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**SOIL RESEARCH IN THE
ECONOMIC DEVELOPMENT
OF SARAWAK**

Report to the
Government of

SARAWAK

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1962



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REPORT TO THE GOVERNMENT

of

SARAWAK

on

SOIL RESEARCH IN THE ECONOMIC DEVELOPMENT OF SARAWAK

by

T.W.G. Dames

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Rome, 1962

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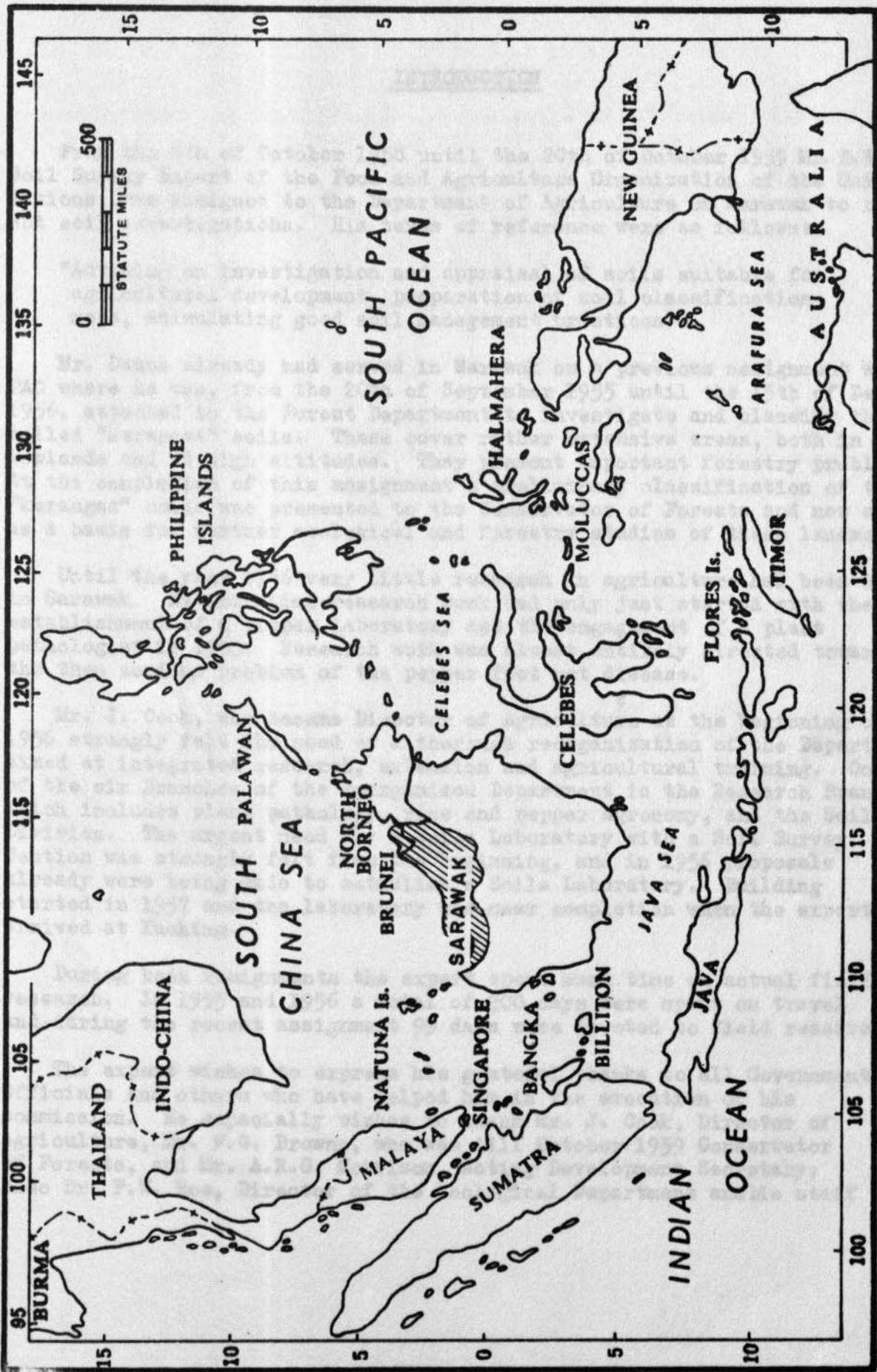
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INTRODUCTION

From the 6th of October 1958 until the 20th of October 1959 Mr. T.W.G. Dames, Soil Survey Expert of the Food and Agriculture Organization of the United Nations, was assigned to the Department of Agriculture of Sarawak to carry out soil investigations. His terms of reference were as follows:

"Advising on investigation and appraisal of soils suitable for agricultural development, preparation of soil classification maps, stimulating good soil management practices"

Mr. Dames already had served in Sarawak on a previous assignment with FAO where he was, from the 20th of September 1955 until the 15th of December 1956, attached to the Forest Department to investigate and classify the so-called "kerangas" soils. These cover rather extensive areas, both in the lowlands and at high altitudes. They present important forestry problems. At the completion of this assignment a preliminary classification of the "kerangas" soils was presented to the Conservator of Forests and now serves as a basis for further ecological and forestry studies of these landscapes.

Until the year 1956 very little research in agriculture had been done in Sarawak. At that time research work had only just started with the establishment of a pepper laboratory and the engagement of a plant pathologist in 1955. Research work was almost entirely directed towards the then serious problem of the pepper foot rot disease.

Mr. J. Cook, who became Director of Agriculture at the beginning of 1956 strongly felt the need of a thorough reorganization of the Department aimed at integrated research, extension and agricultural training. One of the six Branches of the reorganized Department is the Research Branch which includes plant pathology, rice and pepper agronomy, and the Soils Division. The urgent need for a Soils Laboratory with a Soil Survey Section was strongly felt from the beginning, and in 1956 proposals already were being made to establish a Soils Laboratory. Building started in 1957 and the laboratory was near completion when the expert arrived at Kuching.

During both assignments the expert spent much time on actual field research. In 1955 and 1956 a total of 200 days were spent on travel and during the recent assignment 99 days were devoted to field researches.

