus levels are possibly adequate. In the subsoil, increasing concentrations of calcium almost saturate the moderately high exchange capacity (Table 36) and free calcium carbonate is known to be present in some profiles. The over-abundance of calcium may depress the ability of some plants to take in other essential nutrients, such as potassium. (Bailey, 1966).

Table 37. Showing analyses of the top six inches of Kabuloh Family soils from Luak Experiment Station, from two 1/10 acre plots sampled on a grid pattern.

No. of samples	Level	pH (H <sub>2</sub> O)	Total P (%)	'Res' Ca (%)	'Res' Mg (%)	'Res' K (%)	Total N (%)
18	Low	4.3	0.02	0.2	0.2	0.4	0.28
18	High	6.3	0.05	1.0	0.5	0.7	0.64
18	Average	5.8	0.04	0.6	0.4	0.5	0.4

Note:- 'Reserve' levels are those between total and available figures.

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Because of the few restrictions to cultivation, it is thought that Kabuloh soils can be used for a wide crop range, with the possible exception of those intolerant of alkaline, calcium-rich soil conditions. Vegetables, small fruit trees and other shallow-rooted crops such as palms may be more successful than, for example, rubber and coffee, both of which exploit a greater volume of soil. Currently, experiments are being made on oil palm nutrition on these soils at Luak (Appendix A).

SOIL FAMILIES OF THE RECENT ALLUVIAL GREAT SOIL GROUP

Recent Alluvial soils are common in the upper reaches of some rivers in the area, and along the most recent strandline at the coasts. Only the Kayan and Kabong Families are mapped, although it is probable that others occur in places. The main features of the two families are described below, also their genesis and distribution in relation to the environment.

Table 38. The diagnostic features of Recent Alluvial soils in the Bekenu-Niah-Suai area.

ORIGIN OF PARENT MATERIAL	TEXTURE OF TOP 20" MINERAL SOIL	SOIL FAMILY
Riverine	Light-textured	KAYAN
Marine	Light-textured	KABONG

Elsewhere in Sarawak four other families are differentiated, on the diagnostic features headed above as well as on the basis of soil colours.

Soil Families  
Recent Alluvial Group

1. KAYAN FAMILY

Kayan Family soils characteristically are deep, well-drained yellowish sandy loams to sandy clay loams containing lenses of contrasting texture. Detailed descriptions and analyses of a typical Kayan Family soil are given in Appendix B25. They resemble in many respects soils of the Semilajau Family (p. 69).

Surface O horizon material is generally thin or absent and the Al is only weakly developed in most places. Lower horizons consist of deposition sequences of varied thickness with no distinguishable A or B horizon properties, unless there is a buried Al horizon. Successive horizons beneath the Al, therefore, are designated, for example, A/B, C, IIA1, IIC, IIICg.

Moist soil colours are predominantly yellow beneath dark-coloured, organic-rich surface material. Pale yellow matrix colours are also common as are yellowish brown shades. Light grey to yellow mottling may occur in the deep subsoil and the characteristic light grey of gleyed soil may be present at even lower depth.

Textures of the Kayan Family are by definition light-textured in at least the top 20 inches of mineral soil, if heavier the soil qualifies for the related Seduau Family. It is normal in the Bekenu-Niah-Suai area, however, for the deposition sequences to range between sandy and sandy clay loam throughout the profile. Clay loam and clay are rare. Inclusions of stones of any description have not been recorded in Kayan soils of this area. Soil consistence in the family is characteristically loose to friable; structure has not been recorded. Roots are dominant within the top 12 inches of soil, although some large roots penetrate to much greater depths. Internal drainage ranges from imperfect to good; external drainage is slow to medium.

Chemical analyses show the soils to have a low cation exchange capacity beneath the Al horizon, and low base saturation. Available phosphorus and total nitrogen figures are also low, an unfavourable combination resulting in low agricultural value. Mineralogical analyses of Kayan soils have not been made, but since they are found in valleys draining sandstone-rich areas containing Red-Yellow Podsolc soils of known composition (p.72), they can justifiably be described as quartz-rich. The clay fraction is probably dominated strongly by kaolin.

2. KABONG FAMILY

Soils of the Kabong Family are characterised by pale colours, coarse textures and low fertility (Plate 52). Detailed descriptions and analyses of a typical soil are given in Appendix B26.

The profile consists of scattered litter overlying a weakly developed Al horizon which in turn rests on a deep A2/B horizon. There is a rapid change to Cg horizon basal material at depths between 2 and 5 feet.

Soil Families  
Recent Alluvial Group

The soil colours are invariably low in chroma. Where an A1 horizon is present it is a dark greyish brown in which clean transparent quartz grains are visible. It changes abruptly to pale brown or light greyish brown A2 or B horizon material in which individual sand grains range from black to colourless reddish brown and white. Coarse reddish brown to brown mottles are present in places towards the base of the B horizon. The change to the Cg is abrupt and marked by a colour change to light grey or olive grey. Bluish shades have been noted in places. Some Kabong soils contain black organic lenses.

Textures of the Kabong Family soils are restricted entirely to sands and loamy sands. The A1 horizon may be a loamy sand but beneath, there is so little clay or humus that the soil consists virtually entirely of sand-sized material. The only exception is where thin lenses of organic beach debris occur, but this is rare. Horizons rich in shell fragments are known in places, and coral forms coarse inclusions at Cape Payong.

The consistence is loose to very friable, structure is single grain, except in the topsoil where moist soil exhibits a weak fine crumb structure. Roots are most common in the top 12 inches but many penetrate as far as the water table which lies within the Cg horizon. Internally the drainage is excessive to good, externally it is slow or very slow.

Analyses of one Kabong Family soil reveals that the base exchange capacity is less than 1.30 m.e.%, and the base saturation is equally low; elsewhere high calcium levels reflect the presence of shells in the subsoil. Phosphorus and nitrogen levels are both very low. The pH ranges from pH 3.5 in the topsoil to pH 6.8 in the subsoil, the high figures being due to the low buffer capacity; the Group III percentage is among the lowest of the soils in the area. Mineralogical analyses have not been made but the sand fraction is assumed to be quartz-dominated.

DIFFERENTIATING FEATURES BETWEEN RECENT ALLUVIAL SOILS.

The essential difference between the two rather similar Kayan and Kabong soil families is based on their origin. While the Kabong soil is formed in recent marine sediments and is characteristically uniform with depth, the Kayan soils are developed in riverine sediments and retain the mark of successive additions to the profile in times of flood as deposition horizons. The Kayan soils are slightly heavier textured, and are periodically replenished with flood material which gives them an enhanced fertility status by comparison.

GENESIS OF RECENT ALLUVIAL SOILS

In both families of the Recent Alluvial soil group the soils owe their characteristics to the process of alluviation, in which water-borne sediments successively accumulate during times of flood or storms.

Soil Families  
Recent Alluvial Group

In the case of the Kayan Family the accretion of fresh alluvium varies in character at any one site with the intensity and duration of flooding. The greater the rainfall, the greater the amount and velocity of floodwater and the coarser the grade of material transported. Kayan soils occupy upriver levees well above the limit of tidal influence; they are light-textured and the floods that cause the greatest accumulation in these sites are flash floods in which the water rises rapidly to well above levee level for three or four days at the most. As far as known, such floods occur generally three or four times a year; and each may be responsible for eroding an inch or so of the topsoil and the redeposition of a similar amount of new material. At some sites more is removed than deposited, such as on the outside bend of a meander.

The freshly deposited sediments have a rhythmic pattern, best seen in the headwaters of an area draining coarse sandy soils as in parts of the Lambir Hills. Individual horizons have coarse grade material at the base, steadily becoming finer towards the top of the layer. Older deposits tend to have lost this distinction after the leaching downwards of clay-sized material. Adjacent horizons normally contrast in texture, or colour or organic content, or all, sufficiently clearly to be distinguished in the field. The degree of contrast, however, is rarely such that clays underlie sands; it is normally a sequence of sands on sandy clay loam.

Kayan soils only occur in valleys of streams draining area with predominantly arenaceous soils, as in the Suai-Nyalau area; they are never found in land of low relief, even though sandstone is a common rock type, for example, in the lower Sibuti. The equivalent sandy soil in these areas is the Semilajau Family (p.69). The two families grade barely perceptibly into each other, and it is often an arbitrary decision on just where in a valley the processes of podsolisation are sufficiently marked to justify classing a soil as Semilajau. Similarly, the distinction is fine between some clayey Red-Yellow Podsolitic Malang soils and the Recent Alluvial, heavy textured Seduau soils. The Seduau Family is not mapped in the area but probably forms a minor part of associations containing Malang soils.

As the Kayan soils are essentially young the process of clay, base and sesquioxide leaching by definition is minimal, although soil conditions, such as texture, drainage and permeability are favourable for it. It is probable that, unlike with the Semilajau soils, the effect of flooding is felt as much in erosion as in deposition, and that the soils are disturbed regularly much more, otherwise the physical processes at least of podsolisation would be much more evident.

Kabong Family soils occur at the coast on the most recent strandline. They do not show signs of poor sorting as the Kayan soils do, possibly because the beach material is so uniform in grade. The only perceptible sign of soil formation is in weak, coarse reddish mottles close to the watertable, and in gleization below the water table. The initial amount of clay in the soil is so small that the laching of it all would scarcely be noticeable, and clay formation from mineral breakdown is negligible. The mottling indicates mobilization of iron compounds, and in places, where brown,

Soil Families  
Recent Alluvial Group

the downward leaching of humus. Associated soils belong to the Buso Family and these represent the penultimate step in podsolisation of Kabong soils before the Miri Family podsoils are formed. The sequence takes place in a short time as Miri soils can be found in some areas within a few hundred feet of the coast (Niah River mouth, Map 4).

Kabong Family soils occur on the youngest beach, which is almost invariably the highest strandline. It is not certain whether the height of the beach is due to the older beaches further inland being gradually flattened by the impact of rain, or whether the increasing height of beaches towards the coast represents a gradual elevation of the sea level, or both. The origin of the sand has been discussed in the section on topography. (p.44 ).

Shell beds within the profile are uncommon on this part of the coast of Sarawak, but appear to accumulate on the beach at intervals. They are incorporated into the profile intact after strong winds, for example, drift dry sand over them. The movement of wind-blown sand on the shore may be considerable, and is commonly sufficient to bury large logs under 2-3 feet high dunes (Plate 53). The presence of vegetation effectively minimizes this process onshore. Similarly, peat-like lenses in Kabong soils are the result of the covering of banks of comminuted drift-wood, leaves, fruit husks and other organic debris. These tend to occur particularly close to large river mouths.

DISTRIBUTION OF RECENT ALLUVIAL SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Kayan soils are only found in the headwaters of streams flowing from hilly areas having widespread sandy soils, such as in the Lambir Hills, and the upper Niah River area. They occupy narrow levee sites, particularly on inner meander bands (p.36 ); the material they form in is recent, sandy riverine sediments (p.31 ) and they support Riparian Forest (p.48 ) commonly inter-planted with edible fruit trees. They occur within the Flood-plain Photo-association and in narrow valleys within the Ridge and Cuesta photo-associations.

Kabong soils have an equally distinctive environment, being restricted entirely to the present shoreline (p.36 ). They have developed in recent marine sand (p.31 ) and support a specialised Littoral Forest (p.47 ), in places cleared for grazing or the cultivation of water melons. Kabong soils are only found in the Beach Photo-association. (p.16 )

AGRICULTURAL VALUE OF RECENT ALLUVIAL SOILS

Soils of the Recent Alluvial group have a limited agricultural usage, mainly because of features that are associated with the predominantly sandy textures, namely low fertility and bad drainage properties.

Agricultural Value of Kayan Family soils.

Flooding of Kayan soils, although an impediment to the cultivation of low-lying crops, such as vegetables, does at least add fresh supplies of nutrients with each flood, both in solution in the floodwater and in suspension as organic and mineral particles.

Soil Families  
Recent Alluvial Group

To judge by the thickness of sand bands in the profile the floods consist of rapidly moving water capable of depositing layers of from one to ten inches thick at a time. Only sturdy bushes and trees could survive these conditions. Apart from such temporarily waterlogged states the soils tend to be somewhat excessively drained, and in prolonged dry spells sensitive, shallow-rooted crops might be harmed.

The topsoil is the richest part of the profile, although analyses of one profile in the middle Suai River valley show the exchangeable nutrient levels to be almost certainly inadequate for most crops. The subsoil levels are even lower, and in the same profile the extremes of the cation exchange capacity of 0.9 to 7.7 milli. equivalent percent are only saturated from 20 to 3 percent respectively. This reflects poorly on the amount of nutrients added by flood water, unless the interval since the last flood was long. The low exchange capacity and the readily permeable soil do little to prevent thorough leaching and any added fertilisers will need to be given as frequent doses. 'Available' phosphorus in the subsoil is virtually absent.

The most suitable crops for these extremely depleted and flood-prone soils are deep-rooted trees such as local fruit trees, rubber, coffee and possibly bananas, coconuts and citrus. All crops will require plentiful additions of the appropriate fertiliser for optimum yields.

Agricultural Value of Kabong Family Soils.

Flooding does not occur on Kabong soils, and neither therefore is there any periodic addition of nutrients from flood water. It is believed, however, that as they are found on the immediate coastline a certain amount of mineral salts is added periodically from sea spray. The soils are even more permeable, weakly structured and loose than those of the Kayan Family described above, consequently rainwater leaching is maximal. Plants sensitive to drought may be affected adversely on the deepest soils during the occasional long dry periods (p. 29) that seem to be common on the littoral. The water table is fresh almost immediately behind the coastline.

Levels of nutrients in Kabong soils range from extremely low in most, to moderately high in a few- at least in calcium and magnesium. Examples of the extremes are given in Table 39. Kabong soils near the Nyalau river mouth seem to be richer in shell remnants than elsewhere, and it is suspected that the thin band of Kabong soils at Cape Payong will have high calcium levels as coral fragments have been noted on the beach. Even the depleted soil in Table 39 has high base saturation figures because of the extremely low exchange capacity. Kabong soils will be difficult to fertilise because of this feature. Phosphorus levels are almost certainly inadequate for most crops.

The only crop seen growing satisfactorily on the poorer Kabong soils is water-melon. With adequate fertilisers, however, it should be possible to grow coconuts, vegetables, groundnuts and some fruit trees but the cost of fertilising would almost certainly be prohibitive. Light grazing by goats able to live on the coarse grasses may be the only use to which the soils can be put. It is thought that the grass quality is too poor for cattle, although some small herds graze on poor, scrubby pastures on Kabong soil and Tatau soil between the Sibuti River mouth and Cape Bungai.

Table 29. Showing the contrast in levels between a shell-rich soil (Nyalau River mouth) - 428/83, and a depleted soil (Niah River mouth) - 427/84.

Lab. No.	Depth (ins)	pH (H <sub>2</sub> O)	Total N (%)	C.E.C. (m.e.%)	Base sat. (%)	Exch. cations milli. eq. %			Texture	
						Ca	Mg	K Na		
4279	0-5	5.9	0.03	0.42	100	3.7	0.9	0.05	0.2	sand
4280	5-8	5.5	Tr	1.0	76	0.5	0.1	Tr	0.08	sand
4281	8-20	5.9	Tr	1.0	64	0.4	0.1	Tr	0.05	sand
4282	20-42	6.0	Tr	0.7	100	0.4	0.2	Tr	0.06	sand
4283	42-49	5.5	Tr	0.6	90	0.4	nil	0.02	0.07	sand
4284	49-55+	3.5	Tr	3.0	50	0.7	0.7	0.04	0.07	sand
4285	0-5	6.8	Tr	1.05	100	1.8	0.6	0.1	0.4	sand
4286	5-13	7.6	Tr	0.85	100	7.9	0.4	0.04	0.3	sand
4287	13-26	7.8	Tr	0.70	100	12.5	1.2	0.03	0.4	sand
4288	26-30+	8.0	Tr	0.75	100	34.1	2.4	0.04	0.5	sand

Analyses by Agricultural Chemist and Staff, Department of Agriculture, Sarawak.

Soil Families  
Skeletal Group

SOIL FAMILIES OF THE SKELETAL GREAT SOIL GROUP

Only two of the six Skeletal soil families classed in Sarawak are known to occur in the Bekenu-Niah-Suai area, but of those two the Kapit Family is particularly widespread; the Meluan Family only occurs in small areas largely in the middle Niah basin and on the Lambir Hills. The main features of the family are described below, the differences between them outlined and their genesis and relationship with the environment discussed.

Table 40. The diagnostic features separating Skeletal soil families in the Bekenu-Niah-Suai area.

TYPE OF HORIZON BENEATH A OR B HORIZONS	SOIL FAMILY
R horizon	MELUAN
C horizon	KAPIT

Elsewhere in Sarawak the origin of the parent material, the soil drainage and the total phosphorus content of the fine earth are diagnostic features used to separate these from other families of the group.

1. MELUAN FAMILY

Meluan Family soils consist essentially of brownish loams or clays, overlying hard rock. They are well drained and extremely shallow. Analyses of Meluan soils from this area are not available. An augering description is given in Appendix B27.

The surface generally is covered by thin to deep litter and humus and rests directly on a moderately deep, well-rooted A1 horizon. In this area this is a brownish sandy loam to clay loam commonly stony and friable. The underlying soil consists of a few inches of loose to friable, pale to yellowish or brownish sand to clay commonly containing shale or sandstone fragments, and which generally gives way abruptly to hard rock. The rock is believed to be sandstone in the Lambir Hills, or probably limestone in the limestone-rich Subis area; Brown Forest soils overlying limestone characteristically have a sharp B/R transition (p.137). External drainage is slow to rapid, internal drainage is good as deep as the R horizon.

In the Lambir area the soils may consist of miniature podsols (p. 92) and podsols of normal depth. Although this area has not been examined in the field the air photograph characteristics of the cuesta dip slopes strongly resemble those of closely similar land. Elsewhere in Sarawak (Wall, 1964) and on this basis, they are mapped as an association of Meluan and Podsol soils.

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2. KAPIT FAMILY

Kapit Family soils are brownish stony loams to clays overlying soft weathered rock. They are extremely shallow and well drained.

Surface litter and humus are generally scattered or absent. The Al horizon is two or three inches deep in places and consists of dark-coloured loamy well-rooted soil, that is friable and has weak crumb structure. Beneath, is yellowish stony clay loam or clay, rarely sandy clay loam that becomes C horizon material within a few inches of the surface. Unlike the Meluan soils, however, the C horizon can be augered into and it is presumed that roots can also penetrate such material. The weathered rock is predominantly shale or sandy shale. It is rare for Skeletal soils to develop over the soft sandstones of this region. External drainage is generally rapid, internal drainage is good.

DIFFERENTIATING FEATURES BETWEEN SKELETAL SOIL FAMILIES

The only significant difference between the Meluan and Kapit soil families is in the hardness of the parent material. The division between soils developed over soft, augerable rock and hard bedrock is made primarily on the assumption that Meluan soils are of extremely limited agricultural value due to restricted rooting depth, while the Kapit soils could be used in some circumstances for some crops, the rooting depth being less severely restricted. In most other aspects the colour, texture, structure and chemical range of the two families is similar.

GENESIS OF SKELETAL SOILS

Both Meluan and Kapit soils are characterised by being unusually shallow, and this feature is believed to be due to a combination of lithology and erosion.

The rocks identified beneath practically all Skeletal soils in the Bekenu-Niah-Suai area are either limestone or shale, less commonly sandstone. The limestone is generally pure, impervious and hard, and some shales, particularly sandy shales, seem to be more resistant to erosion than most. This may be due to chemical or physical properties, or both.

In addition, Skeletal soils are found typically on steeply sloping land exceeding  $35^{\circ}$  on which surface erosion can be expected to be pronounced (p.46). Land with many slopes exceeding about  $35^{\circ}$  is indicated by overlay shading on the soil map (Map 4). They have also been found, however, in the upper Niah Valley land as thin veneers of alluvium overlying shale, and in the Mulis (Suai) area overlying limestone. Such soils belong to the Binatang Family but have not been described further because of their small distribution. They represent areas in which former stream erosion created a rock platform which subsequently was covered by a spread of alluvium during floods.

Landslides create Skeletal soils, and those are particularly common in the Lambir Hills, where scarp slopes are almost entirely formed in this manner. Sandstone outcrops there are common, and it is suspected that even higher dip slopes contain Skeletal soils, being underlain by hard sandstone. The bare limestone rock at Subis is mapped as an association with thin Calcic Organic soils (p.134), most of which are less than ten inches deep, but which are classified separately because of their unusual properties.

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DISTRIBUTION OF SKELETAL SOILS AND THEIR RELATIONSHIP WITH THE ENVIRONMENT.

Skeletal soils are predominantly confined to higher dip slopes and steeply sloping hills in the Lambir Hill range extending southwest towards Cape Batu, on steep ridges in the upper Sibuti - Upper Niah area, in narrow belts between the Niah and Suai rivers, close to Niah Village and in parts of the land between the Suai and Nyalau rivers. They occur in association with Red-Yellow Podsolc soils as small, linear patches rather than extensive areas, except possibly in the Lambir Hills where they may occur large parts of dip slopes in association with podsol. (p.92 ).

The associated topography ranges from gentle dip slopes to cliffed ridges (p.39 ) (Ashton, p.24-25), the parent materials range from arenaceous rocks and limestone (p.30,31) and the vegetation is either Lowland Dipterocarp Forest, Limestone Forest, or Heath Forest. Skeletal soils are rarely used for cultivation. They were found to occur in the Low Hill, Ridge, Cuesta and Karst photo-associations.

AGRICULTURAL VALUE OF SKELETAL SOILS.

Soil depth and slope are the main limitations to the cultivation of Skeletal soils in this area. Depth is the least important for Kapit Family soils, and slope for Meluan Family soils.

Agricultural Value of Meluan Family Soils.

Generally, soils of this family are found on slopes of less than about 20°, on dip slopes of cuestas and on ridge summits. Slope therefore is not a severe obstacle to cultivation, although as the soils are predominantly sandy, it is possible that gully erosion could develop in favourable circumstances such as after clearing of the forest cover. The underlying rock is hard and forms an effective barrier to rooting.

Meluan soils on the Lambir Hills are believed to be strongly leached and probably podsolised to the extent of having a humus pan resting on the hard rock. They are infertile therefore (c.f. Bako Family, p. 99 ) and would present severe problems in fertilising.

Because of their extremely poor physical and chemical status Meluan soils cannot be recommended for cultivation and should be left under their natural Heath Forest cover.

Agricultural Value of Kapit Family Soils.

Although shallow, Kapit soils are not too full of rock fragments in the C horizon for roots to penetrate. The presence of much fresh shale and sandstone, however, does restrict the volume of soil available for roots to feed on. Slope is a more difficult limitation, as most Kapit soils are found on the flanks of steep ridges exceeding 30°, and many on slopes of more than 60°. Thus, although the soils may be acceptable nutritionally, there being a continuous release of nutrients from weathering rock, it would be quite impracticable to cultivate them, particularly in view of the erosion hazard in, for example, the Lambir Hills. If Kapit soils are found on gentler slopes then it may be possible to plant them with rubber.

A report is given below of the type and development of agriculture in the Bekenu-Niah-Suai area since 1963 when a reconnaissance soil survey report (Wells, 1963) indicated the presence of large areas of land suitable for development. During that year, agriculture in the area was replanned under the First National Five Year Development Plan (Government of Sarawak, 1963). The state of agriculture in 1963 is described briefly as practiced by racial communities. For simplicity, the descriptions of agriculture and the soil divisions have been simplified and the production figures reported, but treated as good yields rather than accurate yields. This is encouraged by a crop-by-crop approach of the state in improving agriculture under the Government in the light of available information on soils. Finally, the probable trends of agricultural development in the area are outlined.

AGRICULTURE IN THE BEKENU-NIAH-SUAI AREA IN 1963.

It is estimated from the 1963 national census (Jones, 1964) that the population of the area in 1960 was approximately 18,000, of whom 85% were engaged actively in agriculture. There was a high degree of occupational diversity, and as such within agriculture there were several racial groups, (Iban, Melanau (including some Kayan and Bidayuh), Pagan, and Chinese, make up about 90% of the population of the area. Their characteristic methods of agriculture are quite distinct and are described

PART SIX

RECENT AND PROSPECTIVE AGRICULTURAL DEVELOPMENT IN THE BEKENU-NIAH-SUAI AREA.

Since 1963, displaced longshoremen in the upper and middle reaches of the Rajahmundry river systems, the tribes of the Rajahmundry river system (May 1963). They moved into the lower reaches of the Rajahmundry river system largely between 1963 and 1969.

The agriculture in 1963 was based on hill rice, shifting cultivation. This entailed the selection of an area of about three acres of primary or healthy-looking secondary forest, the clearing of it in June to July when the Dipterocarp appears and the planting of rice seed by digging stumps in the soil when the Dipterocarp are at the height. There was special attention until harvesting in April. After harvest, the crop clearing was of the forest floor and the vegetation.

Secondary growth in forest repeatedly in successive years, the primary forest for the rice resistant species, the primary forest, and with which many plants have increased in abundance, had not spread so extensively in this area as parts of West Sarawak and neighbouring Indonesia.

An account is given below of the type and development of agriculture in the Bekenu-Niah-Suai area since 1963 when a reconnaissance soil survey report (Wall, 1962) indicated the presence of large areas of land suitable for development. During that year, agriculture in Sarawak was replanned under the First Sarawak Five Year Development Plan (Government of Sarawak, 1963). The state of agriculture in 1963 is described briefly as practiced by racial communities. Of necessity, the descriptions of agriculture and the racial divisions have been simplified and the production figures are probably best treated as good guides rather than accurate figures. This is succeeded by a crop-by-crop appraisal of the progress in improving agriculture made by Government in the light of the available information on soils. Finally, the probable trends of agricultural development in the area are outlined.

#### AGRICULTURE IN THE BEKENU-NIAH-SUAI AREA IN 1963.

It is estimated from the 1960 national census (Jones, 1962) that the population of this area in 1960 was approximately 18,000, of which about 85% were engaged entirely in agriculture. There was a strong racial division in occupation, and as much within agriculture as outside. Four racial groups, Iban, Kedayan (including some Malays and Muslim Kedayans), Punan, and Chinese, made up about 90% of the population of the area. Their characteristic methods of agriculture and crops grown were quite distinct and are described below.

#### IBAN AGRICULTURE

The Ibans in 1963 occupied longhouses in the upper and middle reaches of the three main river systems, the fringes of the Bakong River swamp and the lower Nyalau River system (Map 16). They moved into the area in groups from overfarmed parts of West Sarawak largely between the 1920's and 1950's.

Iban agriculture in 1963 was based on hill rice shifting cultivation. This entailed the selection of an area of about three acres per family of primary or healthy-looking secondary forest, the felling and burning of it in June to July when the Pleiades appear at the horizon and the planting of rice seed by digging stick in August to September when the Pleiades are at the zenith. There was token weeding and superficial attention until harvesting in April. No fertilisers were used, the crop deriving most of its food from the ash of burned vegetation.

If secondary growth is burned repeatedly in successive years, there is a strong tendency for the fire resistant Imperata cylindrica to spread, eventually forming a sheet cover that is extremely difficult to eradicate, and with which woody plants have difficulty in competing. Imperata has not spread so extensively in this area as in overfarmed parts of West Sarawak and neighbouring Indonesia (Sinyagin, p.276).

Average rice yields in the area are estimated to have been between 500 - 1,000 lbs per acre (c.f. Freeman, p.98: 260 - 1,380 lbs/acre from pioneer areas). Experiments in Sarawak at this time showed that by using ammophos fertiliser such yields could have been increased by as much as 70% (Department of Agriculture, 1964, p.14-15). In the following season rice was planted in a newly selected area, the fallow period for any one piece of land ranging from as little as one year on good soil to as much as 15-20 years on poor soils. In 1960, there was an estimated 3,500 acres of hill rice in Miri Rural District - consisting of rather more than the Bekenu-Niah-Suai area (Sarawak Census of Agriculture, p.16) and about 5,700 acres in 1963 (Agricultural Officer's 1964 Annual Report). The extent of secondary forest in 1963/64 is shown on Map 17, as analysed from air photographs: almost all the upriver areas is regrowth from shifting hill rice cultivation.

The soils were chosen basically by the quality of the forest they supported. Those preferred for hill rice were the more fertile loams to clays bearing good forest such as those classed in the Merit Family. The sandier Bekenu and Nyalau soils generally found on high steep hills, such as in the Lambir and Suai-Nyalau areas have poorer forest and were only used if no better soils were available. Although better drained, such sandy soils are inherently less fertile and are less able to retain plant food; in addition, they are prone to gulying and landslides. In the most densely populated Iban areas, such as in the lower Saeh (Niah) basin, the long wide belts of Merit soils were extensively used, whereas the peats, podsols and neighbouring high steep hills were generally avoided (Map 4).

The rice crop was supplemented by interplanted maize and by various tubers, sugar cane, wild fruit, and vegetables. Cash crops were relatively unimportant. One source of cash in 1963 in parts of the Sibuti and Niah Iban areas was coffee (Coffea robusta) grown haphazardly and unfertilised in groups of 5-30 trees on well-drained Malang and Semilajau Family soils. These levee soils, although in some respects richer than Merit soils, were avoided for rice cultivation due to the risk of periodic flooding. Additional cash was derived at irregular intervals from the sale of wild edible fruit, such as durian and rambutan, and from products for export such as jelutong sap (for chewing gum) and illipe nuts, whose oil is used in the confectionery industry.

Small gardens of poorly maintained seedling rubber were kept in the Niah and Sibuti river Iban areas (Map 17) and estimated at 5,000 acres by all races in 1960 (Sarawak Census of Agriculture, Table 11). These gardens were situated close to the Iban longhouses (for ease of access) on the well-drained levee soils of the Malang and Semilajau Families, and in many places spreading on to the poorly drained Bijat and Sebandi Family soils in adjoining basins. Rubber, although growing reasonably well on the poorly drained Bijat soils generally grows faster and gives higher yields on the well-drained residual hill soils but the latter were only used as a rule if they were in the immediate vicinity of the longhouses.

By 1963, a small number of Iban farmers in the Niah and Sibuti river systems had joined the Agriculture Department's Rubber Planting Scheme 'A' (probably less than 500 acres, op.cit.) This scheme, initiated by the Department in 1956, provided rubber of proved stock from nurseries, subsidised fertilisers, weedicides, pesticides and cash grants. The farmer was expected to maintain his garden to the

standards of weeding and terracing set by the Department, which undoubtedly seemed harsh to those who formerly had padi scant attention to anything in their rubber garden but the actual tapping. The selection of land for R.P.S. 'A' gardens had to be approved by Departmental Staff, which ensured that steep hills and the worst sandy or badly drained soils were avoided.

Thus, in 1963, the Ibans were still predominantly engaged in subsistence agriculture over large areas, although a few progressive farmers were cultivating the 'new' R.P.S. rubber. They generally made use of the better soils if available but in a relatively unproductive and unenlightened way. Retarding the progress of the Ibans was the fact that their life and religion were traditionally bound tightly to the time- and labour-consuming shifting hill rice cultivation (Freeman, 1955) and older people in particular were loathe to try growing swamp rice, for example, despite knowing that yields per acre are almost invariably higher. The coffee, fruit and even rubber gardens were considered more as convenient extensions of the forest in which to harvest produce periodically, than as potential sources of income. The reliance on small, occasionally navigable streams for communication in the upper river systems also hampered the spread of improvements and prevented the export of perishable produce (Fisher, p.675).

#### KEDAYAN AND PUNAN AGRICULTURE

The Kedayans (including some Malays, and Kedayans of muslim faith who prefer to be called Malays) in 1963 formed an important segment of the population. They were farmers or fishermen and lived in small riverside villages in the lower Sibuti River basin and on smallholdings in the hilly coastal area north of the Sibuti and Setap rivers (Map 16). In 1963, the Kedayans in the river basins lived mainly by swamp rice cultivation. In the Kelulit, Ranchah and Tiris areas, buffalo sold live to the market at Miri provided extra cash for a few farmers. The animals grazed free range on communal scrubland. Hill rice was grown in a few areas, such as near Luak and Beraya, but only because of the absence of suitable swamp land. Punans inhabited the middle and lower Niah and Suai rivers. They also grew swamp and hill rice as their staple diet. At the three main river mouths they lived in small villages among Melanaus and participated with them in coastal fishing. Some buffalo were kept in a similar fashion to the Kedayans in the Tangap-Niah area but were not used for ploughing in the wet rice fields.

The estimated acreage of wet rice land in Miri Rural District (slightly more than the Bekenu-Niah-Suai area) in 1960 amounted to 3,000 acres (Sarawak Census of Agriculture, p.15) and remained at 3,000 acres in 1963 (Agricultural Officers' 1963 Annual Report). In 1963 there were moderately large areas of old secondary forest on land formerly used for swamp rice cultivation, particularly in the lower Sibuti basin. The Japanese had made the Kedayans and Punans open up these and some adjacent areas of land for intensive wet rice cultivation during World War II. Controlled drainage and irrigation were initiated and yields of rice were reputedly higher than ever before in these areas, which collectively came to be known as the granary of northwest Sarawak. After the war the organisation of labour for clearing, planting and harvesting largely collapsed and the extensive networks of banks and ditches in many places fell into disrepair. The local need for rice was not great and with the absence of incentive many farmers gradually reverted to subsistence

farming; thus large areas of good rice land were left fallow or put to uncontrolled buffalo grazing. Despite this, 400 tons of unhusked, husked and brain rice were exported from the area in 1963, mainly from Kedayan-farmed wet rice fields in the lower Sibuti region (Agricultural Officers' 1963 Annual Report).

The system of wet rice cultivation used was to slash and burn the thick secondary growth of about 1.5 acres per family in June and July, and then to plant the seedling rice in August in puddled soil that had been roughly hoed and shallow flooded by the blocking of vestigial drains. With no manuring and minimal weeding and attention the crop was harvested in the following April. Fallow periods varied from one to three or more years (Lee, p.24). Despite the lack of rigorous cultivation the reported yields of 1,000 to 1,500 lbs. per acre were among the highest in Sarawak, but it is felt that this was more reflection of the good inherent soil fertility than of high standards of cultivation.

During the few years prior to 1963 the Department of Agriculture had shown that yields could be improved materially by introducing new strains, by controlling drainage and irrigation and by following the recommended way of planting and cultivation by hand, buffalo or machine (Department of Agriculture, 1964, p.14-27). The local response however was generally poor, perhaps due to the lack of incentive since more than sufficient rice for a family could be harvested from a small patch of the best rice land with a minimum of effort and trouble. Off-season cropping of the rice land for vegetables and tobacco was scarcely attempted; in addition there had been little response to the Government's introduction of an Assistance to Padi Planter's Scheme in 1959, aimed at improving rice yields by the initiation of wet rice cultivation under supervision, and the donation of cash subsidies for sluice gates and fertilisers.

The soils used by the Kedayans and Punans for swamp padi were poorly drained loams to clays of the Mukah, Sebandi or Bijat Families, or of the richer Pendam Family. These soils are dominant in the rice growing areas of the lower Sibuti basin and in the areas close to Niah and Batu Niah. Their inherent fertility is moderate to high and, provided untimely floods do not occur, good yields are common. The areas of deep, acid peat soils and shallow peat over sand neighbouring the alluvial basins were almost entirely avoided (c.f. Map 4 and Map 17).

Subsidiary crops grown by the Kedayans and Punans consisted mainly of bush and tree fruit planted haphazardly in small stands around homesteads. Small coconut groves had been planted on the leached, quartzose Tatau and Kabong Family soils at the river mouths and on the middle Sibuti River banks with an estimated 10,000 nuts being exported to Miri in 1963 (Agricultural Officers' 1962/63 Annual Report). Close to the Niah River mouth water melons were cultivated satisfactorily on these soils and sold in Miri (about 7,000 in a good season). Seedling rubber and pepper was cultivated on a small scale by a few Kedayans on the hills in the Kalulit (Sibuti) area.

#### CHINESE AGRICULTURE

Chinese settled first in the area at Sibuti (Plate 54) at the end of the nineteenth century, but were not present in large numbers until 1935, when the bazaars of Sibuti and Niah were built. The Batu Niah area is the latest to be settled by Chinese, the bazaar

being built in 1947. Bazaar dwellers are principally Hokkien, Chawan or Hailam, the farmers are almost exclusively Hakka (Kheh).

In 1963 the Chinese, apart from those grouped at Beluru, Bekenu, Niah and Batu Niah bazaars, cultivated smallholdings of less than about three acres in the general vicinity of the bazaars (Map 16). The farmers at that time grew mainly pepper supplemented by rubber, tobacco, vegetables and fruit, all as cash crops. Their livelihood was geared to the production of as much as possible from the smallest piece of land and can properly be described as intensive cultivation.

It is estimated that there were about 500 acres of pepper in the Bekenu-Niah-Suai area in 1960 (Sarawak Census of Agriculture, 1960, p.23) of which probably 95% were grown by Chinese. Pepper then, as now, was a particularly difficult crop to grow well. It requires well-drained, friable, deep soil, such as some Merit Family soils, is susceptible to nutrient deficiencies and diseases (De Waard, 1964; Holliday and Mowat, 1963) and needs careful pruning, weeding and terracing. The crop was planted from cuttings and trained to grow up supports to a height of 10-14 feet. It was grown intensively with about 175 vines per  $\frac{1}{4}$  acre garden. Flowering occurs from October to December but the blossom was removed for the first two years. Harvesting was normally from May to June with average good yields of 8,000 - 10,000 lbs. of green berries per acre. Most gardens in the Niah and Sibuti areas (Map 17) obtained moderately high yields and used liberal applications of guano (Haile, p.91-97) obtained from Niah caves. The soils used were all of the Red-Yellow Podsollic group. In the Niah and Batu Niah districts rather calcareous types of Merit Family soils are widespread and seemed favourable for the crop. In the Sibuti and Bakam areas however the sandier Bekenu and Nyalau Family soils were also used; these have lower inherent fertility but better drainage. Yields on these sandy soils were said by the farmers to be generally lower.

The farmers using sandy soils were generally not discerning enough to take extra precautions on fertilising and terracing, although by following recommendations on cultivation and fertiliser practices given by the Department of Agriculture consistently higher yields might have been ensured, (Department of Agriculture, 1964, p.27-41). The gardens on sandy soils were particularly susceptible to surface wash and gullying due to the practise of bare weeding.

Gardens of Chinese-owned seedling rubber existed in 1963 near Bakam in the north, Beluru, Bekenu, Sibuti, Niah and the Batu Niah areas, mainly on river bank soils and on low hills with Red-Yellow Podsollic soils near the Bazaars. A large block of R.P.S. 'A' rubber (1,200 acres) had been partly planted at Bakam and several other large gardens had also been planted on the Merit soils south of Sibuti, but all were immature in 1963. Tobacco was grown either as a pure stand or as an intercrop with pepper in the Niah-Batu Niah area before 1963 for a small tobacco factory at Niah. The factory produced tinted and perfumed cigarette tobacco for local sale. There were an estimated 30 acres under tobacco in 1963 (Agricultural Officers' 1963 Annual Report) but following the destruction of the factory by fire in 1960 the production dropped and barely met local demand. Tubers, vegetables and sugar cane, groundnuts and tree fruit were grown in small plots around the houses, for both home consumption and the local bazaars.

The Chinese, although not always selecting the best of soils for cultivation made the most intensive use of them. They would undoubtedly have spread farther afield had it not been for the restrictions of land settlement (Lee, p.28).

In 1963, therefore, the situation could be summarised as one of predominantly extensive subsistence agriculture by the Ibans, Punans, and Kedayans, interspersed with small pockets of intensive cash crop cultivation by the Chinese. While the Department of Agriculture had endeavoured by spread advice and give help on the cultivation of rubber, pepper and rice in particular, there was a good deal of suspicion and resistance to accepting advice from 'non-farmers' on the improvement of crops whose rather low yields the farmers had learned to accept as the norm. The general lack of communications severely hampered the extension of recommended practices to Ibans in remote headwater areas. Despite this however the farmers in almost all cases had chosen by trial and error and by imitation the soils most suited to the crops grown. Only in the most heavily populated parts were poor soils used.

#### AGRICULTURE IN THE BEKENU-NIAH-SUAI AREA SINCE 1963

In 1962 the Department of Agriculture issued a reconnaissance soil survey report (Wall, 1962) describing the same area as that in this thesis. The conclusions, summarised, were that of the 1,300 square miles surveyed about 54% was suitable for agriculture and a further 20% marginal. The remainder consisted of deep peat, saline soils, infertile podsoils, or steep hilly land. Large areas of the better land were still under primary forest and after timber exploitation would be eminently suitable for commercial crops, particularly rubber and oil palm. It is shown below that the discrepancies in achievement, between principally the Chinese and the other races are gradually being reduced and, that with the success of planned agricultural development, they will be removed entirely.

#### OIL PALM

The results of the reconnaissance soil survey were encouraging in view of the prevailing opinion at that time that large areas of agricultural land suitable for development did not occur outside parts of West Sarawak, unless already extensively used for shifting cultivation. The Department of Agriculture, whose policy is to diversify crop production, decided to establish an agricultural experiment station in the area with the specific aim of determining the fertiliser requirements of oil palm, virtually a new crop to Sarawak. A suitable site of 1,300 acres was found in the Luak area and the soil surveyed at semi-detailed level in 1963 (Wall, 1964d). Trial oil palm plots have since been successfully established over 40 acres (Plate 55). The hill soils of the Station are predominantly clay loams and clays of the Bekenu and Merit Families and are typical of those in large parts of the Sibuti, Niah and Suai river basins, as well as in large areas fringing the southern parts of the adjacent Bakong and Baram swamps. The soil map of Luak is shown in Appendix A.

One of the most difficult problems facing the Government of Sarawak in 1963 was whether or not to allow commercial plantations to be established. The attitude of the Government prior to the formation of Malaysia was not to encourage the formation of estates and to support smallholding agriculture as much as possible by way of various subsidised Schemes. This was unlike Malaya and Sabah

which had the benefit of substantial external private capital investment in manila hemp, oil palm and rubber in particular. The new Sarawak State Government however in their first five year Development Plan, (Government of Sarawak, 1963), formulated an agricultural policy, part of which entailed the planting of 10,000 acres of oil palm, principally in the Bekenu-Niah-Suai area, and probably on an estate basis with smallholders participating on the estate peripheries.

The Sarawak Government is proceeding to implement this policy, first by making overland communications in the area easier. Thirty miles of all weather road have now been built from Miri over the Lambir Hills and towards the middle Sibuti and Niah basins (Map 17) where it will join a road being started from the only large good roadstone source (limestone) in the region at Subis. A world Bank loan is being negotiated to help cover the high cost. The Commonwealth Development Corporation has already approved a Government-selected block of about 4,300 acres for oil palm on an estate basis adjacent to and east of the Luak Experiment Station. The Corporation is finalising plans on the export of the oil, which will probably be by road to the possible site of a proposed new port at the Baram River mouth; the Sibuti River mouth as a sand bar too shallow for tankers to cross (Map 17).

The prospects of oil palm cultivation in this area are therefore bright. The chief land limitations are not so much from soil fertility, since the palm, like rubber, is hardy and tolerant of poor conditions (Rosenquist, p.155, shows the main soil deficiencies of an upland sedimentary soil in Mabaya to be of nitrogen and phosphorus) but from steeply sloping high land which makes collection and transport of the heavy fruit difficult. The most suitable areas are therefore the extensive belts of Merit and Bekenu-Merit soils, especially where they are intermixed with well-drained alluvium (Maps 17 and 4). Because of this the current soil survey programme includes the mapping of much of this land at semi-detailed level.

#### RUBBER

While it is the policy of the Department of Agriculture to diversify crop production it is accepted that rubber is ideally suited to Sarawak conditions and that it will be the main cash crop for a long time. It is tolerant of a wide range of soils, is non-seasonal and can be left for lengthy periods without any great harm: it is therefore a good crop for smallholders and has a major part to play in the changeover from shifting to permanent cultivation. Price and quality, in the face of artificial latex production, are most important considerations, however, and much attention has been paid to producing higher yields and lowering costs. Technical help is provided to the Government by the Rubber Research Institute of Malaya.