The expert wishes to express his grateful thanks to all Government Officials and others who have helped him in the execution of his commission. He especially wishes to thank Mr. J. Cook, Director of Agriculture, Mr. F.G. Browne, who was till October 1959 Conservator of Forests, and Mr. A.R.G. Morrison, Acting Development Secretary; also Dr. F.W. Roe, Director of the Geological Department and his staff

members Dr. N.S. Haile, Dr. H. Kirk, and Dr. G.E. Wilford who provided very valuable assistance, especially during the first assignment. Several long and interesting travels into the remote interior have been made in the company of the geologists. The same valued help was given by the staff members of the Forest Department, especially by Mr. J.A.R. Anderson, Dr. E.F.W.O. Brunig and Mr. T.W.W. Wood. Finally, I wish to thank Dr. C.D. Sutton, Acting Head of the Soils Laboratory and his staff, and Mr. J. Dunsmore, Rice Agronomist of the Department of Agriculture, for their pleasant co-operation during my recent stay in Sarawak.

1. SUMMARY

In 1955 and 1956 the expert carried out a number of soil reconnaissances in so-called "kerangas" areas in order to prepare a classification of the soils of these areas in view of forestry problems. During the 1958 and 1959 assignment he helped organize the newly established Soils Laboratory, including the training of field personnel. A number of soil surveys in areas intended for agricultural development were carried out during this assignment.

The results of both assignments have been discussed in this report.

The economy of Sarawak has been briefly discussed with special emphasis to those facets for which soil survey is essential. The great importance of soil survey as a basis for agricultural development schemes and land policy has been particularly stressed.

Recommendations on staffing, equipping and on the most efficient methods of soil survey under Sarawak conditions have been discussed in the Chapters IV, V, and VI.

As far as possible, the soils studied during the field surveys have been tentatively grouped into the established Great Soil Groups. Soil profile descriptions with chemical data are given. A sketch map of General Soil Associations has been prepared. The separate areas of groups of soil associations on this map have been delineated largely on the basis of the Land Use Map 1957 which was constructed by the Lands and Surveys Department from aerial photographs and data from the Forest and Geological Departments. It must be strongly emphasized that this General Soil Association Map is only intended to bring out the relationship of the major soils of Sarawak, as far as now known, to the international Great Soil Groups and is not intended for practical use.

II. RECOMMENDATIONS

It is proposed that the recommendations made in this report are followed as far as possible. Special emphasis is laid on the following recommendations:

1. That steps are taken to ensure the execution of a soil reconnaissance of areas intended for agricultural development prior to other technical surveys such as drainage, irrigation and flood control surveys.
2. That large-scale allotment of land, the creation of Mixed Zone Land, resettlement of people, new and re-planting of rubber and coconut trees be based on a soil survey.
3. That it is advisable to produce more detailed reconnaissance soil maps of the "settled cultivation" areas before the introduction of higher levels of management in these areas.
4. That the locations of long-term experimental fields are defined on the basis of detailed soil surveys of the experimental field area, combined with soil reconnaissances of the regions in which the results will be applied.
5. That contoured topographic maps, on a scale of 1 : 50,000, should be produced.
6. That more detailed geological maps with emphasis on geomorphology and lithology should be produced. These maps, as well as those mentioned in 5 above, will be of great value for soil survey work in Sarawak.
7. That the annual publication of the soil maps and reports be produced, as communications of the Soils Laboratory is of the greatest importance.
8. That, if possible, the soil survey of certain areas be made in co-operation with foresters who will simultaneously produce a vegetation map.
9. That the soil scientists should continuously correlate all soil profiles and classify them in suitable units. For this purpose, soil samples of typical profiles should be retained in the laboratory, and all chemical and physical characteristics should be recorded on charts.

III. SOME ECONOMIC ASPECTS OF SARAWAK

A. General nature of the area

Sarawak occupies most of the north-western coastal area of the island of Borneo. It is situated between latitudes 0°50' and 5° North and longitudes 109°36' and 115°40' East.

The characteristic features of the climate are heavy rainfall, a uniform temperature and high humidity. A large part of the country receives between 120 and 160 inches of rain per annum. Although the north-east monsoon from October until March brings heavier rainfall, the rain is generally well-distributed over the year and there are normally no dry months. The temperature varies between 72°F and 88°F at sea level with a mean temperature of 78°F. At 6 a.m. the mean relative humidity for the year is 98 percent and at 2 p.m. 70 percent.

Much of Sarawak is hilly and mountainous. The mountains reach their greatest height in Mount Murud with an elevation of about 8,000 feet. Most of the uplands are strongly dissected by geological erosion and have a rugged appearance. The coastal plain varies in width from nil to over a hundred miles and contains large areas of peat swamps. The main rivers rise in the interior mountain ranges and flow rapidly through deep gorges and over numerous rapids until they reach the coastal plains, where they meander towards the sea. The rivers are the main means of communication in the interior. The largest river, the Rajang, has a length of 350 miles and is navigable for small ocean steamers as far as Kapit, a hundred and fifty miles upstream.

The greater part of Sarawak is still covered by primary forest and about three-quarters of these forested areas are practically uninhabited except for scattered bands of nomadic Penans.

B. Population

The small population, an estimate of 648,362 at the 31st of December, 1957, lives on some 47,500 square miles of land. The people, without much difficulty, can meet their modest daily needs and the standard of living is not low in comparison with many other Asian countries.

The estimated population was made up as follows:

Sea Dayaks	199,595
Chinese	197,723
Malays	158,567
Land Dayaks	50,487
Other indigenous	32,753
Other non-indigenous	9,237
including 2,341 Europeans	

C. Agriculture

The economy of Sarawak is largely based on agriculture. The most conspicuous feature of Sarawak's agriculture is the low level of management. About 40 percent of the population is still dependent on shifting hill padi cultivation; the rubber and pepper smallholders, which make up the balance of the agricultural population, also have a fairly low level of subsistence.