Rubber planted in the Bekenu-Niah-Suai area has steadily increased in acreage almost entirely through the encouraging results of the Rubber Planting Scheme 'A'. An estimated total of about 4,700 acres had been planted under Scheme 'A' by the end of 1965 in the area (Agricultural Officers' 1965 Annual Report). Normally, blocks of 10 acres or more belonging to one or more farmers are planted together. This facilitates supervision and lends itself particularly well to the Iban's community way of living. There is a particularly large Chinese-owned block of about 1,200 acres at

Bakam on the northern border of this area, and substantial acreages have been planted, mainly by Kedayans and Ibans, in all three main river basins (Map 17); smaller areas have been planted recently on the low hills fringing the Bakong swamp. The areas chosen first usually contain Merit and Bekenu Family soils, with smaller acreages on well-drained, river bank Malang Family soils.

An inherent weakness in block planting is that the soil pattern tends to be disregarded once it is established that at least some suitable soils exist in an area, since it is convenient to lay out large, regular farm plots. For example, although much of the Bakam area soils belong to the Merit Family and are suitable for rubber, there are belts of Nyalau and Bekenu soils in the Lambir foothills to the east, coinciding with steep or moderately steep slopes, which at the best are only marginal due to the risk of erosion. This was clearly established after the severe wet season of 1962/63 when many large and small landslides occurred, destroying much valuable young rubber (Plate 28). A semi-detailed soil survey of a similar rubber area in the northern Lambir foothills revealed the same trend (Wall, 1965c) and a detailed study of the sandy Red-Yellow Podsollic soils in the high Lambir Hills (Sample Area IV, Appendix A) showed that 11% of the 60 acres studied had been affected by either landslides or mudflows. (Plate 22).

A recent development resulting from the realisation that some Rubber Planting Scheme areas had been hastily chosen or approved, has been to modify erosion control measures that formerly were adopted directly from Malayan practices. These were to construct 4-6 feet wide contour terraces that tilted gently back into the hill, the desired effect being to divert as much surface water run-off into the soil as possible. While this practice works well with the more clayey soils widespread in Malaya, it has in some circumstances a markedly deleterious effect on the more permeable, weakly structured Nyalau and Bekenu soils of this area. During prolonged periods of heavy rain it is thought that such Nyalau and, to a lesser extent, Bekenu soils readily become saturated to field capacity and that the added weight of water combined with the decrease in particle cohesion causes instability and widespread mass soil movement (Wall, 1965c). Contour terracing since 1965 has been discontinued in areas of predominantly Nyalau and Bekenu soils. Instead, small individual platforms are constructed for each tree; just sufficiently large to ensure that added fertiliser is not washed downslope, and as a small check to some surface water movement which tends to gully these soils.

Since 1964, a Rubber Planting Scheme 'B' has been in progress. This Scheme was stimulated by the Indonesian Confrontation when large communities living in exposed border areas had to be resettled (c.f. the 'Emergency' resettlement in Malay, Kerrual Singh Sandhu, 1964). It has since grown larger in scope until by 1965 it closely resembled the successful Land Development Schemes of Malaya, which entail planned settlement of selected areas with suitable soil. New villages with all amenities are constructed by the Government, and blocks of up to 5,000 acres are felled, cleared and planted with high-yielding rubber by the prospective farmers under Government supervision. Each farmer finally has about ten acres of valuable land of which about eight is rubber, and two for wet rice.

One such Scheme of about 3,000 acres has been started at Lambir just to the north of this area (Plates 56, 28), and there are proposals for at least one scheme in the Sibuti (Setap) area, with prospects for others eventually in the Niah and Suai river basins should the need arise. After the border village resettlement is completed the scheme applies first to people in areas of high population density where there is land shortage. It will also be used to group people in remote areas where there are at present only one or two longhouses per valley system and where Government personnel spend much time and money in moving from one small population centre to the next. While the population density in the Bekenu-Niah-Suai area is not high and the longhouses, even in the upper Suai River, are not extremely remote, the area has the strong advantage of having suitable land. It is likely that Government policy will be to bring in landless people from other areas, particularly from parts of Second and Third Divisions. This will become even more probable when oil palm estates, for example, begin to require large labour forces.

PEPPER

Pepper will probably remain the most important cash crop in the Bekenu-Niah-Suai area until either rubber or oil palm production increases. The crop is admirably suited to the Chinese farmers as the space needed is small, the yields can be high and the skilled attention required can be simplified by the farmers family. Advances in pepper cultivation resulting from intensive agronomical research in the Department of Agriculture have been accepted slowly however. There is a strong temptation to use the readily available guano at Niah (90% of Sibuti-Niah pepper farmers according to a 1964 pepper survey by the Department of Agriculture) as the sole fertiliser, which gives limited improvements rather than trying new, proven inorganic mixtures, including trace elements found to be essential for maintaining healthy plants (de Waard, 1964). Similarly the traditional cultivation practices are hard to break. It has been found that carefully constructed terraces are essential on the clean-weeded soils to prevent gulying in Nyalau and Bekenu soils and surface wash from the more clayey Merit soils. Also, that instead of complete clean weeding, grass strips between rows are useful checks to both soil wash and the spreading of water-borne disease, but neither of these practices are widely accepted. Hedge planting has been confirmed as being superior to the normal pole-planting by increasing vine density per acre by 2.5 times as well as making vine attending easier. This practice has yet to be tried in the area.

Pepper cultivation has found popularity with the Kedayans and Ibans in several progressive communities (Maps 17, 16). It is not generally successful for more than three years however because the farmers are unable to give it the required attention in the rice season and generally do not appreciate the need for extra fertilisers, disease control measures and the choice of good soils. Thus, unfertilised pepper has been noted on both moderately good Merit and poor Nyalau soils in the Sibuti, Niah and Suai Iban areas, the differences in growth being marked. A survey of pepper growing areas by the Department of Agriculture in 1964 showed that there were about 500 gardens in the Niah-Bekenu area alone covering about 300 acres (Agricultural Officers' 1965 Annual Report) of which rather more than half were Chinese owned.

The scope for increased production of pepper is high if sufficient extension work is done on cultivation and manuring practices. Unless this is done the crop will be confined mainly to the Chinese-populated areas.

RICE

The Government is endeavouring to persuade farmers to change from the land-wasting hill rice shifting cultivation, in which 50-70 acres (5 acres/year in rotation) are required per family, to intensive swamp rice cultivation in which less than three acres per family could suffice if used perennially. This cannot be done everywhere due to the lack of suitable valley soils and water for irrigation, and it may be particularly difficult in parts of the coastal and Bakong Swamp areas where deep peat commonly exists right to the foothills of hill land. Some progress has been made, however, and small rice fields on Bijat, Sebandi and Mukah Family soils, properly irrigated and drained, can be seen among Iban country in the Sibuti Valley particularly. The planted wet rice acreage had increased steadily to about 7,600 acres by 1965 (Agricultural Officers' 1965 Annual Report), while the hill rice acreage had increased to 6,500 acres at the same time; increases of 4,600 and 3,000 acres respectively since 1963. Average yields of wet and hill rice from Miri District were 1980 and 1320 lbs. per acre respectively in 1965 (op.cit.)

The greatest scope for rice production is in the lower Sibuti basin where Pendam, Bijat, and Sebandi clayey soils are extensive. Investigations of large blocks of both used and unused land are being made by the Drainage and Irrigation Branch of the Public Works Department, and the Department of Agriculture is introducing new varieties and improved cultivation techniques, such as the use of buffalo for shallow ploughing. Double rice crops in a year and off-season vegetable and tobacco production are features that have still to gain support. Unfortunately there is an unavoidable clash in soil requirements between wet rice and coconuts. Both crops grow best on the same riverine clays, depending on whether the soils are drained or irrigated. A further complication arises in the Sibuti and Niah areas where these same soils are used for communal buffalo grazing. To some extent land use is being planned in these places but as the demand for land rises and agriculture becomes more intensive there will be an increasing urgency to abandon piecemeal, small scale planning and to concentrate on the planning of large natural units of land, such as individual river basins, primarily on the basis of soil patterns.

In 1959, the Department of Agriculture introduced a Scheme for Assistance to Padi (rice) Planters whereby materials and tools for work on a self-help basis and subsistence grants are made to farmers who organise their wet rice holdings in blocks under Departmental supervision. About 60 acres in the Bekenu-Niah-Suai area are now being farmed under this Scheme in the lower Sibuti valley (Bungai).

COCONUTS

It is a commonly accepted belief that coconuts are practically indigenous to tropical sandy shorelines, yet in the Bekenu-Niah-Suai area, and in fact in Sarawak as a whole, coconuts only occur in planted groves at river mouths and lining lower river banks near villages. There appears to be no natural spreading despite fallen fruit commonly being carried down to the sea.

The main soil requirements of coconuts are at least moderately good internal drainage and preferably a fertile soil, but they will grow well on soils as different as the Kabong Family loose sands and drained Bijat Family clays. On the quartzose sandy soils repeated fertilising is essential, however, while on the clayey soils adequate drainage is more important. It appears that the Malayan archipelago is unusual in having coconuts grow on clay soils (Jacks, p.37). No serious attempts have been made to establish coconuts on hill soils in Sarawak, but small plots near Bintulu on Nyalau soils have grown well. By the end of 1965 there were about 250 acres of coconut garden in the area (Agricultural Officers' 1965 Annual Report).

An area of 20-30 acres in the lower Kalulit River (Sibuti) has been progressively opened up and planted with coconuts since 1962 but with disappointing results. The soils consist of deep peat of the Anderson Family except within 100-200 feet of the river bank where daily saltwater flooding of the peat gives saline peats of the Limbang Family. To try and improve the natural drainage small drains have been constructed leading from the peat land to the river. This however appears to have resulted in increasing the area flooded by saltwater, since subsequent peat shrinkage has allowed water to penetrate further along the ditches and into adjoining lowland, there being no tidal control gates. Close to the Kalulit River the coconuts are stunted and many have died: the soil water salinity there at high tide was measured at 20,000 micro. mhos, and clearly the combination of poor soil drainage and high salinity are harmful to the plant. Further inland, where the groundwater table of the peat is at 12 to 18 inches below the surface and the high tide conductivity is at 2,500 to 15,000 micro. mhos the coconuts have grown rapidly but fronds are coloured orange and yellow with black mottles, fruiting is poor, boles are swollen and the palms lean markedly in all directions. The symptoms indicate nutritional imbalance and the peat is not sufficiently coherent to maintain upright even three-year old trees; salinity superficially does not seem a problem at less than about 5,000 micro mhos. Thus, it appears that the Kedayans in this instance chose an area unsuitable for the crop for a number of reasons, and as the peat gradually shrinks the flooding problem will increase.

Since 1959 the Department of Agriculture has maintained a Coconut Planting Scheme which provides good quality seedlings, and cash subsidies and grants for draining and fertilising, conditional upon good husbandry and preferably in large blocks of land: only 80 acres had been planted in the area by the end of 1964 (op.cit.). As stated above however, there is unfortunately a clash in requirements between coconuts and swamp rice on the clayey alluvial basins. While both crops grow well on Bijat and Pendam soils the rice requires controlled flooding and a high water table in the growing season while the coconuts should have drained soil with a water table at least 18-24 inches deep. Thus, before establishing either crop among the farmers as to whether or not the cultivation of one will jeopardize the growing of the other. Ideally it is best to locate the coconuts close to the inherently better-drained river banks leaving the naturally badly drained basins for rice cultivation.

OTHER CROPS

The amount of tobacco grown since 1963 is believed to have increased, with an estimated annual output of 40 tons of shredded and dried leaf for export and local consumption in 1965 (Agricultural Officers' 1965 Annual Report). If prices rose sufficiently for the semi-processed product it would undoubtedly be grown even more widely by the Chinese. None of the various fruit crops are grown as plantations in the area, although elsewhere in Sarawak citrus (mandarin orange) orchards are established close to urban centres. Possibly fruit crops will become more popular as the population of towns increases and communications improve. Crops at present undergoing manurial trials at Luak Experiment Station include local fruit trees, citrus, coffee and cocoa on the Merit and Malang Family soils. Vegetable production slightly exceeds local demand at the present time. It is unlikely that production will increase greatly in the future since the only really large market, Miri, is well supplied locally by an area which already exports fresh vegetables daily to Brunei.

THE FUTURE OF AGRICULTURE IN THE BEKENU-NIAH-SUAI AREA.

Under present Government policy, agriculture will be the mainstay in the agronomy of this area for a long time, although raw materials that could be used for industry exist at Niah and north of Cape Batu, in the form of limestone for cement and terrace quartz sand (Miri Family A2 horizon) for glass respectively. The extraction of timber will rise to a peak within the next few years and then decline as licensing areas are worked out. The tonnage and value of exported timber is shown by river basins in Table 41, and the locations of timber camps on Map 17. The probable main trends in agriculture will be a growing intensification of the present land use, supplemented by the opening up of new land as roads penetrate formerly inaccessible areas.

Hill rice cultivation will decrease in favour of swamp rice production particularly in the middle and lower river courses where suitable soils of the Bijat, Pendam and Mukah Families exist. This trend is being actively encouraged by the Government by the initiation of level surveys to determine drainage and irrigation potential in the lower Sibuti River basin; in addition to at least two large areas there are many small swamps worthwhile investigating from this aspect (Maps 17, 4). The land thought to be suitable for such development amounts to 35 square miles altogether. These clayey soils may also be used for the Coconut Planting Scheme which in places may be extended in addition onto sandy coastal Tatau and Igan Family soils, as in parts of West Sarawak. If copra prices continue to be favourable coconuts may also be grown on the more suitable well-drained hill soils.

Rubber cultivation will probably be concentrated more and more into ten- to one hundred-acre blocks of high-yielding trees within the Rubber Planting Scheme 'A'. If settlers from elsewhere in Sarawak are allowed into the area, up to three large 5,000 acre Rubber Planting Scheme 'B' blocks could be planted, one in each river basin; at the present time the landless population in any one river basin is insufficient to support a block of this size. Generalized areas of unencumbered suitable hill land are indicated on Map 17, and amount to about 540 square miles or 40% of the whole area.

Table 41. The type quantity and value of timber extracted from the Beken-Niah-Suai area in 1963 and 1964.

RIVER SYSTEM AND YEARS	TONNAGE EXPORTED	F.O.B. (£) VALUE EXPORTED	SPECIES	TONNAGE EXPORTED	F.O.B. (£) VALUE EXPORTED	MAIN SPECIES
<u>Suai</u>						
1963	6192	81,700	ramin ( <u>Gonystylus bancanus</u> Miq)	-	-	
1964	151	3,150	alan, ( <u>Shorea albida</u> Sym.)	4,124	39,700	meranti, ( <u>Shorea</u> spp.) kapor
			sepetir ( <u>Copaifera palustis</u> (Sym) Wit)			( <u>Dryobalanops</u> spp.)
<u>Niah</u>						
1963	752	9,700	alan ( <u>Gonystylus bancanus</u> Miq)	12,709	133,350	meranti ( <u>Shorea</u> spp.)
1964	11,852	138,300		48,051	504,600	kapor ( <u>Dryobalanops</u> spp.)
<u>Sibuti</u>						
1963	-	-		15,583	163,300	meranti ( <u>Shorea</u> spp.)
1964	-	-		31,409	329,600	kapor ( <u>Dryobalanops</u> spp.)
<u>Middle Bakong</u>						
1963	-	-		587	6,200	meranti ( <u>Shorea</u> spp.)
1964	-	-		9,774		kapor ( <u>Dryobalanops</u> spp.)

By permission of Forest Department, Sarawak.

Future of Agriculture

The success of oil palm cultivation will rest heavily on the success of the 5,000 acre plantation to be established at Luak by the Commonwealth Development Corporation. Once it is clear that land can be made available cheaply and easily, that labour is available, that roads will link the prospective areas to a port and that terminal facilities exist for storing and transporting the semi-processed material, then commercial firms will almost certainly be keen to apply for land, which is present in large areas, in places as large unencumbered blocks (Map 17). At the present time there is a reluctance for the well-established Malayan agricultural firms to be the first to venture into the area or, for that matter, into Sarawak at all.

The above four crops are likely to be the main ones having large increases in production in the near future. It is not anticipated that others will increase in acreage greatly, although applications have been received by Government to examine the land with a view to planting sugar cane and bananas on a large scale. As far as the people of the area are concerned the effect of the various planned and extant schemes will be to reduce and eventually remove the old contrasts between the 'haves' and the 'have-nots'.

The Bekenu-Niah-Suai area is therefore expected to become an important agricultural producing centre within the next five to ten years. The outstanding feature of the area is the existence of large blocks or belts of valuable unused land (Map 17) with a combination of hills with low, moderately steep slopes and soils of average fertility for Sarawak (Map 4). The two chief impediments to immediate large scale development are a lack of communications and a shortage of labour.

APPENDIX 2 - 1952

... and ...

APPENDIX 3 - 1953

... and ...

... and ...

PART SEVEN

APPENDICES

APPENDIX 4 - 1954

... and ...

... and ...

... and ...

APPENDIX 5 - 1955

... and ...

APPENDIX A - SAMPLE AREAS

Appendix A comprises data on the topography, soils and vegetation of small sample areas, which are selected at sites where conditions are believed to be typical of those in larger topographic, soil and vegetation mapping units.

SAMPLE AREA I (Map 10) - BERAYA

The location of this area is at Beraya, on the coast north of Cape Batu (Fig. 3) where a large marine sand terrace is in the process of dissection, exposing underlying weathered sedimentary rocks. The soils on the terrace consist mainly of poorly drained, infertile, mature Groundwater Podsolis which support a distinct Heath Forest vegetation. Elsewhere in the area studied such soils are known to be widespread, particularly on the most extensive, terraces in the coastal belt.

The dissected terrace consists of thin, discontinuous bands of deeper and better drained Groundwater Podsolis alternating with wider valleys containing Red-Yellow Podsolis soils, some Skeletal soils on steep slopes, and Gley soils in the valley bottoms. This land is used for shifting cultivation of hill rice with noticeably poor yields on the podsol soils; houses and gardens are built almost entirely on the terrace remnants. Similar dissected terrace land is widespread from Cape Batu northeastwards along the coast, and is believed to occur also in the Nyalau-Telong area terrace landscape.

SAMPLE AREA II (Map 11) - NIAH RIVER MOUTH

This area is situated near the mouth of the Niah River (Fig. 3) on the coast. It consists of recent sand beaches, old sand beaches and the outer fringes of peat swamps. The soils range from young, excessively drained and infertile Recent Alluvial soils on the most recent beach, to poorly drained infertile mature Groundwater Podsolis on old, high beaches. Gley soils are found in some swales in association with shallow Peat soils.

The youngest and driest beaches have been cultivated, initially for rice, then for water-melon; latterly they have been used for rough goat pasture: the secondary regrowth and grasses are hardy and coarse. The central poorly drained land is under Mixed Swamp Forest. The oldest beaches have been repeatedly fired, both accidentally and deliberately, resulting in a Heath Forest-like, fire-resistant vegetation.

With the exception of the fire land this landscape is dominant throughout the coastal belt from Cape Bungai to the Nyalau River mouth.

SAMPLE AREA III (Map 12)

This long, linear sample area starts on the coast about midway between the Niah and Suai rivers (Fig. 3) and traverses the extensive coastal peat swamp ending up close to the Suai River. The soils on the littoral resemble those of Sample Area II, but for the remainder of the way they comprise peats of various depths.

The peat occurs as a uniform, raw, acid, woody accumulation that becomes increasingly thick towards the centre of swamp resulting in a surface shape like a saucer. The basal peat lies at or beneath high tide level except close to the coastline. The vegetation supported by the peat is specialised, and more luxuriant than the poor fertility status of the peat would suggest. Most of the large peat swamps in the area studied are believed to be closely similar to this sample area from the point of view of topography and soils, and to a lesser extent vegetation.

#### SAMPLE AREA IV (Map 13)

The location of this sample area is on the crestline of the eastern Lambir Hills (Fig. 3) where young sedimentary rocks have weathered to give well drained Red-Yellow Podsollic soils in association with Skeletal soils.

The landforms are cuestas, the dipslopes and scarp slopes of which are being dissected by numerous gullies and landslides. Predominantly sandy soils characterise the dipslopes, and clayey soils some scarp slopes. Any real differences between the vegetation on the two soil types tend to be blurred possibly due to the ease of seed dissemination over the small areas that the soils are found in. The complexity of the soil pattern is typical of residual soil patterns in Sarawak.

Elsewhere in the Bekenu-Niah-Suai area these soils have been used for hill rice cultivation, and in places for rubber. They are not favoured for cultivation, however, due to the associated high, steep slopes, commonly low fertility and susceptibility to erosion.

#### SAMPLE AREA V (Map 14)

This area in the upper Niah Valley (Fig. 3) was chosen as being representative of the ridge landscape. The soils consist predominantly of the clayey members of the Red-Yellow Podsollic group. Despite the steepness of the slopes the soils are not particularly shallow, and they are largely well drained. While the sample area appears to be typical of the ridge landscape north of the Niah River, the soils are more clayey than in ridge landscape further south towards the Suai River.

The vegetation consists of primary Dipterocarp forest and the composition is distinct from that in Sample Area IV. Elsewhere the soils are commonly used for hill rice cultivation, and in places for pepper and rubber.

#### LUAK AREA (Map 15)

Although surveyed at a semi-detailed level this area serves as an extremely useful indicator of the type of landscape and soils likely to be found in the areas suitable for development further south and east.

The hills are low and, where underlain by shale, have moderately steep slopes with clayey Red-Yellow Podsollic soils. Where underlain by sandstone, however, they tend to be steeper and are mantled by shallower sandier Red-Yellow Podsollic and Skeletal soils. Some areas with extremely gentle slopes are characterised by unusual, calcium-rich Brown Forest soils. The widespread alluvial land contains both poorly drained Gley soils and moderately well drained

APPENDIX B - SOIL SERIES DESCRIPTIONS AND ANALYSES

In Appendix B are detailed field descriptions and chemical analyses of the established soil series. The data is arranged by soil groups and soil families in the same order as that in PART FIVE.

RED-YELLOW PODSOLIC SOILS

1. NYALAU FAMILY

(1) PENINJAU SERIES: S.4387/93.

Location: Fourth Division, Miri-Bintulu road, 18th mile: about half a mile west on main watershed. Sample Area IV, rentis 4, pole 28.

Site: Middle slope of hill.

Parent Material: Lambir Formation sandstone.

Topography: Long dipslope, 15° slope.

Vegetation: Primary Lowland Dipterocarp Forest (See Sample Area IV, Vegetation Map), moderately thick undergrowth of saplings and creepers.

Drainage: Well drained internally; medium to slow external drainage.

Weather: Light showers during last few days, fine previous night.

Sampling date: 22.5.65.

Profile description:

2-0" O horizon - S.4387.

Loose litter and humus containing common fine roots.

0-2(1-2) A1 horizon - S.4388.

Strong brown (7.5YR 5/6) loamy sand; very friable; structureless; abundant fine to coarse roots; clear smooth change to

2-5 (4-6) A2 horizon - S.4389.

Yellowish brown (10YR 6/8) sandy loam, very friable; very weak crumb; few fine roots; clear smooth change to

5-25 (17-25) A22 horizon - S.4390.

Brownish yellow (10YR 6/8) loamy sand to sandy loam with few fine dark brown mottles; friable to very friable; weak crumb; no roots; diffuse broken change to

25-44 (42-44) B2 horizon - S.4391.

Reddish yellow (7.5YR 6/8) sandy loam with few faint fine yellow mottles; very friable; angular to subangular blocky; no roots; gradual smooth change to

44-60 (47-60) B3 horizon - S.4392.

Reddish yellow (7.5YR 6/8) loamy sand; very friable; structureless; no roots; few pinkish white (7.5YR 8/2) sandstone fragments, diffuse broken change to

60-78+ B32 horizon - S.4393.

Reddish yellow (7.5YR 7/8) medium to coarse sand with abundant patches of pinkish white (7.5YR 8/2); very friable; no roots.

Note:- Munsell colours in field moist condition.

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	F Total (p.p.m.)	Ca		Mg Total (%)	Mg Exch. (m.e.%)	K Total (%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	Org. Cont. (%)	G.E.O. (m.e.%)
					Total (%)	Exch. (m.e.%)							
S4387	0	2-0	(1:5) 3.5	105	0.03	0.30	0.02	1.91	0.09	1.19	0.34	15.35	37.00
S4388	A1	0-2	4.3	70	0.03	0.84	0.01	<0.12	0.13	<0.03	0.20	10.81	7.00
S4389	A2	2-5	4.8	60	0.01	0.60	0.02	<0.06	0.10	<0.03	0.10		3.30
S4390	A22	5-25	5.7	40	0.03	0.36	0.01	<0.06	0.10	<0.03	<0.09		1.20
S4391	B2	24-44	5.4	45	0.03	0.36	0.02	<0.06	0.13	<0.03	0.10		0.70
S4392	B22	44-60	5.6	40	0.02	0.24	0.02	<0.06	0.13	<0.03	0.09		0.60
S4393	B3	60-78	5.6	40	0.04	0.36	0.006	<0.06	0.12	<0.03	<0.09		0.60

16.54

Lab. No.	Horizon	Depth (ins)	Group III (%)	Bulk Density	SiO <sub>2</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)
S4388	A1	0-2	2.52	1.24	96.18	0.80	1.39
S4389	A2	2-5	2.98	1.47	90.23	0.80	1.46
S4390	A22	5-25	2.88	1.58	89.21	1.27	2.98
S4391	B2	25-44	4.02	1.76	93.75	1.64	3.97
S4392	B22	44-60	3.98	1.64	95.70	1.17	2.72
S4393	B3	60-78	2.42	1.59	97.04	0.84	1.69

Lab. No.	Fine earth fraction (less than 2.0 mm.)							Total sand (%)	Total (%)	Texture Class
	Silt (%)	Clay (%)	Very fine sand (%)	Fine sand (%)	Medium sand (%)	Total sand (%)	Total (%)			
S4387	16.38	18.98	2.08	18.00	16.80	36.88	72.24	loam (30.30% loss on 1 $\mu$ .)		
S4388	9.43	8.16	7.69	44.09	29.07	80.85	98.44	loamy sand		
S4389	10.02	8.36	7.26	45.05	28.74	81.05	99.43	loamy sand		
S4390	11.69	9.04	6.06	39.29	34.03	79.38	100.11	loamy sand to sandy loam		
S4391	9.14	12.24	5.89	40.76	31.64	79.29	100.67	sandy loam		
S4392	7.24	8.25	4.73	44.62	35.00	84.35	99.84	loamy sand		
S4393	5.20	5.92	2.43	41.66	45.29	89.38	100.48	sand		

(ii) NYALAU SERIES: S.4436/41.

Location: Fourth Division, Miri-Bintulu Road, mile 18, about half a mile west on the main watershed; Sample Area IV, rentis 6, pole 13.

Site: near top of long slope.

Parent Material: Lambir Formation sandstone and subordinate shale.

Topography: long dip slope of 20°.

Vegetation: primary Lowland Dipterocarp (see Sample Area IV, Vegetation Map). Thick undergrowth with about 60% shade at ground level.

Drainage: well drained internally, medium external drainage.

Weather: light showers during last few days. Fine previous day.

Sampling date: 22.5.65.

5 - 0" O horizon

Loose litter and well-rooted dark greyish brown humus.

0 - 2 (1 - 2) A1 horizon. S.4436

Dark brown (10YR 3/3) to dark yellowish brown (10YR 3/4) sandy loam; very friable (less than 0.25); abundant organic matter and yellow mottles as below; weak fine to medium crumb; abundant fine to coarse roots; clear wavy change to

2 - 9 (8 - 10) A2 horizon. S.4437

Yellowish brown (10YR 5/6) sandy loam; very friable (less than 0.25); fine to medium weak crumb; abundant organic staining from above, common fine to coarse roots; gradual smooth change to

9 - 15 (13 - 17) A22 horizon. S.4438

Yellowish brown (10YR 5/6) sandy loam, very friable (less than 0.5); fine to medium, weak crumb to blocky; few signs of clay skins; common fine to coarse roots; gradual smooth change to

15 - 29 (27 - 31) B1 horizon. S.4439

Reddish yellow (7.5YR 6/6 - 6/8) sandy loam to sandy clay loam; very friable (0.0 - 0.75); fine to medium weak crumb to blocky; a few faint clay skins on structural faces; few medium to coarse roots; gradual smooth change to

29 - 49 (46 - 50) B22 horizon. S.4440

Reddish yellow (10YR 6/8) sandy clay loam; very friable (0.0 - 1.25); fine to medium weak blocky; common clay skins on structural faces; few medium roots; gradual smooth change to

49 - 70+ B23 horizon. S.4441

Reddish yellow (10YR 6/8) sandy clay loam; friable (1.5 to 1.75); fine to medium weak blocky; few faint clay skins; no roots; few faint coarse patches of red sandstone(?).

Note:-

The reddish lower subsoil colour is not strong and the soil from this aspect is almost an intergrade to the Likau Series. The A2 horizon contains coarse organic-rich mottles, probably from rooted tree roots.

Munsell colours in field-moist condition.

Table 45. Chemical data

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (p.p.m.)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)	K Total (%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	C.E.C. (m.e.%)	Org. C (%)
S4436	A1	0-2	5.0	115	0.04	0.13	0.02	0.35	0.10	0.20	0.30	20.45	
S4437	A2	2-9	5.4	80	0.02	0.07	0.04	0.08	0.14	0.13	0.21	5.35	1.08
S4438	A22	9-15	5.8	65	0.03	0.22	0.03	0.04	0.14	0.14	0.13	2.95	0.54
S4439	B2	15-29	5.3	60	0.02	0.17	0.04	0.08	0.18	0.12	0.15	3.15	
S4440	B22	29-49	5.3	60	0.05	0.12	0.02	0.08	0.18	0.09	0.10	3.20	
S4441	B23	49-70	5.2	60	0.05	0.09	0.06	0.12	0.17	0.14	0.14	3.15	

Lab. No.	Horizon	Depth (ins)	Group III (%)	Bulk Density	SiO <sub>2</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)
S4436	A1	0-2	3.18	0.82	73.09	1.13	3.89
S4437	A2	2-9	3.42	1.40	86.61	2.00	6.36
S4438	A22	9-15	6.14	1.56	82.37	1.84	6.10
S4439	B2	15-29	6.70	1.66	87.67	2.13	6.88
S4440	B22	29-49	7.12	1.78	86.75	2.36	7.40
S4441	B23	49-70	6.82	1.76	86.93	2.17	7.26

Lab.No.	Silt (%)	Clay (%)	Fine earth fraction			Total sand (%)	Texture Class
			Very fine sand (%)	fine sand (%)	medium sand (%)		
S.4436	17.95	15.86	8.39	31.37	6.03	45.79	loam (including 21.99% loss on 15.)
S.4437	20.25	18.81	13.13	42.20	6.69	61.99	sandy loam
S.4438	19.93	18.47	12.32	39.69	7.16	59.17	sandy loam
S.4439	19.36	20.18	12.22	40.99	7.16	60.37	sandy loam to sandy clay loam
S.4440	18.48	22.14	11.99	39.96	7.03	58.98	sandy clay loam
S.4441	19.51	22.04	12.09	39.96	7.66	59.71	sandy clay loam

Mineralogical data: examined by Dr. G.E. Wilford, Geological Survey, Sarawak.

S.4437; A2 horizon.

{medium sand) : Subangular quartz and limonite.  
 {fine sand) : Subangular quartz and a little limonite.  
 {very fine sand): Subangular quartz, limonite, colourless spinel, well-rounded zircon.

S.4440: B22 horizon.

{medium sand) : Rounded quartz, limonite and limonite/quartz aggregates.  
 {fine sand) : Subangular quartz, limonite zircon and leucoxene.  
 {very fine sand): Subangular quartz and limonite with some zircon.

S.4441; B23 horizon.

{medium sand) : Rounded quartz; limonite and limonite/quartz aggregates.  
 {fine sand) : Subangular quartz with limonite inclusions, zircon, well-rounded tourmaline, hornblende  
 sphene, and authigenic brookite.  
 {very fine sand): Quartz, limonite, and well-rounded pink zircon.

(iii) LIKAU SERIES. S.4442/50

Location: Fourth Division, Miri-Bintulu road, 18th mile, about half a mile west on watershed area in Sample Area IV, rentis 7, pole 18.

Site: about 15 feet from incised gully on lower slope.

Parent Material: Lambir Formation sandstone and subordinate shale.

Topography: dipslope of 20°, gently undulating and being dissected by a gully.

Vegetation: primary Lowland Dipterocarp Forest (see Sample Area IV, Vegetation Map). Moderately thick undergrowth with 70-80% shade at ground level.

Drainage: imperfectly drained internally with medium external drainage.

Weather: light showers during last few days; fine during previous day.

Sampling date: 22.5.65.

Profile description:

Less than one inch of litter and very dark greyish brown, well-rooted humus.

0-3" (2-4) A1 horizon. S.4442.

Dark yellowish brown (10YR 4/4) sandy loam, with common diffuse yellowish brown, and distinct, medium, light grey, white and reddish yellow mottles; very friable (0.0 - 0.25); fine to medium weak crumb to blocky; common fine to medium roots; clear smooth change to

3-8 (7-9) A2 horizon. S.4443.

Brownish yellow (10YR 6/6) sandy loam, with common, prominent, medium to coarse, light grey, white and reddish yellow mottles, very friable (0.25 - 0.75); fine to medium weak blocky, common medium roots; clear, wavy change to

8-18 (12-21) A22 horizon. S.4444.

Brownish yellow (10YR 6/8) sandy loam, abundant, distinct, diffuse pale-yellow, and distinct reticulate strong brown mottles, some associated with root channels; very friable (0.25 - 1.0); medium, weak blocky; common medium roots; clear broken change to

18-27 (26-27) B1 horizon. S.4445.

Brownish yellow (10YR 6/8) sandy loam to sandy clay loam, with common faint diffuse yellow and reddish yellow mottles; very friable (0.5 - 1.0); massive to weak blocky; few medium roots; clear wavy change to

27-38 (36-38) B2 horizon. S.4446.

Brownish yellow (10YR 6/8) sandy clay loam, with few, fine to medium, distinct pale yellow, and common, faint, diffuse reddish yellow mottles; friable (0.75 - 1.0); weak, medium to coarse blocky; few medium roots; few clay skins on structural faces, clear smooth change to

38-53 (50-55) B3g horizon. S.4447.

Yellow (10YR 8/8), light grey and brownish yellow (10YR 6/8) sandy clay loam - the light grey being present as coarse patches, the matrix being various shades of yellow; friable to very friable; slightly plastic (1.5); water oozing from several pores; weak coarse blocky, clear smooth change to

53-67 (65-69) B32g horizon. S.4448.

Mixed yellow, red, yellowish red, light grey and pale yellow soft sandstone with clayey patches.

67-72 B33g horizon. S.4449.

Iron-rich zone, red colours prominent.

72-82+ (auger sample) B34g horizon. S.4450.

As B32g horizon. Water table at 72 inches at time of sampling.

Munsell colours in field condition.

Table 46. Chemical data:

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (p.p.m.)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)	Total Exch. (%)	K Total Exch. (%)	Na Exch. (m.e.%)	C.D.C. (m.e.%)
S4442	A1	0-3	4.8	75	0.03	0.12	0.02	0.16	0.11	0.08	0.21	2.00
S4443	A2	3-8	5.1	50	0.03	0.12	0.03	0.12	0.16	0.09	0.16	2.60
S4444	A22	8-18	5.4	60	0.03	<0.05	0.02	0.15	0.19	0.09	0.17	2.15
S4445	B1	18-27	5.2	55	0.04	0.20	0.02	0.05	0.20	0.08	0.16	2.05
S4446	B2	27-38	5.3	55	0.03	0.10	0.01	<0.05	0.24	0.11	0.15	2.05
S4447	B3 <sub>1</sub>	38-53	5.2	55	0.04	0.10	0.02	<0.05	0.29	0.03	0.10	2.35
S4448	B3 <sub>2</sub>	53-67	5.2	50	0.03	0.10	0.04	0.05	0.35	0.03	0.12	2.15
S4449	B3 <sub>3</sub>	67-72	5.0	50	0.03	0.10	0.04	0.10	0.33	0.02	0.12	2.05
S4450	B3 <sub>4</sub>	72-82	4.3	40	0.02	0.25	0.07	0.10	0.28	0.02	0.11	2.25

Lab. No.	Horizon	Depth (ins)	Org. C (%)	Group III (%)	Bulk Density	SiO <sub>2</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)
S4442	A1	0-3	1.15	3.92	1.41	92.56	0.94	2.73
S4443	A2	3-8	0.24	2.62	1.63	88.52	1.19	3.31
S4444	A22	8-18		3.10	1.70	87.36	1.70	3.76
S4445	B1	18-27		4.98	1.79	91.30	1.88	4.74
S4446	B2	27-38		5.22	1.72	89.25	2.36	5.52
S4447	B3 <sub>1</sub>	38-53		4.76	1.79	89.85	1.50	5.71
S4448	B3 <sub>2</sub>	53-67		7.04	1.76	86.56	2.63	6.23
S4449	B3 <sub>3</sub>	67-72		6.70	1.38	82.39	3.05	5.84
S4450	B3 <sub>4</sub>	72-82		4.48	1.80	88.78	2.16	6.10

2. BEKENU FAMILY

LABANG SERIES. S.4419/26.

Location: Fourth Division, Miri-Bintulu road, mile 18, about half a mile west on watershed area in Sample Area IV, rentis 3, pole 19.

Site: near top of dipslope.

Parent Material: Lambir Formation sandstone and shale.

Topography: hill slope of  $10^{\circ}$  -  $15^{\circ}$ .

Vegetation: primary Lowland Dipterocarp Forest (see Sample Area IV, Vegetation Map): thick undergrowth of saplings and palmaceous trees. About 90% shade at ground level.

Drainage: moderately well drained internally, medium external drainage.

Weather: showery last few days.

Sampling date: 21.5.65.

Profile description:

Scattered surface litter and less than a half inch of humus.

0-1" (1-3) A1 horizon. S.4419.

Brown to dark brown (10YR 4/3) sandy loam with common distinct humus-stained patches; very friable (less than 0.25); fine to medium crumb; abundant fine to coarse roots; clear wavy change to

1-5 (4-6) A2 horizon. S.4420.

Yellowish brown (10YR 5/4) and light yellowish brown (10YR 6/4) loam with few, very faint, very pale brown mottles; very friable ( $< 0.25$ ); fine to medium crumb to blocky; common medium to coarse roots; few signs of clay skins; gradual smooth change to

5-11 (9-13) B1 horizon. S.4421.

Brownish yellow (10YR 6/6) loam; friable (0.75 - 1.5); medium subangular blocky; common clay skins on structural faces; common medium roots; gradual smooth change to

11-23 (23-26) B2 horizon. S.4422.

Yellow to brownish yellow (10YR 7/6-6/6) loam to clay loam or sandy clay loam, with few, distinct, fine to medium light grey to yellow and reddish brown mottles; few clear clay skins; common medium roots; gradual wavy change to

23-39 (36-42) B22 horizon. S.4423.

Reddish yellow (10YR 6/6) loam to clay loam; with few distinct medium light grey to grey and reddish yellow mottles; very friable (0.75-1.25); coarse blocky with much ant activity and many clay skins on structural faces, common fine to medium roots; clear broken change to

39-57 (57-60) B23 horizon. S.4424.

Yellowish red (5YR 5/8) clay loam with abundant, distinct, diffuse, reddish yellow, yellow and medium light grey mottles; friable to firm (1.5-2.0); weak coarse blocky, no clear clay skins; abrupt wavy change to

57-61 (61-64) B24 horizon. S.4425.

Yellowish red (5YR 5/8) stony clay, with abundant moderately hard purplish red stones forming a stoneline, otherwise as for B23 horizon.

61-70+ B25 horizon. S.4426.

Mixed reddish yellow, yellow, light grey and yellowish red clay loam, with common pieces of shale; friable to firm; no roots.

Munsell colours in field-moist condition.

Lab. No.	Fine earth fraction							Total sand (%)	Total (%)	Texture Class
	Silt (%)	Clay (%)	Very fine sand (%)	Fine sand (%)	Medium sand (%)	Total sand (%)	Total (%)			
S4419	27.92	14.89	21.10	33.05	7.75	57.84	100.45	sandy loam		
S4420	32.25	19.88	15.88	25.87	4.40	46.15	98.28	loam		
S4421	33.07	23.11	15.08	24.78	4.26	44.12	100.30	loam		
S4422	32.83	24.39	15.69	24.38	4.66	44.73	101.95	loam		
S4423	28.77	24.69	16.02	25.07	4.33	45.42	98.88	loam - clay loam or sandy clay loam		
S4424	28.04	27.34	15.65	23.38	4.76	43.79	99.17	loam - clay loam		
S4425	34.67	31.51	13.35	11.59	10.46	35.40	101.53	clay loam		
S4426	42.07	33.80	10.66	7.53	7.36	25.85	101.72	clay loam		

Mineralogical data: examined by Dr. G.E. Wilford, Geological Survey, Sarawak.

- S4420; A2 horizon; : medium sand : Quartz with indeterminate inclusions, and iron ore grain of ?ilmenite.  
: fine sand : Quartz and limonite.  
: very fine sand : Quartz, limonite, volcanic glass shard, zircon, pale brown spinel, sphene, brown tourmaline, ?leucoxene.
- S4423; B22 horizon; : medium sand : Quartz with limonite.  
: fine sand : Quartz, limonite, chert, zircon, and ?leucoxene.  
: very fine sand : Quartz, limonite, and rare sphene, zircon, and ?spinel.
- S4426; B25 horizon; : medium sand : Quartz and limonite.  
: fine sand : Quartz and limonite.  
: very fine sand : Subangular quartz with limonite, hypersthene, zircon, and ?tourmaline.

3. MERIT FAMILY

(i) PINTASAH SERIES. S.4410/18. (35-9)

Location: Fourth Division, Miri-Bintulu road, mile 18, about half a mile west on watershed area in Sample Area IV, rentis 3, pole 4.5.

Site: just below top of rounded hill.

Parent Material: Lambir Formation shale.

Topography: on 20° - 25°, convex slope.

Vegetation: primary Lowland Dipterocarp Forest (see Sample Area IV, Vegetation Map). Moderately thick middle storey with about 80-85% shade at ground level.

Drainage: moderately well drained internally, medium to rapid external drainage.

Weather: showery previous few days.

Sampling date: 21.5.65.

Profile description:

2-0"

Scattered litter and thin humus.

0-1 (0-3) A1 horizon. S.4410.

Dark yellowish brown (10YR 3/4) silty loam; very friable (< 0.25); fine to medium crumb; much organic matter; abundant fine roots; clear wavy change to

1-4 (4-7) A2 horizon. S.4411.

Yellowish brown (10YR 5/6 - 5/8) silty clay loam with common dark staining from above; very friable (less than 0.25); fine to medium crumb; common fine to coarse roots; diffuse smooth change to

4-13 (10-13) B1 horizon. S.4412.

Reddish yellow (7.5YR 6/6) to yellowish brown (10YR 5/8) silty clay loam; friable (0.75-1.0); weak blocky; common clay skins and much ant activity on structural faces; common fine to medium roots; gradual smooth change to

13-19 (17-21) B2 horizon. S.4413.

Strong brown (7.5YR 5/8) silty clay loam, friable (1.0-1.5); medium to coarse blocky; abundant clay skins on structural faces; common medium roots; gradual change to

19-28 (arbitrary) B22 horizon. S.4414.

Reddish yellow (7.5YR 6/6) to yellowish red (5YR 5/8) silty clay; with few, distinct coarse yellow mottles; firm (1.0-1.5); medium blocky; abundant clear clay skins on structural faces; common fine to medium roots; arbitrary change to

28-39 (37-41) B23 horizon. S.4415.