Well over half of the national income is earned through agriculture. The most important single contributor is rubber, followed by rice, pepper fruits, and vegetables. The national income is supported by an important export of timber and by the production of various forest products such as rattan, jelutong and damar. At irregular intervals, on the average once in 5 years, the forest yields a valuable crop of illipe nuts, the seeds of various Shorea species which are exported and produce a fat which is mainly used as a substitute of cocoa butter. The petroleum industry, and, to a less extent, the extraction of bauxite contribute further to the economy.

The Annual Report of the Department of Agriculture for the year 1958 gives the estimated total acreage of rubber as 295,800 acres, of which only 13,285 acres are estate rubber, the rest being nearly all small-holdings. The report states:

" At present upward of 90 percent of the planted acreage comprises old, unselected, seedling trees irregularly planted, badly maintained and tapped and rapidly approaching the stage where they must be considered as a wasting asset especially in the face of increasing competition from other countries. "

The rubber output is low and is estimated at 350 pounds per acre. This would, by present prices, amount to the low sum of Str. \$ 265. The land used for rubber cultivation could produce several times more than at present.

The rehabilitation of the rubber industry has been energetically pursued and it is of interest to reprint here the following statements in the above-mentioned Annual Report:

"Steps to be taken to rehabilitate the industry are seen in the introduction of the subsidised Rubber Planting Scheme in the middle of 1956. This scheme embraces estates and small-holdings of all races and is concerned with the replanting of uneconomic gardens and the establishment of new holdings under high-yielding rubber. It provides for the payment of subsidies, in cash and kind, originally fixed at \$ 200 per acre for new planting, but increased to \$ 250 per acre following the decision to levy an export cess on rubber, and at \$ 450 per acre for replanting. By the end of 1958 a total of 21,487 acres had been planted with high-yielding rubber in the proportion of $7\frac{1}{2}$: 1 of newplanting to replanting.

Such has been the enthusiasm accorded to the Rubber Planting Scheme by smallholders that the original target of 10,000 acres to be planted in five years was well encompassed in less than half that time. Accordingly, because the greatest benefits will accrue from planting the maximum acreage in the minimum time it was deemed wise to continue planting as long as this interest was maintained, and in 1958 a sum of \$ 12 million was set aside to cope with a revised target of 40,000 acres. But so great has been the continued response, that a still further target has been set, namely 60,000 acres. To meet part of the additional foreseen expenditure it was necessary to introduce legislation to impose a cess of 2 cents per lb. on all rubber exported from Sarawak with effect from 1st January, 1959. An undertaking has been given by Government that the proceeds from this cess will be devoted exclusively to the furtherance of the rubber industry. "

The cultivation of black pepper is entirely in the hands of Chinese peasants. It is a highly traditional family affair. The holdings are small and hired labour is avoided. An average size is some 750 vines, or about 1 acre. There are a roughly estimated 6,000 acres. The Chinese method of growing pepper, also found on the island of Banka in Indonesia, is the most intensive found. A good yield in Sarawak at a price of Str. \$ 110 per picul (133.33 lbs) could, under proper traditional methods, give a gross return of \$ 3000 to \$ 4000 per acre. Present yields give an estimated return of \$ 2000 per acre. Establishment costs are very high and recurrent costs, especially of cultivation practices and manuring, are excessive. Great care is needed to keep a garden in good shape. The traditional use of burnt earth, prepared from primary forest, is now no longer allowed. Probably, largely as a result of this, gardeners have difficulty in fertilizing. Many holdings therefore seem to have an unbalanced nutrient status.

No research was done on black pepper in Sarawak before the last war; studies on foot rot disease (*Phytophthora* sp.) began in 1955. In 1959 an agronomist began work on this crop with the primary object of reducing costs of production through suitable applications of inorganic fertilizers and improved cultivation.

Rice is the staple food of the people and large quantities of it have to be imported. Rice is grown as hill padi by the bush-fallow system and as wet padi in flat terrain. It is estimated that about 200,000 acres are annually planted to hill padi, but it must be emphasized that this is a very rough estimate attained by indirect computation. In fact, it is hardly possible to give an estimate of the total planted acreage of the hill padi actually planted by the interior peoples throughout the country. The estimate of the land annually planted to wet padi is some 73,000 acres. In these swamp padi areas there is very little irrigation and in most cases no drainage.

It is estimated that 40 percent of the population are dependent on hill padi cultivation. It is generally accepted that in Sarawak hill padi should only be grown once on the same piece of land; after which a bush fallow period of 12 to 15 years is required to restore the soil and vegetation to the point where another rice harvest is possible. In reality, in many places in Sarawak, the bush fallow has now been reduced to 6 or 7 years and sometimes padi is grown on the same land for two consecutive years. The latter practice is considered to be especially harmful.

The yields of hill padi are very low and a yield of 125 gantangs (5.33 lbs) of padi per acre is regarded as satisfactory. The yield of wet padi may on the average be estimated at 200 gantangs, although yields of 400 gantangs are common in some selected areas.

Wet padi land is capable of being planted annually, although this is at present seldom the case, but the hill land should only be used once in 12 to 15 years time. The actual contribution to the economy of the country by hill padi cultivation is thus extremely small. The system involves so much work that it makes the growing of other crops difficult. Moreover, it is estimated that with this system the average family requires 70 to 140 acres of land. From an economic point of view the hill padi system is highly wasteful.

It is difficult to see that there is much chance of effectively improving the output of hill padi. It appears that the best way of improving the standard of living of the Dayak peoples is to assist them in growing wet rice on banded "sawahs" with good drainage and, where possible, irrigation; and in the planting and management of rubber on the hill sides with the additional cultivation of fruit trees, tapioca, maize, sweet potatoes and vegetables. In many cases this implies resettlement of Dayaks from the interior in the lowlands. In other instances, adequate level alluvial land suitable for wet padi cultivation may be found in the interior.

The research studies in hill padi farming planned by the rice agronomist include such problems as the use of fertilizers, the length of bush fallow, improved fallow vegetation, and the introduction of high-yielding rice varieties. It seems likely that in many of the poor and steep hill areas the introduction of these improvement measures will be difficult. Both the improvement of the fallow vegetation and the introduction of high-yielding varieties will demand heavy fertilizer applications.