Yellowish red (5YR 5/8) silty clay, with common, faint to distinct, fine to coarse reddish yellow and yellow mottles; firm (1.25-1.75); abundant clear clay skins on structural faces; weak blocky; few fine to medium roots; abrupt, wavy change to

39-44 (42-46) B24 horizon. S.4416.

Yellowish red (5YR 5/8) stony clay; friable to firm (1.75-more than 4.0); few clay skins evident; structureless; abundant small dark red to yellow pieces of fine sandstone(?) forming a stoneline; no roots; gradual wavy change to

44-54 (arbitrary) B25 horizon. S.4417.

Yellowish red (5YR 5/8) stony clay loam with common, prominent to distinct, fine to medium yellow and light grey mottles from weathering shale, otherwise as B24 horizon.

54-65+ B26 horizon. S.4418.

Yellowish red (5YR 5/8) stony silty clay loam, with abundant, prominent, fine to coarse light grey and yellow mottles from weathering shale, otherwise as B24 horizon.

Munsell colours in field-moist condition.

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	F Total (p.p.m.)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)	Total (%)	K Total (%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	C.E.C. (m.e.%)
S4410	A1	0-1	4.1	155	0.02	0.10	0.12	0.55	0.36	0.36	0.15	0.20	16.6
S4411	A2	1-4	4.6	115	0.04	0.05	0.15	0.05	0.42	0.42	0.12	0.17	11.75
S4412	B1	4-13	4.6	105	0.03	0.05	0.15	0.10	0.46	0.46	0.10	0.17	10.40
S4413	B2	13-19	4.8	110	0.03	0.05	0.15	0.10	0.45	0.45	0.10	0.17	9.60
S4414	B22	19-28	4.6	75	0.02	0.15	0.20	0.10	0.52	0.52	0.07	0.17	9.60
S4415	B23	28-39	4.6	100	0.02	0.05	0.13	0.05	0.44	0.44	0.10	0.17	10.80
S4416	B24	39-44	5.3	120	0.02	<0.05	0.13	0.05	0.54	0.54	0.12	0.17	9.55
S4417	B25	44-54	5.0	85	0.02	<0.05	0.15	0.05	0.58	0.58	0.10	0.09	6.20
S4418	B26	54-65	5.2	90	0.02	0.14	0.26	0.04	0.28	0.28	0.15	0.13	8.30

Lab. No.	Horizon	Depth (ins)	Org. C (%)	Bulk Density	Group III (%)	SiO <sub>2</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)
S4410	A1	0-1	5.23	1.10	6.00	71.60	3.15	10.00
S4411	A2	1-4	1.01	1.40	8.42	74.17	3.52	11.06
S4412	B1	4-13		1.54	9.64	71.47	4.18	11.79
S4413	B2	13-19		1.87	9.66	75.96	4.55	13.31
S4414	B22	19-28		1.65	11.36	73.85	4.32	13.76
S4415	B23	28-39		1.69	11.76	66.90	5.11	15.06
S4416	B24	39-44		1.80	18.06	57.99	10.28	16.74
S4417	B25	44-54		1.74	15.44	67.24	9.48	16.29
S4418	B26	54-65		1.80	15.28	65.26	7.18	17.92

Lab. No.	Silt (%)	Clay (%)	Very fine sand (%)	Fine earth fraction fine sand (%)	Medium sand (%)	Total sand (%)	Total (%)	Texture Class
S4410	49.03	31.12	7.95	8.31	4.28	16.87	97.02	silty clay loam
S4411	51.57	33.32	5.93	5.59	1.93	13.45	98.44	silty clay loam
S4412	51.08	36.28	4.73	4.66	1.67	11.06	98.42	silty clay loam
S4413	49.77	38.17	7.13	5.00	1.50	13.63	101.57	silty clay loam
S4414	47.60	40.59	4.93	4.90	1.73	11.56	99.75	silty clay
S4415	44.56	46.29	4.60	3.66	1.47	9.73	100.58	silty clay
S4416	35.80	39.87	5.26	4.06	17.38	26.70	102.37	clay
S4417	39.92	36.07	8.73	3.33	14.22	25.05	101.04	clay loam
S4418	46.59	37.47	4.46	4.16	8.99	17.61	101.67	silty clay loam

Mineralogical data: examined by Dr. G.E. Wilford, Geological Survey, Sarawak.

- S4411; A2 horizon; medium sand : Mainly subangular quartz, some limonite, and a few chert grains.  
fine sand : Subangular to rounded quartz, chert, and some limonite.  
very fine sand : Mainly very fine subangular quartz and a few chert with some limonite and rare zircon, brookite ? garnet, ? tourmaline.
- S4415; B23 horizon; medium sand : Mainly subangular quartz with some limonite  
fine sand : Mainly subangular quartz and some limonite, chert and rare ?pyrite, zircon and ?spinel.  
very fine sand : Mainly subangular quartz with some limonite and rare tourmaline, zircon and apatite.
- S4418; B26 horizon; medium sand : Limonite fragments and dust.  
fine sand : Mainly limonite, some quartz and rare ?ilmenite.  
very fine sand : Limonite and subangular quartz in about equal proportions, rare zircon.

(ii) LUAK SERIES. S.4308/16 (35-8)

Location: coastal Fourth Division, Beraya area about 8 miles south of Miri. Sample Area I, rentis 5, 2,350 feet.

Site: middle slope of low, 30-foot high hill.

Parent material: shale of Miri Formation.

Topography: convex slope, 15°-20° at site, on low hill of dissected terrace landscape.

Vegetation: secondary from hill rice cultivation, about five to six years old. Consists of sedges and hardy bushes (see Sample Area I, Vegetation Map).

Weather: fine last five or six days.

Sampling date: 21.1.65.

Profile description:

0-5" (4-6) A1 horizon. S.4308

Dark yellowish brown (10YR 4/4) loam with distinct, diffuse yellowish brown mottles in bottom three inches of this horizon; friable (1.75-2.75); weak crumbly to subangular blocky; common, medium roots; few pieces of charcoal; clear wavy change to

5-17 (13-19) A2 horizon. S.4309

Yellowish brown (10YR 5/8) clay loam with common clear humus staining on structural faces; friable (2.25-3.25); subangular blocky; few fine to medium roots; common distinct clay skins and much ant activity, on structural faces; common, clean, fine quartz grains; diffuse even change to

17-25 (arbitrary change) B1 horizon. S.4310

Yellowish brown (10YR 5/6) clay loam; friable (2.0-2.25); subangular blocky; common, clear clay skins and much ant activity on structural faces; few, fine and medium roots; common clear quartz pebbles; arbitrary change to

25-35(32-37) B2 horizon. S.4311

Yellowish brown (10YR 5/6) clay with few, distinct, diffuse, reddish brown and light grey mottles; very firm (1.75-2.75); massive, breaking to angular blocky; few fine and medium roots; abundant distinct clay skins; common fine quartz pebbles. Diffuse, smooth change to

35-47 (46-49) B22 horizon. S.4312.

Yellowish brown (10YR 5/6) clay with common, distinct, fine and diffuse coarse light grey mottles in bottom three inches of horizon; firm (1.5-2.0) and slightly plastic; massive, breaking to subangular blocky; few fine and medium roots; abundant distinct clay skins on structural faces; common clear fine quartz pebbles. Abrupt, wavy change to

47-49 (49-50) B23 horizon. S.4313.

Brownish yellow (10YR 6/6) and grey clay, with common, distinct, medium reddish brown and few medium light grey mottles; firm (1.5-2.5); massive, breaking to blocky; few clay skins around quartz pebbles which are up to a half inch in diameter; rare medium roots; abrupt, wavy change to

49-56 (56-61) B24 horizon. S.4314.

Brownish yellow (10YR 6/6) clay with common fine to coarse, distinct light grey and reddish brown mottles (from iron-rich shale); very firm (1.5-3.5); massive, breaking to angular blocky; few quartz grains, rare roots; diffuse, broken change to

56-70 (arbitrary change) B3 horizon. S.4315.

Brownish yellow (10YR 6/6) clay, with abundant, prominent light grey and diffuse reddish yellow mottles; firm to very firm (1.75-2.25); slightly platy from structure of shale; no roots, rare quartz pebbles; arbitrary change to

70-85+ B32 horizon. S.4316.

As B3 horizon but contains much more unweathered platy shale and rare quartz.

Munsell colours in field-moist condition.

Table 49. Chemical data:

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (p.p.m.)	P Av. (p.p.m.)	Ca		Mg		K		C.E.C. (m.e.%)
						Total (%)	Exch. (m.e.%)	Total (%)	Exch. (m.e.%)	Total (%)	Exch. (m.e.%)	
S4308	A1	0-5	4.5	50	10	0.09	124	0.07	72	0.23	106	8.48
S4309	A2	5-17	4.7	85	3	0.04	trace	0.12	29	0.28	84	9.54
S4310	B1	17-25	4.8	90	4	0.02	34	0.13	42	0.34	82	8.48
S4311	B2	25-35	4.9	65	4	0.02	84	0.18	14	0.32	82	8.90
S4312	B22	35-47	4.7	65	2	0.01	24	0.17	25	0.44	95	9.75
S4313	B23	47-49	4.8	60	3	0.02	24	0.16	32	0.40	95	9.00
S4314	B24	49-56	5.1	123	3	0.02	24	0.21	26	0.45	95	8.90
S4315	B3	56-70	5.1	90	3	0.02	24	0.17	29	0.47	135	11.45
S4316	B32	70-85	4.6	101	2	0.02	24	0.20	58	0.49	113	12.51

Lab. No.	Horizon	Depth (ins)	Na Exch. (m.e.%)	V/% air	Gr. III (%)	SiO <sub>2</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	TiO <sub>2</sub> (%)
S4308	A1	0-5	37	21.3	5.64	83.39	3.07	8.72	0.54
S4309	A2	5-17	29	21.9	6.14	80.37	3.69	10.48	0.48
S4310	B1	17-25	31	15.6	9.72	74.39	3.69	11.43	0.65
S4311	B2	25-35	32	16.0	8.88	77.63	4.41	12.50	0.65
S4312	B22	35-47	31	15.6	10.04	73.64	4.65	12.82	0.63
S4313	B23	47-49	35	13.5	13.20	74.24	6.57	12.76	0.63
S4314	B24	49-56	24	17.5	16.88	70.15	11.47	14.90	0.73
S4315	B3	56-70	39	16.1	13.02	66.17	8.06	15.28	0.69
S4316	B32	70-85	34	15.5	11.60	68.88	6.72	14.27	0.69

4. SEMILAJAU FAMILY

SEMILAJAU SERIES. S.2599/04. (35-63)

- Location: Fourth Division, south of Miri at Luak Experiment Station, rentis 3, pole 2.50.
- Site: about 150 feet from the banks of the Luak Dami-Stream.
- Parent Material: recent riverine sands.
- Topography: gently sloping levee with small swale nearby.
- Vegetation: primary or old secondary Riparian Forest. Few large trees, many of medium size; thin ground cover.
- Drainage: imperfectly drained internally, medium external drainage.
- Weather: fine last two days, showers overnight.
- Sampling date: 9.10.63.

Profile description:

- 1-0" litter (no humus).
- 0-2(1/2-2) A1 horizon. S.2599  
Light grey to pale yellow fine sand; loose; single grain; no roots; abrupt and irregular change to
- 2-3 (1-3) A1 horizon. S.2600  
Dark brown grading to brown loamy fine sand; loose; single grain; common, fine to medium roots; gradual, undulating change to
- 3-14 (13-15) A2 horizon. S.2601.  
Light yellowish brown (2.5Y 6/4) loamy fine sand; loose; single grain to very fine weak blocky; common medium roots; gradual, smooth change to
- 14-29 (25-34) A22 horizon. S.2602  
Light yellowish brown (2.5Y 6/4) loamy fine sand, with common, faint, diffuse, pale yellow to light grey and brownish yellow mottles; very friable to loose; massive, breaking to very weak angular blocky; much ant activity; few medium roots; sharp; irregular change to
- 29-38 (37-39) B2 horizon. S.2603  
Light yellowish brown (10YR 6/4) fine sandy loam, to fine sandy clay loam with abundant faint to distinct, diffuse brownish yellow and pale yellow mottles; massive, breaking to angular blocky; clear, smooth change to
- 38-50+ B2g horizon. S.2604  
Pale yellow (2.5Y 7/3) fine sandy clay loam with abundant, medium, diffuse and distinct reddish brown and light grey mottles; friable; massive, breaking to angular blocky.

Munsell colours in field-condition.

Table 50. Chemical data:

Lab. No.	Horizon	Depth (ins)	P Total (p.p.m.)	Ca Total (%)	Mg Total (%)	K Total (%)	C.E.C. (m.e.%)
S.2599	A1	0-2	68	0.06	0.01	0.25	2.50
S.2600	A12	2-3	155	0.02	0.07	0.19	6.29
S.2601	A21	3-14	100	0.02	0.07	0.19	3.25
S.2602	A22	14-29	102	0.01	0.11	0.24	2.64
S.2603	B1	29-38	86	0.02	0.10	0.26	3.55
S.2604	B2g	38-50+	149	0.02	0.15	0.35	3.96

5. MALANG FAMILY

MALANG SERIES. S.1140/45 (35-53)

Location: Fourth Division, middle Niah River valley, true left bank, almost opposite mouth of Sekaloh Stream.

Site: levee, about fifty feet from the river bank.

Parent Material: recent riverine clayey alluvium.

Topography: gentle slope of 2-3<sup>o</sup>, lower than highest point of levee.

Vegetation: primary or old secondary Riparian Forest with many fruit trees.

Drainage: imperfect internal drainage, medium to slow external drainage.

Weather: fine last two or three days.

Sampling date: 6.7.62.

Profile description:

No humus or litter.

0-5" (4-7) A1 orizon. S.1140

Brown (10YR 5/3) loam, friable and slightly plastic; crumbly; common fine to medium roots; clear smooth change to

5-10 (9-10) A2 horizon. S.1141

Pale brown (10YR 6/3) clay loam, with common, coarse, faint light grey patches and few, distinct, medium reddish brown and faint pale yellow mottles; slightly plastic; massive; common, medium to fine roots; clear distinct change to

10-16 (15-18) Bg horizon. S.1142.

Light yellowish brown (2.5Y 6/4) clay loam with abundant distinct prominent, coarse pale yellow to light grey, medium reddish brown and brownish yellow mottles; some soft black, possibly manganese concretions; friable to firm; massive; few medium roots; gradual even change to

16-29 (27-31) B2 horizon. S.1143

Pale yellow (2.5Y 7/4) clay loam, with abundant distinct, medium to coarse reddish brown and yellowish brown mottles; common fine black (manganese?) mottles; firm; massive; few fine roots; gradual smooth change to

29-36 (36-38) B22 horizon. S.1144

Strong brown (5YR 5/6) clay loam to clay, with abundant, prominent pale yellow, few medium to coarse light grey and abundant, faint, fine black (?manganese) mottles; firm; massive; few fine roots; clear, even change to

36-50+ B23 horizon. S.1145

As B22 horizon but fewer black and pale yellow mottles, very firm and no roots.

Note: This profile is situated behind the well-drained and stronger coloured Malang Series phase and exhibits surface-water rather than groundwater gleying.

Munsell colours in field condition.

No chemical data.

GREY-WHITE PODSOLIC SOILS

6. TRIBOH FAMILY

Augering description of undifferentiated series.

Location: Fourth Division, lower Sibuti River valley area near Menjelin Stream mouth about half a mile from true left bank in rubber garden on low hill.

Site: about ten feet from small gully, on undulating terrace top.

Parent Material: Quaternary, quartzose sandy alluvium, and weathered sandstone.

Topography: low terrace of Jerudong age, about thirty feet above local base level, slightly dissected by incised gullies.

Vegetation: poor, old seedling rubber with thick undergrowth of young seedlings.

Drainage: well drained internally; slow external drainage.

Weather: light showers overnight.

Description date: 17.6.62.

Augering description:

Scattered litter and thin humus.

0-9"

White loamy fine sand, loose, single grain; few roots.

9-35

Pale yellow fine sandy loam, very friable and containing many crumbling reddish brown and yellow sandstone fragments.

35-40+

Yellow fine sandy clay loam to clay with common distinct reddish yellow and light grey mottles; friable to firm, slightly plastic.

Notice:- The upper thirty five inches are probably terrace alluvium essentially while the soil beneath is possibly partly residual from the sandstone exposed in a gully nearby.

No chemical data available.

GROUNDWATER PODSOLS

7. MIRI FAMILY

MIRI SERIES. S.4317/24 (35-37)

- Location: coastal Fourth Division, about eight miles south of Miri in the Beraya area, Sample Area I, rentis 1, 1,350 feet.
- Site: about twelve feet from terrace edge.
- Parent Material: Quartzose beachsand of middle Quaternary age.
- Topography: about thirty feet above local base level and seventy feet a.s.l. on 'Jerudong' terrace.
- Vegetation: primary Heath Forest (see Sample Area I Vegetation Map); few trees with diameter exceeding twelve inches; thick lower storey of seedlings and young trees; almost 100% shade at ground level.
- Drainage: excessive to B22h horizon which is waterlogged. Very slow external drainage.
- Weather: fine last five or six days.
- Sampling date: 21.2.65.

Profile description:

3-0" O horizon. S.4317.

About one inch of litter and two inches of fine, granular or crumbly dark reddish brown (10YR 3/3) humus with abundant clear quartz grains and all sizes of roots; abrupt, wavy change to

0-2 (2-4) A1 horizon. S.4318.

Dark greyish brown (10YR 4/2) loamy sand, loose to very friable (less than 0.0); single grain to weak crumb; abundant clear quartz grains; abundant fine to coarse roots; clear, wavy change to

2-7 (6-9) A2 horizon. S.4319.

Greyish brown (10YR 5/2) loamy sand to sand; loose to very friable (less than 0.0); single grain, common medium and coarse roots; diffuse, even change to

7-17 (arbitrary change) A22 horizon. S.4320.

Light grey (10YR 7/1) sand, very friable to loose (0.5-0.175); weak angular blocky to single grain; few medium roots; arbitrary change to

17-26 (24-28) A23 horizon. S.4321.

Light grey to white sand (10YR 7/1-8/1); very friable to loose (0.25-1.25); weak angular blocky to single grain; no roots; clear, undulating change to

26-33 (32-35) B2h horizon. S.4322.

Dark greyish brown (10YR 4/2) loamy sand to sand, with common, distinct, coarse light greyish brown mottles, very friable to loose (0.5); single grain to weak blocky, moist to wet; clear, broken change to

33-46 (45-47) B22h horizon. S.4323.

Black (10YR 2/1) and very dark brown (10YR 2/2) loamy sand; moist to wet, non-sticky, non-plastic, firm to friable, but forming a hard pan in the profile (more than 4.5); sub-angular to angular blocky when broken; no roots; rapid groundwater seepage occurs; clear, smooth change to

46-56+ B23 horizon. S.4324.

Brown (10YR 5/3) loamy sand with distinct horizontal bands of dark brown; very firm and slightly softer than the above horizon when digging (more than 4.5); subangular blocky when broken; no roots; no obvious groundwater seepage.

Munsell colours in field condition.

Table 21. Chemical data.

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (p.p.m.)	P Av. (p.p.m.)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)	K Total (%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	C.E.C. (m.e.%)
S4317	O	3-0	3.3	40	3	0.04	96	0.09	101	0.05	98	120	30.50
S4318	A1	0-2	3.7	60	2	0.02	48	0.08	29	0.02	20	31	13.00
S4319	A2	2-7	4.4	35	trace	trace	0	0	0	0.01	50	26	0.80
S4320	A22	7-17	4.8	25	"	"	0	0	0	0.01	29	24	0.53
S4321	A23	17-26	4.8	35	"	"	0	0	0	0.01	20	26	0.53
S4322	B2	26-33	4.1	25	"	"	0	0	0	0.02	20	29	2.45
S4323	B22	33-46	3.7	27	3	"	0	0	0	0.03	23	31	8.55
S4324	B23	46-56	4.9	35	1	0.01	24	0.005	14	0.04	25	31	5.83

Lab. No.	Horizon	Depth (ins)	V/W % air	Org. C (%)	Group III (%)	SiO <sub>2</sub> (%) OD	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%) OD	TiO <sub>2</sub> (%)
S4317	O	3-0	84.2	26.31	0.70	58.83	0.09	0.32	0.13
S4318	A1	0-2	63.0	4.33	0.64	87.93	0.04	0.51	0.08
S4319	A2	2-7	21.7	0.24	0	96.76	0.04	0.44	0.04
S4320	A22	7-17	23.4	0.48	24.60	0.04	0.32	0.08	0.08
S4321	A23	17-26	23.7	0.06	0.16	95.70	0.04	0.44	0.19
S4322	B2	26-33	28.5	0.82	0	97.52	0.04	0.51	0.08
S4323	B22	33-46	33.6	1.30	0.06	98.1	0.04	0.38	0.08
S4324	B23	46-56	30.3	1.10	1.10	95.06	0.04	1.01	0.06

8. BUSO FAMILY

PENIAN SERIES. S.4331/36. (35-39)

- Location: coastal Fourth Division, about one mile south of K. Niah village, Sample Area II, rentis 4, 1,760 feet.
- Site: crest of a distinctive beach ridge.
- Parent Material: recent quartzose beach sand.
- Topography: old beach ridge, almost flat top, about two feet above nearby swale.
- Vegetation: primary Littoral Forest (see Sample Area II, Vegetation Map). About twenty five trees of more than twelve inches diameter within one hundred foot radius. Thick, pole-like sapling undergrowth, about 95% shade at ground level.
- Drainage: moderately well drained internally; very slow external drainage.
- Weather: fine and dry for the last ten or eleven days at least.
- Sampling date: 26.2.65.

Profile description.