It is recognized by the Government that the standard of living of the hill farmer will be more readily improved by the introduction of sawah cultivation in flat alluvial land for the growth of rice and of other crops such as sweet potatoes, maize, green peas and vegetables, combined with well-managed rubber plantations on the hill sides.

Research in hill padi cultivation remains necessary, because it will take time to gradually change over from hill padi to sawah padi cultivation. Successful improvement measures may greatly reduce the area used for shifting cultivation and thus prove to be a safeguard against wasteful land use.

Another new project of the Department of Agriculture is the subsidized Coconut Planting Scheme which came into being in 1959. Coconut trees are entirely a smallholders crop in Sarawak. The total aggregate acreage, put variously between 25,000 and 50,000 acres, comprises either scattered palms or loose groups of smallholdings, each of which is seldom greater than 5 acres in size. The Coconut Planting Scheme aims at everybody having a few coconut trees around the house. Up to 15 seedlings are given free to the peasants. The planting of 16 or more palms is only done after an official of the Department has inspected the area to be planted. In the first instance the farmer can plant up to 5 acres, which may later be expanded to 10 acres.

All efforts made by the Department of Agriculture in the last three years, such as the stimulation of rubber and coconut cultivation, and the growing of wet padi are aimed toward giving the Dayak or other farmer a certain piece of land which he will eventually consider his own. This should lead to a more stable type of agriculture. The schemes have some unforeseen favourable results. The planting of rubber, with the obligation of terracing, makes the interior farmer used to the changkul and also makes him fertilizer-conscious. The rubber scheme has already penetrated into the remotest interior.

To obtain a much needed diversification the Government plans to introduce new agricultural export crops such as oil palm and cocoa.

D. Land Use

An idea of the present land use may be conceived from the Land Use Map which has been prepared, largely from aerial photographs, by the Land and Survey Department in 1957. It gives the following data:

	<u>Square miles</u>	<u>Percent of land area</u>
Settled Cultivation	2,699	6
Shifting cultivation	8,724	18
	<u>11,423</u>	<u>24</u>
Mangrove and nipah forest	620	1
Mixed swamp forest	4,445	9
Alan swamp forest	442	1
Padang paya forest	773	2
Kerangas forest	1,691	4
Other forest	28,106	59
	<u>36,077</u>	<u>76</u>
Grand total...	47,500	100

48,050

A total of 10,780 square miles or 22.7 percent of the country is Forest Reserves and Protected Forests. The areas of "other forest" and of "shifting cultivation", comprising 77 percent of the total, are nearly all hills and mountains. Of the areas marked as "kerangas" on the map, about three-quarter are situated in the hills. It is estimated that about half of the "settled cultivation" areas are hilly land, so that some 83 percent of the country is hilly or mountainous. Twelve percent of the land is covered by swamp forests of several types. These swamp forests have almost entirely deep-peat deposits. One percent of the land is made up by mangrove and nipah tidal swamps. Thus, there remain only some 3 percent of level, alluvial, mineral soils.

A rough estimate thus gives the following figures:

Hills and mountains	83 percent	<i>mostly 2/3 hills etc.</i>
Peat swamps and tidal swamps	13 "	<i>mostly 2/3 hills etc.</i>
Lowland kerangas areas	1 "	<i>mostly 2/3 hills etc.</i>
Alluvial soils	3 "	

For agriculture, the alluvial soils and the low hilly terrains are the most important.

At present, the land in Sarawak is, apart from the areas of intensive pepper cultivation and other perennial crops, used on a very extensive scale. Large parts of the areas marked on the Land Use Map as being under settled cultivation are very extensively used; in these areas the agriculture can be greatly improved by modern methods.

Although there is still much primary forest, land suitable for shifting hill padi cultivation is becoming very scarce. In several places this has created serious problems for the interior peoples.

IV. THE SOIL SURVEY IN SARAWAK

A. Introduction

A basic knowledge of the soils is of primary importance in solving many of the problems discussed in the previous chapter.

The Government has realized the urgency of soil research in connection with the rapid development of the Colony, and has in its Development Plan 1959 - 1963 set aside large sums of money towards the solving of the above-mentioned problems.

B. Objectives of the soil survey in Sarawak

1. The increase of population and the poor inherent fertility of the soils have resulted in a shortage of suitable hill-padi land and a dangerous shortening of the bush-fallow period. Moreover, the shifting cultivation system by itself is too uneconomic to justify its continuance in its present form.

In many instances the solution of the problem involves resettlement of the hill people either in other hill areas or into the plain. In some cases, sufficient areas of flat land suitable for sawah cultivation within the present watershed may be found. Resettlement of Dayaks from the hills into the lowland areas can lead to serious mistakes without a planned settlement scheme based on a soil map. On the basis of the soil map and the report, the areas suited for sawah cultivation and other crops are defined; also the necessary reclamation measures are assessed. As a result, a decision can be taken whether or not the resettlement is feasible in view of existing facilities. If the resettlement is decided upon, a more detailed soil map can be made for planned farm settlement. The irrigation, drainage, and flood control survey is made by the Drainage and Irrigation Section of the Public Works Department. The main irrigation and drainage channels should be constructed before the settlers arrive to make their sawahs and plant their rubber.

The soil survey has the task of finding suitable areas for resettlement or improved cultivation, both in the interior and the lowland areas, and of producing soil maps and reports as basis for a planned farm settlement with an equitable distribution of sawah and hillland per farm. Matters concerning internal migration cannot satisfactorily be settled without a knowledge of the soils, both of the area from which the people migrate and of that in which they settle.

2. Related to the problem of the hill farmers are the drainage and irrigation schemes of the Government in several alluvial areas in the lowlands. In areas intended for drainage and irrigation schemes a soil reconnaissance should be made prior to the drainage and irrigation survey. The soil map and the report will define and describe the exact areas where such a survey is needed, thus eliminating unsuitable land.