- 3-0" O horizon. S.4331.  
Dark reddish brown humus; crumby; abundant clean quartz grains; abundant fine to coarse roots.
- 0-3 (1-3) A1 horizon. S.4332.  
Dark greyish brown (10YR 4/2) sand; loose; single grain; common fine to medium roots; clear, wavy change to
- 3-10 (8-11) A2 horizon. S.4333.  
Light brownish grey (10YR 6/2) sand, with few diffuse greyish brown mottles; loose, single grain; common fine and medium roots; gradual, smooth change to
- 10-29 (23-29) A3 horizon. S.4334.  
Pale brown (10YR 6/3) sand, with abundant quartz grains stained light yellowish brown; loose to very friable; single grain to very weak blocky; few medium roots; clear, broken change to
- 29-35 (35-45+) A32g. S.4335.  
Light grey (10YR 7/2) sand; few quartz grains stained yellowish brown; wet, non plastic, non sticky; single grain; quartz coarser than in top two feet; no roots; clear broken change to
- 35-45+ B2hg. S.4336.  
Dark brown (10YR 3/3) loamy sand; wet, non sticky, non plastic; no roots. This horizon tends to occur in bands and coarse patches.
- Watertable at 44" below O horizon; water tastes fresh but is rather smelly and dark brown in colour.
- Munsell colours in field condition.

Table 52. Chemical data:

Lab. No.	Horizon	Depth (ins)	pH(H <sub>2</sub> O) air fresh dry	P Total (p.p.m)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)	Total (%)	K Total (%)	K Exch. (m.e.%)	C.E.C. (m.e.%)
S4331	O	3-0	3.5	88	0.05	0.84	0.03	0.36	0.03	0.03	0.47	11.40
S4332	A1	0-3	3.5	40	0.05	0.60	0.02	0.35	0.02	0.03	0.06	4.70
S4333	A2	3-10	4.9	30	0.10	0.72	0.01	0.24	0.01	0.03	0.05	0.40
S4334	A3	10-29	4.7	45	0.07	0.78	0.01	0.12	0.01	0.03	0.04	1.00
S4335	A32g	29-35	5.0	20	0.05	0.84	0.01	0.24	0.01	0.03	0.04	1.10
S4336	B2hg	35-45	5.0	65	0.06	0.72	0.01	0.24	0.01	0.03	0.04	0.75

Lab. No.	Horizon	Depth (ins)	Total N (%)	Org. C (%)	Cond'y (micro mmos)	Gr. III (%)	V/# % air	SiO <sub>2</sub> (%)	Fe <sub>2</sub> O <sub>3</sub> (%)	Al <sub>2</sub> O <sub>3</sub> (%)	Na Exch. (m.e.%)
S4331	O	3-0	0.32	5.72	111	trace	52.8	82.8	0.09	0.26	0.11
S4332	A1	0-3	0.10	2.29	69	0.07	38.0	95.5	0.05	0.26	trace
S4333	A2	3-10	0.01	0.09	22	trace	27.3	94.1	0.05	0.19	0.11
S4334	A3	10-29	0.01	0.04	14	0.38	25.8	99.0	0.33	0.19	trace
S4335	A32g	29-35	trace	0.01	14	0.15	25.6	93.9	0.14	0.52	trace
S4336	B2hg	35-45	0.01	0.20	14	0.36	26.8	98.8	0.14	0.25	trace

GLEYSOILS

9. SEMADOH FAMILY

Augering description of undifferentiated series.

Location: on the low watershed area between the upper Sibuti River and a tributary of the upper Bakong, the Laong Stream, about one mile southeast of the border of the Bekenu-Niah-Suai area.

Site: on a low hill about ten feet from path leading to Rh. Laong.

Parent Material: predominantly Lambir Formation sandstone.

Topography: long, gently undulating dipslope of less than 8°, small pond nearby.

Vegetation: poor primary forest resembling Heath Forest.

Drainage: poor internal drainage, slow external drainage.

Weather: heavy rain overnight.

Description date: 2.5.65.

Augering description:

2-0" litter and humus.

0-2 Greyish brown sandy loam, with common, distinct light grey mottles; very friable; common roots.

2-19 Pale yellow and light grey sandy clay loam, with few, distinct, coarse brownish yellow mottles; friable.

19-35 Light grey clay, with common, distinct, medium, brownish yellow to reddish yellow mottles.

35-40+ Light grey clay, with common, distinct, medium strong brown mottles; plastic and slightly sticky.

Note:-  
As with all the Semadoh soils examined in the area, it cannot be dismissed that they are in part, if not fully, of alluvial origin. They are almost entirely found on low hills with gentle slopes at heights and in neighbourhoods where alluvial terraces also occur. This site, however, is adjacent to an area where a stream has incised its bed deeply, to expose hard sandstone forming a waterfall (Wong Ng. Singih), and above which groundwater movement is sufficiently impeded to give poorly drained residual Semadoh soils.

No chemical data available.

10. BLJAT FAMILY

Undifferentiated series. S.1039/42. (35-42)

Location: Fourth Division, middle Sibuti River Valley, 5,600 feet along path from Rh. Tinggi to the Tanyit Stream.

Site: close to Tanyit Stream, true right bank.

Parent Material: recent riverine clayey alluvium.

Topography: almost flat alluvial basin.

Vegetation: three-year old secondary growth consisting of sedges and hardy bushes.

Drainage: poor internal drainage, slow external drainage.

Weather: rain overnight.

Sampling date: 25.6.62.

Profile description (augering):

No litter or superficial humus.

0-7"

Brown silty loam, plastic, crumby; common roots.

7-15

Yellowish brown silty clay loam with abundant very faint pale yellow to light grey mottles, abundant dark brown manganese(?) streaks; mottles become coarser with depth, firm.

15-49

Mixed light grey, yellowish brown and pale yellow clay; common dark brown streaks as above, slightly plastic, slightly sticky.

49-50+

Light grey silty clay with few distinct dark brown streaks and reddish yellow mottles; plastic, sticky.

Table 53. Chemical data:

Lab. No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (p.p.m.)	Ca Total (%)	Mg Total (%)	K Total (%)
S1039	A1	0-7	4.3	363	0.05	0.28	0.56
S1040	Bg	7-15	4.1	254	0.02	0.25	0.52
S1041	Cg	15-30	4.0	189	0.01	0.22	0.46
S1042	C2g	30-49	4.0	182	0.02	0.25	0.65

11. PLAN FAMILY

SALITUT SERIES. augering description.

Location: Fourth Division, south of Miri at Luak Experiment Station, rentis 2, 1,800 feet.  
Site: about thirty feet from Luak Damit Stream.  
Parent Material: recent riverine sands.  
Topography: gently sloping ground behind highest point of stream levee.  
Vegetation: old secondary growth; dense shrubs and young trees.  
Drainage: poor internal drainage, slow external drainage.  
Weather: showery previous week.  
Description date: 24.8.63.

Augering description:

No litter or humus.

0-3"

Greyish brown fine sandy loam; very friable, many roots.

3-20

Yellowish brown fine sandy loam with few, faint light grey and strong brown mottles; very friable.

20-40

Pale brown and greyish brown sandy clay loam with common distinct strong brown mottles.

40-45+

Grey loamy sand; wet, non sticky, non plastic. Groundwater table 40" below surface.

No analytical data.

12. SEBANDI FAMILY (35-51)

Undifferentiated series - augering description. S.1108/11.

Location: Fourth Division, middle Bakong River valley, upper Malang Stream valley on path from Rh. Malang to Rh. Gudang Tengah.

Site: ten feet from path in flat ground under old rubber.

Parent Material: recent riverine clays.

Topography: flat alluvial land.

Vegetation: poorly maintained seedling rubber, about twenty years old. Thick undergrowth of sedges, rubber seedlings, pandans and hardy shrubs.

Drainage: very poor internal drainage, very slow external drainage.

Weather: heavy rain overnight and showery weather previously.

Sampling date: 21.6.62.

Profile description (augering).

0-3" A1 horizon.

Very dark greyish brown peaty loam; crumbly and moist; abundant roots.

3-9 Cg horizon. S.1108

Light yellowish brown clay, with common faint pale brown mottles; plastic and slightly sticky; common roots.

9-20 Cg2 horizon. S.1109

Light grey clay, with common distinct and diffuse reddish yellow mottles; plastic and sticky.

20-31 Cg3 horizon. S.1110.

Grey clay, with common distinct reddish yellow and olive yellow mottles; plastic and sticky.

31-45+ IIC horizon. S.1111.

Dark greyish brown peaty clay grading with depth to peat.

Table 54. Chemical data:

Lab. No.	Horizon	Depth (ins)	pH	P		P Av. (p.p.m.)	Org. C (%)	N Total (%)	C.E.C. (m.e.%)	Total bases
				Total (p.p.m.)	(p.p.m.)					
S1108	Al	3-9	7.4	1041	12	5.57		0.64	59.9	68.66
S1109	Cg	9-20	7.4	548	7				46.9	31.58
S1110	Cg2	20-31	7.0	715	20				58.9	59.82
S1111	IIC	31-45	5.4	265	14				95.1	85.22
Lab. No.	Horizon	Depth (ins)	Exchangeable (m.e. %)				Base sat. (%)	Mn. (p.p.m.)	SO <sub>4</sub> (%)	
			Ca	Mg	K	Na				
S1108	Al	3-9	61.25	6.84	0.32	0.25	100	7	0	
S1109	Cg	9-20	29.6	1.57	0.22	0.19	63	trace	0	
S1110	Cg2	20-31	52.13	7.09	0.36	0.24	100	trace	0	
S1111	IIC	31-45	78.56	6.38	0.28	0.0	90	trace	0.38	

13. GONG FAMILY

Undifferentiated series - augering description.

Location: Fourth Division, lower Sibuti River valley, Pelapi area, about two and a half miles from Sibuti River.

Site: about ten feet from path to the upper Kubab Stream on flank of low hill.

Parent Material: predominantly Quaternary, coarse-textured alluvium and colluvium.

Topography: low dissected terrace, about fifteen feet above recent alluvial valley; gently rounded hill with convex slopes of less than 15°.

Vegetation: old secondary forest with sedges, woody shrubs and pandans forming thick undergrowth.

Drainage: poor internal drainage, slow external drainage.

Weather: moderately dry weather for the last week.

Description date: 16.6.62.

Augering description:

Scattered litter and thin dark humus.

0-7"

Pale brown loamy sand; very friable, common roots.

7-12"

Pale brown and grey loamy sand; loose to very friable; few roots.

17-28"

Pale brown and grey sandy loam as coarse patches and containing light yellowish brown mottles; slightly plastic and slightly sticky.

28-45+"

Light grey sandy clay loam with common reddish yellow, pale brown and brownish yellow mottles, plastic; sticky.

No analytical data available.

14. TATAU FAMILY

~~4285/88 ?~~

TATAU SERIES.

Location: Coastal Fourth Division, near Niah River mouth, Sample Area II, rentis 1,500 feet.

Site: near a low swale among beach ridges.

Parent Material: recent quartzose marine sand.

Topography: a former beach, with slopes less than 5°.

Vegetation: secondary growth, consisting of sparse, coarse grasses and hardy shrubs (see Sample Area II, Vegetation Map).

Drainage: poor internal drainage, very slow external drainage.

Weather: fine for last ten days.

Description date: 24.2.65.

Soiling description:

No litter or humus.

0-7"

Greyish brown sand, with abundant clean quartz grains; much incorporated humus, loose; single grain; common fine roots.

7-20

Light greyish brown sand, with few, faint, diffuse light yellowish brown mottles; loose; few roots.

20-22

Grey sand, non sticky, non plastic, no roots.

22-43+

Light grey sand; non sticky, non plastic; few, prominent yellowish brown to strong brown mottles as far as 40".

Groundwater table 40" below surface.

No analytical data.

15. MATU FAMILY

Undifferentiated series - augering description.

Location: coastal Fourth Division, about half way between the Niah and Suai river mouths near the Senurok River, Sample Area III, rentis 1, 1,900 feet.

Site: near the edge of a beach ridge; adjacent to a swale.

Parent Material: recent quartzose marine sands.

Topography: on the margin of a beach ridge, slope less than 5°.

Vegetation: primary Littoral Forest (see Sample Area III); thin undergrowth among several trees of large girth.

Weather: fine for the last two weeks.

Description date: 28.2.65.

Augering description:

0-2"

Dark reddish brown loamy peat; friable; abundant roots.

2-6

Greyish brown sand; non plastic; non sticky; few roots.

6-29+

Light grey sand, with common distinct greyish brown mottles; non sticky; non plastic.

Too wet to auger deeper.

Groundwater table 25 inches from base of the O horizon.

No analytical data.

SALINE GLEY SOILS

16. RAJANG FAMILY

Undifferentiated series - augering description.

Location: lower Sibuti River valley, at left bank of mouth of Penirak Stream.

Site: 135 feet from river bank.

Parent Material: recent estuarine clay.

Topography: virtually flat estuarine swamp.

Vegetation: Saltwater Swamp Forest with mangrove, pandans and palm trees forming a thick growth.

Drainage: poor internal drainage; slow external drainage.

Weather: fine last few days.

Description date: 26.8.65.

Augering description:

0-14"

Brown mucky loam, with many dead roots and scattered surface debris.

14-31+

Dark grey clay loam containing much organic matter; plastic; moderately sticky and sulphurous smelling.

Conductivity of soil water 19,000 micro mhos by portable conductivity meter.

No further analytical data from this site.

17. PENDAM FAMILY

Undifferentiated series - 4387/90 (25-55)

Location: lower Sibuti River valley, near beginning of Kpg. Jangalas - coast track at the Jangalas Stream.

Site: about 150 feet from the true left bank of the Jangalas Stream.

Parent Material: recent mixed riverine and estuarine clays.

Topography: virtually flat land.

Vegetation: coconut garden containing sugar cane, bananas and ground cover of grasses.

Drainage: poor internal drainage; slow external drainage.

Weather: fine for last few days.

Sampling date: 5.4.61.

Profile description:

0-5" A1 horizon. 4387

Very dark greyish brown (10YR 3/2) silt loam to silty clay loam; slightly plastic and slightly sticky; massive to very weak blocky; many fine to medium roots; common earthworms; clear, smooth change to

5-18 Cg horizon. 4388

Greyish brown (10YR 5/2) silty clay, with common, fine distinct strong brown mottles mainly along root channels; sticky, slightly plastic; massive, many fine roots,

18-38 Cg2 horizon. 4389

Greyish brown (2.5Y 5/2) silty clay; plastic and sticky; massive; some fine organic particules in places; few fine roots.

38-56+ IIC horizon. 4390

Dark grey silty clay containing some fine and coarse decomposing organic matter; plastic and sticky; massive; no roots.

Groundwater table is at twelve inches from surface.

Munsell colours in field condition.

Lab. No.	Depth (ins)	Horizon	pH	P AV. (ppm)	Or. C (%)	Total N (%)	O.E.C. (m.e.%)		
								Ca	Mg
4387	0-4	A1	3.6	2	2.40	0.04	39.2		
4388	4-16	Cg	3.6	3	3.99	0.17	23.5		
4389	20-25	Cg2	3.9	8	4.29	0.17	24.1		
4390	40-56+	IIC	2.6	4	5.08	0.11	18.8		
Lab. No.	Depth (ins)	Horizon	Ca	Exchangeable (m.e.%)				Base sat. (%)	SO <sub>4</sub> (%)
				Mg	K	Na			
4387	0-4	A1	1.72	2.10	0.47	2.94	19	nil	
4388	4-16	Cg	0.84	1.41	0.13	0.81	14	nil	
4389	20-25	Cg2	0.94	2.35	0.16	0.56	17	nil	
4390	40-56+	IIC	0.90	1.84	0.21	1.17	22	0.96	

18. NONOK FAMILY

Undifferentiated series - augering description.

- Location: coastal Fourth Division, about four miles northeast of the Nyalau River mouth and a quarter of a mile inland from the coast.
- Site: two hundred feet from a stream flanked by Nypa vegetation known to be indicative of saline or brackish water.
- Parent Material: recent quartzose marine sands.
- Topography: swale among old beach ridges.
- Vegetation: few tall trees, palms (Oncosperma filamentosa), clear undergrowth.
- Drainage: poor internal drainage; very slow external drainage.
- Weather: heavy rain previous night.
- Description date: 1.5.61.

Augering description:

- 0-4"  
Dark brown loamy peat, common roots.
- 4-20  
Pale brown sand, non sticky, non plastic; few roots.
- 20-30+  
Light olive brown sand; non sticky, non plastic; no roots.
- Too wet to auger deeper. Groundwater at twelve inches from surface.
- No analyses available.

19. LIMBANG FAMILY

Undifferentiated series - augering description.

Location: Fourth Division, lower Sibuti River Valley near the Kalulit Kanan River mouth in a coconut garden.

Site: about one hundred feet from the Kalulit Kanan River.

Parent Material: deep organic debris.

Topography: virtually flat land.

Vegetation: four to five year old coconuts: ground between is bare. The previous vegetation was probably mangrove.

Drainage: very poor internal drainage; very slow external drainage. Small drains have been dug, but these were full of saltwater at the time of examinations.

Weather: heavy rain overnight.

Description date: 27.8.65.

Augering description:

0-12"  
Very dark brown peat; crumby.

12-50+  
Very dark brown mucky peat; large twigs and organic fragments identifiable.

Conductivity of groundwater (at 12 inches) is 20,000 micro mhos by portable conductivity meter.

No other chemical data available.

PEAT SOILS

20. IGAN FAMILY

Undifferentiated series - S.4337/39. (85-73)

Location: coastal Fourth Division, about mid way between the mouths of the Niah and Suai rivers, Sample Area III, 1,800 feet.

Site: margin of peat swamp.

Parent Material: organic debris overlying recent quartzose marine sand.

Topography: flat; more or less at the junction of the littoral beach ridges and swales, and the peat swamps.

Vegetation: Mixed Peat Swamp Forest (see Sample Area III); moderately thick undergrowth; several large-girthed trees with stillroots; many low pandans at ground level.

Drainage: very poor internal and very slow external drainage.

Weather: fine for the last two weeks.

Sampling date: 28.2.65.

Profile description:

0-31" O horizon. S.4337.

Dark brown to dark reddish brown peat, rather fine and fibrous; common roots.

31-37 IICg horizon. S.4338.

Greyish brown peaty sand with common patches of organic matter, slightly plastic, non sticky; few roots.

37-38+ IICg2 horizon. S.4339.

Light greyish brown sand, with common patches of organic matter; non plastic, non sticky; no roots.

Groundwater table within the O horizon and dark brown-coloured.

Table 56. Chemical data:

Lab.No.	Horizon	Depth (ins)	pH (air dry)	pH (wet)	P Total (p.p.m.)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)
S.4337	0	0-31	2.5	3.7	750	0.07	0.84	0.06	1.08
S.4338	Cg	31-37	2.5	3.1	40	0.1	0.74	0.01	0.48
S.4339	C2G	37-38+	2.8	3.5	50	0.08	0.67	0.01	0.17

Lab.No.	Horizon	Depth (ins)	K Total (%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	N Total (%)	Cond. micro mhos	C.E.C. (m.e.%)	Org. C (%)
S.4337	0	0-31	0.03	0.72	0.25	2.05	414	59.30	28.26
S.4338	Cg	31-37	0.06	0.05	0.11	0.03	829	2.80	1.57
S.4339	C2G	37-38+	0.03	0.06	0.31	0.02	373	1.90	1.06

21. MUKAH FAMILY

Undifferentiated series -- augering description.

Location: Fourth Division, upper Suai River Valley in area drained by lower Gelasah Stream in a small valley following path from Rh. Gelasah to the stream headwaters.

Site: an estimated one and a half miles from the longhouse in a flat-bottomed valley.

Parent Material: organic deposits and recent riverine clay.

Topography: flat land in valley.

Vegetation: young secondary growth after wet rice cultivation, consisting of sedges mainly.

Drainage: very poor internal and very slow external drainage.

Weather: rain overnight.

Description date: 19.7.62.

Augering description:

0-30"

Very dark brown peat; waterlogged and rather fibrous, with abundant roots.

30-40+

Light grey to white clay or silty clay; plastic and moderately sticky.

Groundwater table at the surface and dark brown-coloured.

No analyses are available.

22. ANDERSON FAMILY

ANDERSON SERIES. S.4379/82. -(35-79)

Location: coastal Fourth Division, between Niah and Suai rivers, about 10,000 feet from the coast in Sample Area III.

Parent Material: deep organic deposits.

Topography: almost flat surface of peat swamp.

Vegetation: Alan Forest (see Sample Area III).

Drainage: very poor internal and very slow external drainage.

Weather: fine for last two weeks.

Sampling date: 28.2.65.

Profile description:

0-50"+

Very dark brown to dark reddish brown woody peat, rather less wet in the upper six inches than below. Divided arbitrarily into four twelve-inch layers for sampling. Groundwater table lies at about six inches and is dark brown-coloured.

Table 57. Chemical data:

Lab.No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (p.p.m.)	Ca Total (%)	Ca Exch. (m.e.%)	Mg Total (%)	Mg Exch. (m.e.%)	K Total (%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	C.E.C. (m.e.%)
S4379	0	0-12	(1:5) 3.2	335	0.03	0.95	0.04	1.20	0.08	0.67	0.76	86.00
S4380	02	12-24		208	0.02	0.95	0.006	1.44	0.08	0.38	0.78	89.60
S4381	03	24-36		95	0.03	0.48	0.01	0.72	0.08	0.10	0.70	99.00
S4382	04	36-48	(1:5) 3.2	95	0.04	0.72	0.04	0.72	0.08	0.10	0.83	100.00
Lab.No.	Horizon	Depth (ins)	Org C (%)	Group III (%)	Loss on ignition (%)							
S4379	0	0-12	28.22	0.46	98.87							
S4380	02	12-24	28.22	0.42	98.85							
S4381	03	24-36		0.34	99.05							
S4382	04	36-48		0.44	99.00							

CALCIC ORGANIC SOILS

23. KAPOR FAMILY

Undifferentiated series - augering description.

Location: Fourth Division, summit of Subis Mountain,  
Niah area.

Parent Material: organic deposits.

Topography: rugged karst.

Vegetation: Limestone Forest with thick undergrowth and a  
few medium-girth trees.

Drainage: well drained internally, very slow external  
drainage.

Weather: showers overnight.

Description date: 4.7.62.

Augering description:

0-6"  
Scattering of leaves on crumby very dark brown (mull ?),  
ramified by network of fine and medium roots.

6+  
Large angular limestone boulders.

No chemical data are available.