In this respect it is good to bring the attention to paragraph 2 (b) of the Official Memorandum from the Director of the Public Works Department to the Chief Secretary regarding the policy of the Drainage and Irrigation Section of that Department which reads as follows:

" The Drainage and Irrigation Section will be responsible for investigation, survey and design of major projects up to the stage of construction and will assist Divisional Engineers with local problems in connection with drainage and irrigation schemes. "

It seems advisable to revise this policy in such a way that the execution of a preliminary soil survey is ensured.

3. For large new plantings of rubber a reconnaissance soil survey of the area is valuable in defining the most suitable sites. A more detailed reconnaissance of the selected area will make it possible to prepare a planned settlement scheme. Also, in the case of large replanting schemes, a soil reconnaissance could save considerable expense. In general, for the whole rubber industry a more detailed soil survey of the "settled cultivation" areas would be valuable.

4. The soil survey will be of assistance when establishing the field experiments of the Research Branch of the Department of Agriculture. Detailed soil maps will have to be made of permanent or long-term experimental fields lest the results are misinterpreted. Also it is vital that the soils used for the experiments are representative for large areas.

5. The increased demand for land will no doubt lead to the creation of Mixed Zone Land. An important task of the soil survey will be to prepare soil reconnaissance maps of Crown Land areas to define areas suitable for the creation of Mixed Zone Land. On the basis of more detailed reconnaissance maps of the Mixed Zone Land areas, a planned settlement scheme can be made to provide the farmers with equal lots of land and soil types suitable for various crops, and to make plans for roads, drainage and irrigation works, bazaars and wharfs.

In the past many settlers on Mixed Zone Land have been compelled to abandon their land because of the poor quality of the soils. This can be avoided in the future.

6. Detailed soil maps of the "settled cultivation" areas are valuable. These areas have a comparatively dense population and are extensively used. They are especially suited for agricultural development. The most suitable as a beginning is the Kuching-Bau-Serian area.

7. Soil reconnaissance maps of areas opened up by newly constructed roads are needed to assess the extent of suitable agricultural land and to serve as a basis for further development schemes.

8. Soil surveys are needed to define suitable areas for the introduction of new cash crops.

9. The preparation of a general soil association map of the whole country is another soil survey task. However, important this map may be, it should not, at the present time, be made the target of a systematic survey. The difficult physical character of the terrain and the lack of communications would make this survey a slow and uneconomical project. Also, the absence of contoured maps makes this enterprise hardly feasible at this time. It is advisable to give preference to soil surveys which will assist in solving many of the immediate problems. These surveys will in the end provide the data for a broad soil association map of Sarawak.

V. THE EXECUTION OF A SOIL SURVEY IN SARAWAK

Most of the tasks of the soil survey described previously in the report are, at least in the first instance, concerned with land capability assessment and general exploration. For these purposes, soil reconnaissance surveys of varying intensity are required to produce soil association maps. In general, this would mean in Sarawak a survey with about 1 mile interval between out lines. In areas that have been selected for special projects such as irrigation and land settlement schemes, soil reconnaissance maps with more detail are needed.

Usually such soil association maps are produced on a scale of 1 : 100,000 or even smaller; however, in Sarawak it is advisable to produce them on a scale of 1 : 25,000. They can then be used with the aerial photographs. The route and sample map of the survey will give an idea of the intensity of the survey and of the limitations of the map for practical use.

Detailed soil maps, on a scale of 1 : 25,000 or larger, showing the soil types and phases are presently only required for such small areas as field experiments and agricultural stations.

The maps of the "settled cultivation" areas still will be reconnaissance type, although of greater detail.

Before the survey party leaves for the field a study should be made of all available data on geology, climate, population, accessibility, and present land use of the area. In many instances, officers of the Geological Department and the Forest Department have personal knowledge of specific areas. The Forest Department has acquired a wide knowledge of the peat-swamp and kerangas areas of Sarawak. A close co-operation with these Departments will be of great value.

The lack of topographic maps suitable as base maps for a soil survey is a serious drawback. Contoured topographic maps are lacking. Maps at a scale of 1 : 50,000 are available only for a small part of the country, and these have been made from the aerial photographs without ground control. They lack contour lines and the topographic detail is scanty because of the limitations of aerial photographs in jungle covered areas. It is, therefore, highly important that contoured topographic maps on a scale of 1 : 50,000 be provided.

Good quality aerial photographs at an approximate scale of 1 : 25,000 are available for the greater part of the country. Most of these date back to the years 1947 to 1955.

The base map for the soil survey is frequently constructed from aerial photographs. For soil reconnaissance maps it is not considered necessary to use the slotted template method of assembling, but for more detailed soil maps of selected areas this method is necessary to prepare a more accurate base map. In general, it is advisable that such base maps be prepared by the Land and Survey Department. Such maps will not only serve for the soil survey, but also for other basic researches, such as irrigation and land planning surveys.

The aerial photography analysis makes it possible to mark in advance on the base map the larger areas of deep-peat swamp and kerangas which are recognizable by their specific vegetation. It is, in most cases, possible to prepare from the photographs a morphological sketch map showing areas of flat land, hilly land, and very steep land. It is, however, often not possible in jungle-covered terrain to distinguish on the photographs flat land from strongly dissected low hilly land, nor to define smaller areas of deep peat and kerangas.

As a result of this preliminary study in the laboratory, it is possible to exclude at once large areas from the survey, or to limit the field survey in certain parts and give more attention to more promising areas.

The typical aspects of Sarawak and the lack of roads and foot-paths, certainly of mapped foot-paths, make it necessary to use traverses. The vegetation usually does not allow a view of the land for more than a score of metres. Often the slightly elevated ground of the river levees along the banks is of very limited width, sloping down rapidly into lower-lying swampy terrain. Foot-paths often run along these narrow river levees. Often there is little knowledge of the real character of the land. All reports, not based on systematic field survey, which mention the presence of "large areas of excellent padi land" and the like should be investigated. Also, the terminology used by the local people often is confusing. "Paya" or swamp is a term which, in the local vocabulary, includes deep and shallow peat swamps as well as flooded areas of mineral soil.