BROWN FOREST SOILS

24. KABULOH FAMILY

(i) KABULOH SERIES (type profile) S.2562/68. (35/1-7)

- Location: Fourth Division, Luak Experiment Station, rentis 5, 5,600 feet.
- Site: on sloping land about four hundred feet from the rentis at 60° from north.
- Parent Material: calcareous light olive grey shale of the Sibuti Formation.
- Topography: on a slight three-foot rise among very gently undulating land.
- Vegetation: primary Lowland Dipterocarp Forest with several large-girthed trees nearby. A thick middle storey and ground storey giving about 80% shade at ground level.
- Drainage: well to moderately well drained internally, slow to medium external drainage.
- Weather: fine for the last two days.
- Sampling date: 8.10.63.

Profile description:

1-0" O horizon

Litter, twigs, no humus.

0-3 (2-5) A1 horizon. S.2562

Mixed dark greyish brown (10YR 4/2) and brownish yellow (10YR 6/6) clay loam, friable, tended to be slightly plastic; strong, coarse crumb to subangular blocky, common fine to coarse roots; gradual, wavy change to

3-9 (7-11) A/B horizon. S.2563

Light yellowish brown (2.5Y 6/4) clay loam; firm, sub-angular blocky, with clay skins on structural faces; common medium roots; gradual, smooth change to

9-22 (19-23) B2 horizon. S.2564

Light yellowish brown (2.5Y 6/4) clay; firm; blocky, with clay skins on structural faces; common ant activity; common medium roots; gradual smooth change to

22-40 (37-41) B22 horizon. S.2565

Pale yellow (2.5Y 7/4) clay with abundant fine to medium dark brown (manganese?) mottles; very firm; blocky, with clay skins on structural faces, common medium roots; smooth gradual change to

40-45 (40-46) B3 horizon. S.2566

Greyish brown (2.5Y 5/2) clay, with abundant distinct brownish yellow and few dark brown mottles; very firm with tendency to be slightly plastic; massive to slightly blocky; clear, smooth change to

45-55+

Light olive grey (5Y 6/2) platy, calcareous shale.

Munsell colours in field-moist condition.

Table 58. Chemical data:

Lab.No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	P Total (ppm)	Ca Total (%)	Mg Total (%)	K Total (%)	C.E.C. (m.e.%)	Org. C (%)	Group III (%)	V/W % air
S2562	A1	0-3	6.5	306	0.6	0.4	0.5	33.25	2.59	9.8	17.7
S2563	A2	3-9	6.3	232	0.5	0.4	0.6	27.13	1.21	11.0	14.0
S2564	B21	9-22	7.2	190	0.6	0.4	0.7	27.80	0.77	13.9	-
S2565	B22	22-40A	7.2	195	0.5	0.4	0.5	29.38	0.81	11.0	10.5
S2566	B3	22-40B	7.5	315	2.7	0.4	0.6	39.13	0.38	11.4	12.8
S2567.	C1	40-45	7.7	350	9.8	0.7	0.7	20.36		10.3	10.2
S2568	G2	45-55+	7.4	325	9.7	1.0	0.6	15.91		9.6	14.9

(11) PENIRAK SERIES: S.4566/69 (augering) (3530)

Location: Fourth Division, lower Sibuti River basin, Penirak area, close to timber railway from Kaya Kapor camp to the hills in the southeast.

Site: mid slope of hill that the railway makes a cutting through.

Parent Material: shale, and probably marl of Lambir Formation.

Topography: convex slope of 22° on hill about sixty feet high, from which limestone protrudes in places.

Vegetation: old secondary regrowth from hill rice cultivation, about ten years old. Several trees of more than twelve inches girth occur.

Drainage: well drained internally; medium to rapid external drainage.

Weather: fine for last two days.

Sampling date: 30.8.65.

Profile description.

2-0"  
Surface litter, no humus.

0-2 Al horizon. S.4566  
Dark greyish brown clay; firm; fine, strong, subangular blocky; common roots.

2-8 B2 horizon. S.4567  
Dark yellowish brown (10YR 4/4) clay, very firm; medium-strong subangular blocky; few roots.

8-18 B22 horizon. S.4568  
Yellowish brown (10YR 4/6) clay; very firm; strong subangular blocky; distinct black (manganese?) streaks on augered soil core; few roots.

18-24 B23 horizon. S.4569  
Yellowish brown (10YR 4/6) clay among hard limestone; very firm; no roots; black streaks as above, but less clear.

24+  
Too much limestone to auger.  
Munsell colours in field-moist condition.

Table 59. Chemical data:

Lab.No.	Horizon	Depth (ins)	pH (H <sub>2</sub> O)	Ca Exch (m.e.%)	Mg Exch (m.e.%)	K Exch. (m.e.%)	Na Exch. (m.e.%)	N Total (%)	C.E.C. (m.e.%)	Org C (%)	Gr. III (%)	V/W % air	CaCO <sub>3</sub> (%)
S4566	A1	0-2	6.0	29.3	< 0.05	0.38	0.24	0.46	25.0	4.88	10.90	51.96	0.14
S4567	B2	2-8	6.0	20.1	< 0.05	0.29	0.15	0.30	20.5	2.80	11.01	13.89	0.16
S4568	B22	8-18	6.7	26.5	< 0.05	0.18	0.12	0.20	21.0	1.39	15.52	13.22	0.07
S4569	B23	18-24	7.4	42.8	< 0.05	0.11	0.14	0.17	26.5	1.07	18.26	13.31	0.60

RECENT ALLUVIAL SOILS

25. KAYAN FAMILY

Undifferentiated series - S.1210/17.

- Location: Fourth Division, middle Suai River Valley, on the true left bank of the Suai River near the mouth of the Keliring Stream.
- Site: about thirty feet from the river bank.
- Parent Material: recent riverine alluvium.
- Topography: levee, about twelve feet above the river level; slightly undulating surface.
- Vegetation: secondary regrowth, four or five years old, consisting of sedges, grasses and ferns with a few bushes and shrubs.
- Drainage: imperfect internal drainage, slow external drainage.
- Weather: showers during the day.
- Sampling date: 18.7.62.

Profile description:

Thin scattering of litter; surface bare in patches.

0-5" (5-7) A1 horizon. S.1210

Pale brown (10YR 6/3) fine sandy loam; few very faint fine yellowish brown mottles; friable; weak crumby; abundant fine to medium roots; clear smooth change to

5-18 (17-18) A2 horizon. S.1211

Yellowish brown (10YR 5/6) loamy sand; top four inches mottled slightly with colours from above horizon, and the lower four inches with colours from the subjacent horizon, and with light grey and reddish yellow; very friable; massive to weak blocky; common medium roots; clear smooth change to

18-21 (21-22) A22 (?) horizon. S.1212

Pale brown (10YR 6/3) fine sandy loam, with abundant, distinct, diffuse light grey (10YR 7/1) and reddish yellow mottles; very friable; weak blocky; common fine to medium roots; abrupt clear change to

21-29 (28-29) A23(?) horizon. S.1213

Yellowish brown (10YR 5/6) fine sandy loam; friable and slightly plastic; massive, breaking to weak subangular blocky; common fine to medium roots; clear, smooth change to

29-39 (35-40) A24(?) horizon. S.1214.

Yellowish brown (10YR 5/4) fine sandy loam with few faint, fine light grey mottles; friable, slightly plastic, massive, breaking to weak subangular blocky; few fine roots; few faint clay skins; gradual wavy change to

39-54 (53-55) B2 horizon. S.1215.

Yellow (10YR 7/6) fine sandy loam to fine sandy clay loam, with few, faint, coarse grey and reddish yellow mottles, massive, breaking to weak subangular blocky, friable, very few fine roots; abrupt, wavy change to

54-68 (68-70) IIC horizon. S.1216.

Brownish yellow to yellowish brown (10YR 6/6-5/6) fine sandy clay loam to silty clay loam, with common, faint, medium, light grey and reddish yellow mottles; firm but plastic; massive, breaking to subangular blocky; clay skins visible in places; few fine to medium roots; gradual, smooth change to

68-83+ IIC2 horizon. S.1217.

Yellowish brown (10YR 5/4) fine sandy clay loam to silty clay, with common distinct, light grey mottles, firm but plastic; massive, breaking to angular blocky; no roots; some charcoal(?).

Munsell colours in field-moist condition.

Lab.No.	Horizon	Depth (ins)	PH	P AV. (ppm)	Organic (%)			Total N (%)	C.E.C. (m.e.%)
					Ca	K	Na		
Lab.No.	Horizon	Depth (ins)	Ca	Mg	Exchangeable m.e.%			% Base Sat.	Mn (in ppm)
					Ca	K	Na		
S1210	A1	0-5	4.6	3	1.44		0.09	8.0	
S1211	A2	5-18	4.7	1				0.9	
S1212	A22?	18-21	4.6	trace				4.1	
S1213	A23?	21-29	4.6	trace				4.0	
S1214	A24?	29-39	4.5	trace				3.2	
S1215	B2	39-54	4.7	trace				4.0	
S1216	IIC	54-68	4.6	0.0				7.7	
S1217	IIC2	68-83	4.6	0.0				5.0	
S1210	A1	0-5	0.31	0.22	0.09	0.0	8	trace	
S1211	A2	5-18	0.0	0.15	0.03	0.0	20	trace	
S1212	A22?	18-21	trace	0.0	0.03	0.03	1	trace	
S1213	A23?	21-29	trace	0.10	0.04	trace	4	trace	
S1214	A24?	29-39	0.21	0.10	0.04	0.0	11	trace	
S1215	B2	39-54	0.10	0.10	0.06	0.0	7	trace	
S1216	IIC	54-68	0.0	0.15	0.05	0.0	3	trace	
S1217	IIC2	68-83	0.21	0.10	0.03	0.0	7	0	

26. KABONG FAMILY

OYA SERIES. S.4325/30. (35-66)

- Location: coastal Fourth Division, Niah River mouth area, Sample Area II, rentis 2, 230 feet.
- Site: about forty feet from the most recent coastal beach.
- Parent Material: recent quartzose beach sand.
- Topography: on a gentle slope of less than  $5^{\circ}$  of an old beach ridge.
- Vegetation: secondary regrowth after water melon cultivation, about two years old. Mainly coarse, tufted grasses and hardy shrubs (see Vegetation Map, Sample Area II).
- Drainage: internal drainage free to excessive, external drainage very slow.
- Weather: fine for last ten days.
- Sampling date: 26.2.65.

Profile description.

No surface litter or humus.

0-2" (1-3) A1/2 horizon. S.4325.

Greyish brown (10YR 5/2) sand; loose; single grain; abundant quartz grains, some stained light yellowish brown and yellowish brown; common patches of humus; common fine to medium grass roots; clear even change to

2-11 (11-13) A2 horizon. S.4326.

Light brownish grey (10YR 6/2) sand, with common light yellowish brown and yellowish brown and clean quartz grains; loose; single grain; common medium roots; clear, wavy change to

11-27 (25-35) B1 horizon. S.4327.

Light yellowish brown and brown (10YR 5/3) sand, with common diffuse and few coarse prominent yellowish brown and dark yellowish brown mottles, also coarse patches of light grey to pale brown towards base of horizon (Subsample S.4328); loose; single grain; few medium grass roots, two large Casuarina roots, abrupt, broken change to

27-40 (40-42) B2 horizon. S.4329.

Yellowish brown and brown (10YR 5/3) sand to loamy sand; with few distinct, coarse light grey mottles; the darker colour is concentrated in bands and almost circular patches, possibly associated with roots and deposition layers, and there is a distinct line at the top of this boundary, loose and very friable, no roots; smooth even change to

40-60+ Cg horizon. S.4330.

Light grey to grey (10YR 7/2) sand, with common, fine black specks, while shell fragments and light yellowish brown to yellowish brown quartz grains; non sticky, non plastic, no roots; water table at fifty one inches below surface and fresh. There are a few, prominent, coarse dark reddish brown mottles probably associated with old twigs or roots.

Note:-

This profile is tending towards the Buso Family Groundwater Podsol.

Munsell colours in field condition.

Lab. No.	Horizon	Depth (ins)	pH air dry	pH (wet)	P total p.p.m.	C <sub>1</sub>		M <sub>3</sub>		K	
						Total (%)	Exch. (m.e./%)	Total (%)	Exch. (m.e./%)	Total (%)	Exch. (m.e./%)
S4325	AL/2	0-2	5.3	3.5	60	0.10	0.55	0.06	0.65	0.03	0.06
S4326	A2	2-11	4.5	4.2	50	0.10	0.36	0.02	0.60	0.03	0.05
S4327	B1	11-27A	5.0	4.8	50	0.06	1.03	0.03	0.22	0.03	0.05
S4328	B1	11-27B	5.5	5.7	25	0.08	0.60	0.01	0.48	0.03	0.05
S4329	B2	27-40	5.4	5.8	88	0.06	0.48	0.01	0.48	0.03	0.05
S4330	C3	40-60+	5.0	5.8	50	0.06	0.48	0.02	0.60	0.03	0.05

Lab. No.	Horizon	Depth (ins)	Na Exch. (m.e./%)	N total (%)	Conductivity micromhos	C.E.C. (m.e./%)	O.C. C (%)	Group III (%)	V/W % air
S4326	A2	2-11	0.12	0.01	27	0.60	0.16	0.76	27.0
S4327	B1	11-27	0.11	0.01	27	0.80	0.08	0.08	24.7
S4328	B1	11-27	0.11	0.01	41	1.20	0.04	0.32	225.1
S4329	B2	27-40	0.11	0.01	14	0.60	0.07	1.05	24.8
S4330	C3	40-60	0.11	0.01	22	1.30	0.03	0.82	25.8

SKELETAL SOILS

27. MELUAN FAMILY

Undifferentiated series - augering description.

- Location: Fourth Division, Suai River Valley, upper Mulis Stream on path from lower Mulis area to Batu Niah.
- Site: about fifteen feet from path near low lying alluvial area in headwaters of Mulis Valley.
- Parent Material: probably residual/alluvial/colluvial clayey mixture overlying limestone.
- Topography: gently undulating low hill about fifteen feet high, through which hard limestone protrudes in places.
- Vegetation: very old secondary Lowland Dipterocarp Forest; quite thick undergrowth and about 90% shade at ground level.
- Drainage: internal drainage imperfect; external drainage slow.
- Weather: fine for last three days.
- Description date: 14.7.62.

Augering description:

Scattered litter, no humus.

0-3"

Dark brown loam with some charcoal fragments; crumbly; abundant roots.

3-9"

Brownish yellow clay loam to clay, with abundant faint to distinct light grey and pale yellow mottles becoming diffuse with increasing depth; friable to firm; few roots.

9+

Hard olive grey limestone, not augerable.

Note:-

Four augerings within ten feet gave soil depths of 10", 14", 12" and 14" before reaching hard limestone; one other augering was more than 48 inches deep.

No chemical data.

28. KAPIT FAMILY

Undifferentiated series - augering description.

Location: Fourth Division, lower Sibuti area, Benawas Hill.

Site: upper slope about ten feet from ridge top.

Parent Material: fine sandstone or sandy shale, of the Lambir Formation.

Topography: on a ridge slope of  $70^{\circ}$ , ridge height, about two hundred feet; stepped slope.

Vegetation: old rubber garden with thick undergrowth of rubber seedlings, and other saplings and pandans.

Drainage: internal drainage free, external drainage rapid.

Weather: fine for the last week.

Date of descriptions: 14.6.62.

Augering description:

No litter or humus.

0-8"

Light yellowish brown fine sandy clay loam; very friable to loose; slightly crumbly; a few hard subangular stones; few roots.

8.

Rubby greyish brown fine sandstone (no reaction to HCl).

No chemical data.

APPENDIX C - ANALYTICAL METHODS USED IN SOIL

CHEMICAL ANALYSIS AND SOIL FERTILITY

RATINGS.

1. pH: by glass electrode using soil/distilled water ratio of 1:2.5 on air-dried soil, unless otherwise stated.
2. Conductivity: by electric conductivity meter giving micro mhos/cm. at 25°C.
3. Organic carbon: by Walkley - Black's method (Jackson, 1958, p.219).
4. Nitrogen: by Kjeldahl's method (op. cit., p.183).
5. Sulphate: by turbidity method (op. cit., p.265).
6. Calcium carbonate: by Tinsley's method (Metson, 1956, p.26).
7. Manganese: by potassium periodate method (Jackson, 1958, p.105).
8. 'Reserve' nutrients: one gram of soil is ignited at 800°C for thirty minutes and then digested with concentrated hydrochloric acid for thirty minutes. Total phosphorus is extracted with perchloric acid and then determined by the molybdenum blue method using ascorbic acid as the reducing agent. Calcium and magnesium are determined by E.D.T.A. titration after removing iron and aluminium by precipitation as hydroxides. Potassium is determined by flame photometer (Bailey, 1966, in press).
9. Group III compounds. These consist of mainly iron and aluminium oxides with chromium oxide. The compounds, comprising almost entirely iron and aluminium in the soils of this area, are determined by taking the precipitated hydroxides from 'reserve' nutrient analysis (see 8 above), igniting them and weighing (Bailey, 1966, in press).
10. Exchangeable bases. Cation exchange capacity is determined by leaching the soil with N ammonium acetate, and for highly calcareous soils by an alternative method described by Metson (1956, p.104-114). Calcium and magnesium are determined by E.D.T.A. titration after destroying the ammonium acetate by evaporation and ignition. Potassium and sodium are measured by flame photometer (op. cit.).
11. 'Available' phosphorus: extracted using 0.03N  $\text{NH}_4\text{F}$  and 0.1N HCl (Bray and Kurtz solution II). The phosphorus is measured using Fogg and Wilkinson's method (1958).
12. Bulk density: by displacing air from a weighed soil ped with kerosene, and by measuring the volume of the ped by the displacement of kerosene (Bailey, pers. com., 1966).
13. Air/soil percentage on a volume/weight basis. This is an alternative method to 12 above used for structureless, loose, single grain sands. It is measured by determining the weight of kerosene required to displace air from weighed soil occupying a known volume.

14. Total silica, aluminium, iron and titanium: by fusion with sodium carbonate, using Dobritskaya's method (1962).
15. Mechanical analysis: based on Piper's pipette method (1950, p.59-74).

The size of soil separates are those of the U.S. Department of Agriculture's Scheme (U.S.D.A., 1951, p.207).

<u>Size</u>	<u>Millimeters</u>	<u>British standard equivalent mesh size.</u>
Very coarse sand	2.0 - 1.0	8 - 16
Coarse sand	1.0 - 0.5	16 - 30
Medium sand	0.5 - 0.25	} 30 - 60
Fine sand	0.25 - 0.10	
Very fine sand	0.10 - 0.05	60 - 150
Silt	0.05 - 0.02	} filtrate from 150 mesh size.
Clay	less than 0.02	

#### SOIL FERTILITY RATINGS.

The following table is extracted from the Agricultural Chemist's Annual Report, 1964 (Department of Agriculture, 1966, p.66). It is based on greenhouse and field experiments with annual crops on mainly Red-Yellow Podsollic soils.

Table 42. Soil Fertility Ratings.

NUTRIENTS	LOW		MEDIUM		HIGH	
	(less than)				(more than)	
P-total (p.p.m.)(%)	400	0.04	400-700	0.04-0.07	700	0.07
P-available (p.p.m.)(%)	20	0.002	20-60	0.002-0.006	60	0.006
K-available (p.p.m.)(%)	50	0.005	50-150	0.005-0.015	150	0.015
Ca-available (p.p.m.)(%)	500	0.05	500-2000	0.05 - 0.20	2000	0.20
Mg-available (p.p.m.)(%)	100	0.01	100-2000	0.02 - 0.20	2000	0.20
N-total (%)		0.25		0.25 - 0.50		0.50
pH		4		4 - 5		5
C.E.C. (m.e.%)		10		10 - 20		20
C (%)		2		2 - 10		10
'Reserve' iron and aluminium oxides (%)		5		5 - 20		20

Notes on the table: The levels given are those found to correlate most significantly with yields of certain annual crops, such as maize, hill rice and spinach, and although they can be used with discretion as a guide to soil fertility for some perennial crops, it is unlikely that the ratings will be as significant for such crops.

The soil analyses used most for soil classification are those giving total or 'reserve' levels. The latter give levels approximating to the total and are not directly related to soil fertility, as only a proportion of the 'reserve' levels are available to plants. 'Reserve' levels can be used indirectly to indicate soil fertility, however, by comparing them with the 'available' ratings in Table 42 above. Clearly, where 'reserve' nutrients are less than the 'low' 'available' nutrient rating the soil is extremely impoverished in this nutrient: but where the 'reserve' level exceeds the 'high' 'available' rating, no valid comparisons can be made.

The exchangeable nutrients levels are given in some tables. These approximate to the 'easily available' nutrients. They can be compared similarly to the ratings in Table 42, only where the levels exceed the 'low' 'available' rating.