In the laboratory, the preliminary net-work of traverses is marked on the base map. The main traverses are drawn across the general strike of the geological strata, if possible, in order to get a good cross-section of the different geological formations in the area. The traverses are made with the use of a hand compass and measured with a 100-foot tape, the end of each tape being marked by a numbered pole. In sloping and steep terrain, especially in more detailed surveys, it is necessary to make corrections for map distances. The slope gradients are measured with the hand level. Hand levelling in Sarawak is of great importance during soil surveys, especially in level terrain, to be able to make justified recommendations concerning drainage and irrigation.

It is recommended that the directives of the Soil Survey Manual (Agricultural Handbook No. 18) 1951 of the United States Department of Agriculture should be followed in respect to profile descriptions and classifications of soil texture, structure, relief, slope, soil drainage, permeability and run-off; also to adopt the system of nomenclature and classification of soil profiles into soil series, types and phases as described in that Manual. The slope and relief classes will have to be modified to establish classes which bear a closer relation to agricultural conditions in Sarawak.

Soil colours should be determined in dry and wet conditions by the use of the Munsell Colour Charts, which are now used in most parts of the world.

Soil micro-monoliths of typical profiles should be made in the field, preferably in duplicate; one of which will serve for exchange with foreign institutes.

Each soil sample of the profiles of the main units should be retained in tins in the soil sample store for correlation and classification purposes. The soil scientists should, from the start, give great attention to a continuous correlation and classification of the soil units of all mapped areas.

It is especially important that final soil maps and reports be published as communications of the soils laboratory, so as to make them generally available.

VI. THE ORGANIZATION OF THE SOIL SURVEY SECTION

Because of the great immediate need of soil knowledge, it is advisable to have four soil scientists in the Soil Survey Section instead of the originally intended staff of two.

Each soil scientist should have two assistant soil surveyors. These assistants should be tested as to their suitability for soil survey work during the first two years of service. It is recommended that they receive a short training with the Land and Survey Department in aerial photography analysis, and a course in normal ground survey practices. In addition to this, it is advisable for them to follow a course in the driving and maintenance of outboard engines. They will receive their field training from the soil scientist. At the end of their training they should be able to carry out a soil survey on their own: to investigate, describe and sample soil profiles and to prepare soil maps and comprehensive field reports. The soil scientist, together with the soil chemist, should prepare the final soil map and report, including recommendations.

Practically everywhere in Sarawak a soil survey can only be done by means of traverses; therefore, it is advisable to train two or three "mandurs" for this work. They will need, at the end of their training, to be able to lead a party of labourers and to prepare a net-work of traverses marked on a base map. In the case of major soil surveys, they could leave for the field in advance of the soil survey team and have part of the traverses ready when the team arrives. In minor surveys they will accompany the team. In suitable terrain, especially in well-drained areas, their parties can make soil pits in advance. Their work will considerably shorten the time needed for the survey and thus save expense. They are best recruited among the Iban or other Dayak races.

Furthermore, it is advisable to attach, if possible, a farm-irrigation engineer to the soils laboratory. There is very little level land in Sarawak which does not need drainage before it can be successfully used. Flood control is often necessary and, where possible, it is an advantage to establish irrigation.

The Drainage and Irrigation Section of the Public Works Department will mainly be concerned with larger schemes. In general, it will be most important to develop larger areas of, say, over 1000 acres size because of the greater assistance that can be given to these areas than to smaller ones. Still, there are a great number of smaller areas in favourable locations along the lower reaches of the rivers and in the interior, the development of which is considered to be of great importance. This is apparent from the provision made for these schemes in the Development Plan 1959-1963 mentioned before.

The farm-irrigation engineer could make his field survey in conjunction with the soil survey team. He will be able to prepare his farm settlement plan on the basis of the soil map. These smaller schemes can be carried out by the people of the Long House under the supervision of the engineer. The engineer also can assist the Divisional Agricultural Officers with the execution of small drainage and irrigation works.

Communications are mainly by river in Sarawak. For an efficient execution of the survey it is essential that the team has its own outboard engines. Locally hired engines are expensive and unreliable.

It is advisable that the soils laboratory has a duplicate set of aerial photographs on a scale of approximately 1 : 25,000.

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The Drainage and Irrigation Section of the Public Works Department will mainly be concerned with larger schemes. In general, it will be most important to develop larger areas of, say, over 1000 acres since because of the greater maintenance that can be given to these areas than to smaller ones. Still, there are a great number of smaller areas in favorable locations along the lower reaches of the rivers and in the interior, the development of which is considered to be of great importance. This is apparent from the provision made for these schemes in the Development Plan 1952-1953 mentioned before.

VII. GENERAL REMARKS ON SOIL SURVEY IN SARAWAK

A modern soil survey produces a soils map and report. The latter includes descriptions of the soil units mapped, and recommendations regarding the suitability and capability of these units for agriculture, and, where possible, gives predictions of their productivity for various crops. But, besides these, the report gives data on the physiography, geology, topography, morphology, drainage conditions, population, present land use, land rights, and accessibility of the area covered by the survey.

The soil survey thus makes it possible to provide recommendations on: the best use of the land, the suitability of defined areas for various crops, the necessary reclamation measures such as drainage, irrigation and flood control, and on soil management practices, including erosion control.

Soil survey is a fundamental engineering work which should precede any survey for specialized purposes such as irrigation, drainage and land settlement. These preliminary soil surveys may save large amounts of money and prevent disappointments.

Thus, the Soils Laboratory is concerned with all matters of land use and land policy. As such, the Soils Laboratory has, when fully established, a similar standing as the Geological Department has in matters concerning geology and mining policy.

It would be advisable if the Head of the Soils Laboratory or the senior soil scientist was a member of such committees concerned with land policy as the Governor in Council, the Development Board, the Natural Resources Board, and Land Settlement and Migration Committees. The highly specialized character of soil science makes this member the only authority capable of giving well-founded information and recommendations on the best use of soil and the need for further basic soil research.

In more advanced agricultural countries the soil report provides predictions on crop growth and yields on specific soil units. These predictions are based on available data from the same or similar soil units elsewhere. At the present time such predictions can hardly be made in Sarawak, as apparently no reliable data is available concerning crop growth and yields, response to fertilizers, and other management practices. The future results of the experiments of the Research Branch of the Department of Agriculture will have to provide these data. The soil scientist should maintain a close contact with the other Divisions of the Department, and, where pilot, settlement, and drainage and irrigation schemes are put into practice, should study the productivity of the specific soil units and their response to improved methods of management.

Also, contact with soil scientists in other countries, especially those with similar conditions of soil and climate, will be useful.

VIII. EXAMPLES OF FIELD INVESTIGATIONS

A number of field investigations have been carried out by the expert during both assignments. The locations of these surveys are marked on map 1. During the surveys of the second assignment, two assistant soil surveyors have been trained. Interim reports and, in some cases, final reports have been presented to the Government after completion of these surveys.

A. A soil reconnaissance was made of an area of 6,000 acres in the Kebulu Forest Reserve in the interior of the 4th Division. This is an example of a soil reconnaissance made on behalf of the resettlement of the Ibans, whose present hill land is exhausted. A total of 2,200 acres of flat alluvial and low hill land were found suitable for agriculture; with sawahs on the alluvials for rice and food crops and with rubber planting on the hills. It was recommended that the Ibans not be allowed to practise hill padi cultivation. All soils are extremely or very strongly acid, having pH values varying from 4 to 5, and they are extremely poor in plant nutrients. As experience shows, however, these soils are, with good management, capable of producing wet rice and rubber. It would be wasteful to fell the good forest for hill padi cultivation. The forest provides a valuable source of timber and other products, as well as for later expansion because of increase of population.

The Department of Agriculture was advised that it could assist in executing the recommended type of agriculture by providing a junior agricultural assistant to help the people in the planting of rubber, the construction of sawahs, and in sawah-rice cultivation.

B. A reconnaissance was made in the Semengkoh Forest Reserve south of Kuching. This is an example of a soil survey made on behalf of an experimental research program of the Department of Agriculture. The purpose of the survey was to find a suitable site for a hill-padi experiment. Although preliminary aerial photography analysis had suggested some likely areas, the result of the reconnaissance was: due to the strongly dissected character of the terrain no area of sufficient size and homogeneity of soil and slope could be found.

C. A reconnaissance was made in a primeval forest area south of the new road from Serian to Balai Ringin. This reconnaissance was a continuation of that in the Semengkoh Forest Reserve. This time a suitable area was found with a uniform 20 degrees slope and covered by one representative soil type. The experiment is now being carried out with the co-operation of the Land Dayaks who have felled, burnt and planted part of the trial plots according to the instructions of the rice agronomist.

D. A soil reconnaissance was carried out in the Sebandi area south of Lundu, and in the adjacent Sungei Pasir Agricultural Reserve. At the same time an area of alluvial land opposite Lundu village, called Tanjon Purun, where for a long time annual wet-rice cultivation without drainage and irrigation has been successfully carried out, was investigated for comparison. The aim of the reconnaissance was to find a suitable area for sawah-rice cultivation and to assess the suitability of the Sungei Pasir Reserve for padi and rubber cultivation.

The Tanjon Bemban area near Sebandi covers 880 acres, of which 500 acres proved to have recent alluvial silty clay loam, silty clay, and clay soils which as a rule are rich in organic matter. Deep-peat soils were found in 320 acres and there are 60 acres of low hills. The 500 acres of alluvial land have been recommended for wet padi cultivation. Special attention must be given to drainage and to the control of floods, both from the river and by water from the peat swamp. The deep-peat soils are unsuitable for reclamation. The soils of the hills are poor, but they can be used for rubber planting with good management and rather heavy fertilization. This Tanjon Bemban area is an example of a smaller wet rice area which could be developed with the help of a farm-irrigation engineer.

The problem in this case resulted from a settlement of Ibans from the 2nd Division to Sebandi in 1955. Although the settlers had to promise to grow wet rice in the plain, and not practise hill-padi cultivation, they were not assisted in these new methods of cultivation. No preliminary soil survey had been made and the land allotted to them appeared to be unsuitable. Misharvests were common. In the flat alluvial area, the rice was grown on the shifting hill padi system; and there was a strong tendency to revert to hill farming at great distances from the Long House.

The Tanjon Bemban area can without doubt produce the same annual crops as the Tanjon Purun area has done for years. The Tanjon Purun area itself can be greatly improved by simple drainage measures. The drains, which were started during the Japanese time, have not been completed by the farmers. With better drainage this land could give good yields of food crops in the off-season such as maize, soya beans, green peas, sweet potatoes, water-melon and vegetables.

The Sungei Pasir Reserve proved to be almost completely covered by deep peat. There are some small hills and terraces. The soils of these hills and terraces are "Humus Podzols" and light-textured Yellow Latosols, both of very low value for agriculture. Thus, the Reserve does not provide any possibilities for agriculture.

E. Rapid investigations were carried out in two coastal areas near Bintulu. These were intended for the planting of coconut palms under the subsidized Coconut Planting Scheme. Both areas had to be rejected because of poor soil and drainage conditions. In one area the soil was a shallow "Humus Podzol" and in the other a pure quartz-sand soil. The latter area was flooded and is bordered by an extensive peat swamp which made drainage unfeasible. Much expense was saved; the more so as the construction of a five mile long drain had been planned. Traverses had already been made by the Land and Survey Department and the 110 five-acre plots had been laid out and marked by pegs.

A third area in the vicinity was investigated and found more suitable so that the urgent planting scheme could proceed.

F. A soil reconnaissance of some 19,000 acres was carried out in the Limbang river valley between the villages Ukong and Danau. This is an example of a soil reconnaissance made for the introduction of new export crops.

The aim of the reconnaissance was to appraise the potentialities of the area for agricultural use, especially for the cultivation of oil palms. To be economically sound an area of 5,000 acres of level or gently sloping, either well-drained or well-drainable of adequate fertility, and with good accessibility is required for an oil palm estate.