APPENDIX D - ACREAGES OF THE SOIL MAPPING UNITS IN MAP 4

SOIL ASSOCIATION	MAPPING SYMBOL	ACREAGE (nearest 10)	PERCENTAGE OF AREA (nearest 0.1%)
Anderson 1	And 1	12,300	1.4
Anderson 2	And 2	46,260	5.5
Anderson 3	And 3	89,550	10.7
Bako/Meluan	Bko/Mln	2,430	0.3
Bako/Nyalau	Bko/Nyl	740	0.9
Bako/Semadoh	Bko/Smd	1,370	0.2
Bekenu	Bkn	440	< 0.1
Bekenu/Anderson	Bkn/And	1,260	0.2
Bekenu/Kapit	Bkn/Kpt	24,800	2.9
Bekenu/Kayan	Bkn/Kyn	920	0.1
Bekenu/Malang	Bkn/Mlg	8,660	1.0
Bekenu/Merit	Bkn/Mrt	113,020	13.6
Bekenu/Miri	Bkn/Mri	740	0.1
Bekenu/Nyalau	Bkn/Nyl	70,190	8.4
Bijat	Bjt	14,240	1.7
Bijat/Anderson	Bjt/And	19,170	2.3
Bijat/Kapit	Bjt/Kpt	50	< 0.1
Bijat/Kayan	Bjt/Kyn	690	0.1
Bijat/Malang	Bjt/Mlg	42,090	5.0
Bijat/Mukah	Bjt/Mkh	20,040	2.4
Bijat/Pendam	Bjt/Pnd	1,560	0.2
Buso	Bso	230	< 0.1
Buso/Igan	Bso/Ign	1,960	0.2
Buso/Matu	Bso/Mtu	330	< 0.1
Buso/Tatau	Bso/Tta	180	< 0.1
Gong/Malang	Gng/Mlg	90	< 0.1
Igan	Ign	10,150	1.2
Kabong/Tatau	Kbn/Tta	210	< 0.1
Kabuloh	Kbl	90	< 0.1
Kabuloh/Malang	Kbl/Mlg	140	< 0.1
Kabuloh/Merit	Kbl/Mrt	50	< 0.1
Kabuloh/Nyalau	Kbl/Nyl	1,840	0.2
Kapit	Kpt	40	< 0.1
Kapor/Rock	Kpr/Rock	2,580	0.3
Kayan	Kyn	970	0.1
Kayan/Malang	Kyn/Mlg	8,800	1.0
Kayan/Plan	Kyn/Pln	420	0.1
Matu/Igan	Mtu/Ign	12,760	1.5

SOIL ASSOCIATION	MAPPING SYMBOL	ACREAGE (nearest 10)	PERCENTAGE OF AREA (nearest 0.1%)
Merit	Mrt	104,570	11.3
Merit/Anderson	Mrt/And	1,790	0.2
Merit/Kayan	Mrt/Kyn	800	1.0
Merit/Malang	Mrt/Mlg	116,480	13.9
Merit/Meluan	Mrt/Mln	2,120	0.2
Merit/Miri	Mrt/Mri	1,870	0.2
Merit/Nyalau	Mrt/Nyl	31,570	3.8
Miri	Mri	2,460	0.3
Miri/Nyalau	Mri/Nyl	2,320	0.3
Miri/Triboh	Mri/Trb	3,020	0.3
Mukah	Mkh	650	0.1
Mukah/Anderson	Mkh/And	5,180	0.6
Mukah/Limbang	Mkh/Lmb	780	0.1
Nyalau	Nyl	4,750	0.5
Nyalau/Kapit	Nyl/Kpt	26,740	3.2
Pendam	Pnd	810	1.0
Rajang	Rjn	6,450	0.8
Rajang/Limbang	Rjn/Lmb	2,560	3.0
Rajang/Nonok	Rjn/Nnk	1,780	0.2
Tatau	Tta	720	0.9
Tatau/Igan	Tta/Ign	270	0.1
Semilajau	Sml	90	0.1
Semilajau/Malang	Sml/Mlg	1,070	0.1
<b>Total</b>		<b>830,210</b>	<b>(1,297 square miles)</b>

Total area by measuring perimeter

832,357 (1,300 square miles).

APPENDIX E - GLOSSARY OF TECHNICAL AND LOCAL TERMS

The following technical terms are arranged alphabetically and are largely defined in the U.S. Department of Agriculture's Soil Survey Manual (1951) and in the Seventh Approximation to their Soil Classification (1960), except in the case of soil texture where some general terms are defined as used in Sarawak.

A HORIZON. Mineral horizon consisting of: (1) horizon of organic-matter accumulation formed or forming at or adjacent to the surface; (2) horizon that has lost clay, iron or aluminium with resultant concentration of quartz or other resistant minerals of sand or silt size; or (3) horizon dominated by 1 or 2 above but transitional to an underlying B or C horizon (U.S.D.A., 1960, p. 25).

A1 HORIZON. Mineral horizon, formed or forming at or adjacent to the surface, in which the feature emphasised is an accumulation of humified organic matter intimately associated with the mineral fraction (op. cit.).

A2 HORIZON. Mineral horizon in which the feature emphasised is loss of clay, iron or aluminium, with resultant concentration of quartz or other resistant minerals in sand and silt sizes (U.S.D.A. 1960, p.25-26).

ALBIC HORIZON. A surface or lower horizon having such thin coatings on the sand and silt particles that the hue and chroma of the horizon are determined primarily by the colour of the sand and silt particles. Especially in soils rich in quartz, moist chromas of albic horizons are 3 or less, and dry chromas less than 3. Chromas are lower than those of an underlying argillic horizon, unless the chroma of the argillic horizon is 2 or less. Dry values are higher and moist values usually higher than those of an underlying argillic horizon, and always higher than those of an underlying spodic horizon. An albic horizon usually lies on an argillic horizon, spodic horizon or on a fragipan or an equally impervious horizon or layer (U.S.D.A., 1960, p.60).

ARGILLIC HORIZON.

An argillic horizon forms below an eluvial horizon but may occur at the surface if a soil has been partially truncated. It meets the following requirements:

1. Where an eluvial A remains, and there is no lithologic discontinuity between the A and the argillic horizon, it contains more clay than the A as follows:
  - a. If the A has less than 15 per cent clay in the fine earth (less than 2 mm.) fraction, the argillic horizon must contain at least 3 per cent more clay than the A. (13 per cent versus 10 per cent, for example).
  - b. If the A has more than 15 per cent clay and less than 40 per cent in the fine earth fraction, the ratio of the clay in the argillic horizon to that in the A must be 1.2 or more.

c. If the A has more than 40 per cent clay in the fine earth fraction, the argillic horizon must contain at least 8 per cent more clay than the A. (50 per cent versus 42 per cent, for example).

2. The argillic horizon must be at least one-tenth the thickness of the sum of all overlying horizons, or more than 15 mm. (6 inches) thick; and the clay increases required under item 1 must be reached within a vertical distance of 30 cm. (12 inches) or less.
3. If peds are present, an argillic horizon must show clay skins on some of both the vertical and horizontal ped surfaces and in the fine pores, or must show oriented clays in 10 per cent or more of the cross section.
4. If a profile shows a lithologic discontinuity between the A and the argillic horizon, or if only a plow layer overlies the argillic horizon, the argillic horizon need show only clay skins in some fine pores and, if peds exist, on some vertical and horizontal ped surfaces, or the clay skins must constitute approximately 10 per cent of the cross section.
5. The argillic horizon does not necessarily have more clay than the C horizon, but it should have more fine clay than the C (U.S.D.A., 1960, p.35-45).

B HORIZON. Horizon in which the dominant feature or features is one or more of the following:

1. An illuvial concentration of silicate clay, iron, aluminium, or humus, alone or in combinations;
2. A residual concentration of sesquioxides or silicate clays, alone or mixed, that has formed by means other than solution and removal of carbonates or more soluble salts;
3. Coatings of sesquioxides adequate to give conspicuously darker, stronger or redder colours than overlying and underlying horizons in the same sequum but without apparent illuviation to meet requirements of 1 or 2 in the same sequum, condition in sequums lacking conditions defined in 1, 2 and 3 that obliterates original rock structure, that forms silicate clays, liberates oxides, or both, and that forms granular, blocky or prismatic structure if textures are such that volume changes accompany changes in moisture (U.S.D.A., 1960, p.26).

B2 HORIZON. That part of the B horizon where the properties on which the 'B' is based are without clearly expressed subordinate characteristics indicating that the horizon is transitional to an adjacent overlying A or an adjacent C or R (U.S.D.A., 1960, p.27).

Bh HORIZON. A B horizon in which accumulations of decomposed illuvial organic matter, appearing as dark coatings on sand or silt particles, or as discrete dark pellets of silt size, are indicated by h. If used, this suffix follows the letter B or a subdivision of B, as Bh or B2h (U.S.D.A., 1960, p.28).

Bir HORIZON. A B horizon which containing accumulations of illuvial iron as coatings on sand or silt particles or as pellets of silt size; in some horizons the coatings have coalesced, filled pores, and cemented the horizon (U.S.D.A., 1960, p.28).

C HORIZON. A mineral horizon or layer, excluding bedrock, that is either like or unlike the material from which the solum is presumed to have formed, relatively little affected by pedogenic processes, and lacking properties diagnostic of A or B but including materials modified by:- (1) weathering outside the zone of major biological activity; (2) reversible cementation, development of brittleness, development of high bulk density, and other properties characteristics of fragipans; (3) gleying; (4) accumulation of calcium or magnesium carbonate or more soluble salts; (5) cementation by such accumulations as calcium or magnesium carbonate or more soluble salts; or (6) cementation by alkali-soluble siliceous material or by iron and silica. (U.S.D.A., 1960, p.27).

CLAY SKINS. These are films of translocated clay of varying thickness which coat structured peds or aggregates and line pores and channels in the soil. In thin section under the microscope they are linearly birefringent and oriented.

CONSISTENCE. This is a term used to describe the resistance to deformations of the soil measured in the field qualitatively by the pressure between fingers. It is described under different moisture conditions according to whether the soil is moist, wet or dry. (see U.S.D.A., 1951, p.231-234). In Appendix B the consistence in some profile descriptions has been measured by a pocket soil penetrometer, whose ratings grade from 0 - 4.5 depending on the soil resistance when pushing in the instrument.

#### DEPTH

#### DRAINAGE CLASSES.

(i) internal.

Very poorly drained: water is removed from the surface so slowly that the soil remains wet for a large part of the time. The water table is commonly at or near the surface during a considerable part of the year (U.S.D.A., 1951, p.170). Podsollic soils are characteristically dark grey or peaty at the surface and light grey, with or without mottles beneath.

Poorly drained: water is removed so slowly that the soil remains wet for a large part of the time. The water table is commonly at or near the surface during a considerable part of the year (op. cit.). Podsollic soils have little or no dark topsoil and are light grey beneath, with or without mottles.

Imperfectly drained or somewhat poorly drained: water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time. (op. cit.). Podsollic soils are uniformly greyish, brownish or yellowish in the upper A horizon but are mottled below 6 - 16 inches.

Moderately well drained: water is removed from the soil somewhat slowly, so that the profile is wet for a small but significant part of the time. (U.S.D.A., 1951, p.171). Podsollic soils have uniform colours in the A and upper B horizons, but are mottled in the lower B and C horizons - taken to be below 16 - 48 inches in Sarawak.

Well drained: water is removed from the soil readily but not rapidly (op. cit.). Podsollic soils are free of mottlings and horizons may be brownish, greyish, yellowish or reddish. They may be mottled deep in the C horizon or below depths of several feet - taken to be more than 48 inches in Sarawak.

Somewhat excessively drained: water is removed from the soil rapidly (op. cit.). Podsollic soils are free of mottling and are brown, yellow, grey or red and may have thin A horizons with no mottlings in the solum.

Excessively drained: water is removed from the soil very rapidly. (U.S.D.A., 1951, p.172). Podsollic soils are commonly brownish, yellowish, greyish or reddish and free of mottlings throughout the profile.

(ii) external. (U.S.D.A., 1951, p.167).

Ponded: None of the water added to the soil as precipitation or by flow from surrounding higher land escapes as run-off. The total amount of water that must be removed from ponded areas by movement through the soil or by evaporation is usually greater than the total rainfall. Ponding normally occurs in depressed areas and may fluctuate seasonally.

Very slow: Surface water flows away to very slowly that free water lies on the surface for long periods or enters immediately into the soil. Much of the water either passes through the soil or evaporates into the air. Soils with very slow surface run-off are commonly level to nearly level or very open and porous.

Slow: Surface water flows away so slowly that free water covers the soil for significant periods or enters the soil rapidly and a large part of the water passes through the profile or evaporates into the air. Soils with a slow rate of surface run-off are either nearly level or very gently sloping, or absorb precipitation very rapidly. Normally there is little or no erosion hazard.

Medium: Surface water flows away at such a rate that a moderate proportion of the water enters the soil profile and free water lies on the surface for only short periods. A large part of the precipitation is absorbed by the soil and used for plant growth, is lost by evaporation, or moves downward into underground channels. With medium run-off, the loss of water over the surface does not reduce seriously the supply available for plant growth. The erosion hazard may be slight to moderate if soils of this class are cultivated.

Rapid: A large proportion of the precipitation moves rapidly over the surface of the soil and a small part moves through the soil profile. Surface water runs off nearly as fast as it is added. Soils with rapid run-off are usually moderately steep to steep and have low infiltration capacities. The erosion hazard is commonly moderate to high.

Very rapid: A very large part of the water moves rapidly over the surfaces of the soil and a very small part goes through the profile. Surface water runs off as fast as it is added. Soils with very rapid rates of runoff are usually steep, or very steep and have low infiltration capacities. The erosion hazard is commonly high or very high.

FAMILY. (U.S.D.A., 1951, p.300-302). This category is used to make the similarities and differences among the soils apparent at a level between that of the great soil group and that of the soil series. The soil family should consist of similar soil series, and all soil series within one soil family should be members of the same great soil group. In the absence of a precise American definition the soil families in Sarawak are differentiated primarily on genetic characteristics that preferably are also of use for applied sciences, such as agriculture, drainage and irrigation and road construction.

GLEYS. A gley horizon is characterised by pale matrix colours indicating intense reduction of, for example, iron due to slow-moving or stagnant soil water. Bluish and greenish shades also occur in places. Horizons of low chroma in which the colour is due to uncoated sand or silt particles are not considered gleyed. Wetness by itself is not considered a criterion of gleying.

GROUP III COMPOUNDS. These consist mainly of iron and aluminium oxides with chromium oxide. Chromium oxide is believed to present, if at all, in very small concentration in this area, as it normally is present only in basic igneous rocks. The degree of extraction used for Group III Compounds represents a level between total and available extractions (see Appendix C).

KERANGAS. A widespread local term meaning infertile land on which hill rice will not grow; commonly synonymous with podsol soils or Grey-White Podsollic soils.

LANDAS. A local term used throughout Sarawak for the rainer season, roughly between October and March.

#### MINERAL AND ORGANIC SOIL

Mineral soil is considered that which contains less than 30 per cent organic matter. Organic soil contains more than 30 per cent organic matter. For classification purposes no distinction is made between peat and muck, all being termed peat. Where muck is mentioned, the word is used in the sense of finely comminuted woody debris, not in the sense of peat with a high percentage of mineral matter.

At the great soil group level soils are classified as 'mineral soils' or 'organic soils' on the basis of the horizons below the surface ten inches.

MUCK. A general term used for comminuted, fine or decomposed organic matter in which plant remains are no longer distinguishable. Muck commonly contains more inorganic material than peat. It must contain at least 30% of organic matter, or more than 17.4% organic carbon if the mineral fraction is more than 50% clay, or more than 11.6% organic carbon (20% or more organic matter) if the mineral fraction has no clay, and proportionately for intermediate values. (U.S.D.A., 1960, p.62).

**MUNSELL COLOURS.** Soils colours are measured by comparison with Munsell soil colour charts which are arranged according to numerical measurements of hue, value and chroma. Hue gives the spectral colour, value refers to the lightness of colour and chroma is the relative purity or strength of the spectral colour.

**O HORIZON.** The O horizon may be found at the surface horizon of mineral soils, or at any depth beneath the surface in buried soils, but they have been formed from organic litter derived from plants and animals and deposited on the surface. The O horizons do not include soil horizons formed by illuviation of organic material into mineral material, nor do they include horizons high in organic matter formed by a decomposing root mat below the surface of a mineral material.

Because organic horizons at the surface may be readily altered in thickness or be destroyed by fire or by the activities of man or other animals, the depth limits of organic horizons that are at the surface are always measured upward from the top of the underlying mineral material. Two subdivisions are recognised: (U.S.D.A., 1960, p.25).

**ORGANIC SOIL.** See mineral soil.

**ORTSTEIN.** See plinthite.

**PEAT.** Peat consists of identifiable plant remains, with the same minimum values, of organic matter and organic carbon as defined for muck.

**PLINTHITE.** (GK. plinthos, brick) is the sesquioxide rich, humus poor, highly weathered mixture of clay with quartz and other diluents, which commonly occurs as red mottled, usually in platy, polygonal, or reticulate patterns; plinthite changes irreversibly to hardpans or irregular aggregates on repeated wetting and drying, or it is the hardened relicts of the soft red mottles. The lower boundaries of plinthite are often diffuse or gradual, but they may be abrupt at a lithologic discontinuity.

Plinthite may occur as a constituent of a number of horizons, including ochric and umbric epipedons, orgillic horizons, oxic horizons, and C horizons. It is a form of the material which has been called laterite, renamed to obtain a better combining form for the new nomenclature. It normally forms in horizons below the surface, though it is commonly exposed at the surface, and may, under some conditions, form at the surface.

From a genetic viewpoint, plinthite represents segregation of iron with probable additions in many cases from other horizons or from higher lying adjacent areas.

The original segregation of the iron is normally in the form of soft, more or less clayey, red mottles. It is possible that at times the original formation may be hard. Generally, the plinthite forms in horizons that are, at some season, saturated with water.

When present in small amounts, the plinthite generally forms a discontinuous phase in the soil; that is, the individual mottles or aggregates are not connected with each other. If present in large amounts, the plinthite may form a continuous phase. In this case, on hardening, a massive layer is formed that has irregular somewhat tubular inclusions of yellowish, greyish or white, soft, clayey material. If exposed, these inclusions may be washed out, and thus an iron-stone with many coarse tubular pores is left. Figure 25 shows such an exposure of hardened plinthite.

The lower boundaries of plinthite are normally diffuse. The upper boundary may be abrupt if it is at the soil surface or if it has been truncated and later buried by another material. The segregations of iron may continue down for several tens of feet. The amount of iron in the mottles may gradually decrease with depth until the point is reached where the content is too low to permit hardening. (U.S.D.A., p.62).

R HORIZON. Underlying consolidated bedrock, such as granite, sandstone, or limestone. If presumed to be like the parent rock from which the adjacent overlying layer or horizon was formed, the symbol R is used alone. If presumed to be unlike the overlying material, the R is preceded by a Roman numeral denoting lithological discontinuity. (U.S.D.A., 1960, p.28).

RESIDUAL SOIL. Soil developed in situ from bedrock, in contrast to alluvial soil developed in transported material. Residual soil may have been subject to small-scale solifluction, but not to colluviation.

'RESERVE' NUTRIENTS. These are calcium, magnesium and potassium levels determined by a moderately strong extraction method (Appendix C). They represent levels between the total and available extractions.

SALINITY. Three salinity levels are recognised, defined in terms of groundwater conductivity (expressed in micro mhos per cm. at 25°C).

- |                 |   |                        |
|-----------------|---|------------------------|
| non-saline      | - | under 500 micro mhos   |
| weakly saline   | - | 500 - 4,000 micro mhos |
| strongly saline | - | over 4,000 micro mhos. |

SERIES. A soil series is a group of soils having soil horizons similar in differentiating characteristics and arrangement in the soil profile, except for the texture of the surface soil, and developed from a particular type of parent material. The soils within a series are essentially homogeneous in all soil profile characteristics except texture, principally of the A or surface horizon, and in such features as slope, stoniness, degree of erosion, topographic position and depth to bedrock where these features do not modify greatly the kind and arrangement of soil horizons. (U.S.D.A., 1951, p.280).

SESQUIOXIDES: iron, aluminium and titanium oxides.

## SPODIC HORIZON.

A spodic horizon is one which shows the following properties:

1. Amorphous coatings of humus and allophane or of humus, allophane, and free sesquioxides on particles of sand or silt; or rounded to subangular pellets of humus or of humus and sesquioxides between 20 and 50 microns in diameter; or both.
2. More than 0.29 per cent organic carbon or 1 per cent free sesquioxides in some part.
3. No clay skins; under crossed polarizers coatings in thin sections show slight or no birefringence and no extinction on rotation, which indicates substances forming the coatings are not both crystalline and oriented.
4. No structure, or structure other than blocklike; or blocklike structure only if the grade of structure is weak.
5. Carbon-nitrogen ratios of more than 14, if profile is virgin.
6.  $\text{SiO}_2/\text{R}_2\text{O}_3$  ratio in clay fraction less than that in clay fraction of overlying A2 or albic horizon and less than that in clay fraction of parent material. (U.S.D.A., 1960, p.49).

**STRUCTURE.** Soil structure refers to the aggregation of primary soil particles into compound soil particles, or clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness. The aggregates are measured in terms of grade, size and shape. (U.S.D.A., 1951, p.p.225-230).

## TEXTURE

Six broad texture classes are recognised, as follows:

**Fragmental soils:** Stones, cobbles, gravel, and coarse sand.

**Sandy soils:** Sands other than coarse sand, and loamy sands.  
**Light loamy soils:** Light sandy loams (less than 15 per cent clay) other than light very fine sandy loam; and light loams (less than 15 per cent clay).

**Light silty soils:** Silt; light silt loam (less than 15 per cent clay); and light very fine sandy loam (less than 15 per cent clay).

**Heavy loamy soils:** Heavy sandy loams, loams, and silt loams (all with more than 15 per cent clay); sandy clay loam; clay loam and silty clay loam.

**Fine-textured soils:** Clay, silty clay, and sandy clay. (U.S.D.A., 1960, p.100).

In many great soil groups a distinction is made at the family level between light-textured and heavy-textured soils. Where this single division is made between the classes, the following definitions are meant:-

Light-textured soils. Sandy, light loamy and silty soils. (Fragmental soils are not included).

Heavy-textured soils. Heavy loamy and fine textured soils. Where there is a textural increase down the profile and a textural B horizon is present, classification is made on the texture of the B horizon.

Within the group of Red-Yellow Podsollic soils a division into three texture groups is made in the case of residual soils. Where three texture groups are employed, the following definitions are meant:

Light-textured soils. Soils in which the B horizon is sand, light loam, light silt or heavy loam. If heavy loam, the B horizon is heavy sandy loam, heavy loam or sandy clay loam. Silty clay loam and clay loam are excluded.

Medium-textured soils. Soils in which the B horizon is silty clay loam, clay loam or fine textured but is not clay unless the A2 horizon is sandy clay loam or lighter-textured than sandy clay loam.

Heavy-textured soils. Soils in which the A2 horizon is clay loam or fine textured and the B horizon is fine textured.

II HORIZON. The roman prefix indicates a layer of contrasting material in the profile representing a lithologic discontinuity. The first contrasting layer is unnumbered (being understood as I) and where two or more horizons are developed in one of the numbered layers, the Roman number is applied to all the horizon designations in that material. e.g.

A1-A2-B1-B21-IIB22-IIB3-IIC1-IIIC2-IVR

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