The oil palm project involves the establishment of an estate for processing and marketing which has its own plantations of some 1,000 acres; in addition 4,000 acres will be planted by small and medium holders with the assistance of the estate.

Of the total of 19,000 acres of land, 17,500 acres are suitable for various forms of agriculture. No less than 15,000 acres are level or nearly level with silty clay loam, silty clay, and clay soils; some 2,500 acres are low hill land; and some 1,500 acres are peat soils.

The level mineral soils are all considered to be suitable for oil palm cultivation. From the 15,000 acres an area of some 8,000 acres has been recommended for oil palm cultivation; including ample land for house compounds, additional food crops, and rubber plantations, as well as range land for the holders. The most suitable areas for the nuclear estate, and for the some 50 acres of large pilot scheme which will proceed large-scale planting, have been plotted on the map. There is ample irrigation water in the Limbang river the year round, and all level land also could be developed for irrigated rice cultivation. The hills have moderate slopes and the soils generally are of sufficient depth and quality for rubber planting. Without doubt oil palm will also grow well on the low hills.

The level soils are poorly or imperfectly drained, but they are well-drainable because of the high location of the plain above the river.

This large area of well-drainable and irrigable mineral soils is an exceptional good agricultural area for Sarawak, and is at present only extensively used. With drainage for oil palm and rubber, and with irrigation for sawah cultivation it can be developed into a prosperous agricultural region.

The peat areas must be left as such. They can provide timber for house building and other purposes.

As a result of the reconnaissance an oil-palm estate is now being established by the Colonial Development Corporation.

G. The Trusan valley near Trusan village has been investigated and proved to have conditions similar to the Limbang valley. Some of the recent alluvial soils are lighter-textured sandy loams and clay loams. These soils have good structure; for this reason the area has been considered for cocoa cultivation. It is intended to establish a cocoa trial plot in this area.

H. A soil reconnaissance survey was made in the Serian Irrigation Project area. A more detailed soil map of the area is felt advisable to provide more accurate information. The soils of the hilly terrains are an integral part of the project for the cultivation of rubber, and some of them appear to be of very poor quality. Moreover, peat soils are locally found in the plain.

A survey of the Drainage and Irrigation Section has been in progress since January 1959, involving detailed levelling and soil augerings. Because of the absence of soil survey facilities at the time, it was not possible to carry out a preliminary soil survey.

IX. MAJOR SOILS OF SARAWAK

A. General

A schematic soil association sketch map (Map No. 2) has been prepared on the basis of the profile studies made during the soil reconnaissances shown on map No. 1, and on data on geology, topography, vegetation, and land use.

Laboratory data were very limited at the time of the preparation of this report. Some samples collected in 1955 and 1956 have been analysed by the Institute for Soil Research at Bogor, Indonesia, and I have to thank Mr. H. Jahja, Head of the Institute, for his kind co-operation. It is hoped that further analyses will be carried out on samples collected during the field trips. These samples have been collected from well-prepared soil pits representative of a number of important Sarawak soils.

The aim of this chapter is to give profile descriptions of some of the major soils of Sarawak. The soils that have been studied until now in Sarawak and Brunei could be correlated with the following Great Soil Groups: Yellow Latosols, Red-Yellow Podzolic Soils, Low Humic Gley Soils, Grey Hydromorphic Soils, Ground-Water Podzols, Lithosols, Alluvial Soils, and Bog Soils, including many transitional soils. Furthermore, the soils of some basaltic plateaux have been grouped together as "Linau-Balui Soils, Brown Latosols, and related Hydromorphic Soils". The relationship of the Linau-Balui Soils to the established Great Soil Groups is not clear.

B. General character of the country

(1) Physiography, relief and drainage

The broad morphologic characteristics of Sarawak have been discussed in Section III.

According to the geological map of Sarawak, the country's 47,500 square miles are mainly of sedimentary rocks, only 1,600 square miles being of igneous rocks*. The greater part of central and east Sarawak is built up of an intensely folded succession of Cretaceous and Eocene marine graywacke and subgraywacke sandstones, slates, and shales which extend through Brunei and North Borneo. This succession is usually very thick, locally reaching a thickness of 50,000 feet. The second largest succession is formed by the Neogene marine sandstones and shales and some limestone. Other pre-Tertiary rocks mainly comprise slates, phyllites, shales, chert, sandstones and limestones. The igneous rocks are in part Palaeozoic and Mesozoic, in part Tertiary. They occur as

*

Personal thanks to Dr. N.S. Haile of the Geological Department for correcting notes on the geology of Sarawak.

large granitic and granodioritic masses and as small granitic, andesitic and dioritic intrusions, with a few gabbro intrusions. Young Tertiary and Quaternary volcanic activity gave rise to the covering of some areas in central and east Sarawak by thick basic and intermediate lava flows and tuffs; these are now found as large isolated remnants in the Hose Mountains and in the Linau-Balui and Usun Apau mountain plateaux.

A summary, showing the area and lithological characteristics of the rocks of the greater part of Sarawak, and of Brunei, is given below, based on information in the British Borneo Geological Survey Report, 1956.

SEDIMENTARY FORMATION

	<u>Area</u> Sq. miles	<u>Characteristic features</u>
QUATERNARY	7,100	Marine and fluviatile alluvium comprising mud, sand, and gravel; coral in a few coastal areas
Neogene	13,000	Mainly marine sandstone, sand, shale, clay and limestone; coal seams occur and Miocene oil is worked. Aquitanian (Te 1-4) deposits are included
TERTIARY Paleogene	14,800	Mainly geosynclinal graywacke feldspathic sandstone, conglomerate, slate, phyllite, and shale occurring mainly in the Rajang Group. Limestone in places, and continental beds in west Sarawak where coal-bearing estuarine deposits also occur
CRETACEOUS	2,000	Graywacke, slate, phyllite, marl, limestone, shale, chert, and pyroclastic rocks
CRETACEOUS AND JURASSIC	860	Limestone, shale, sandstone and chert (Bau Series); Cretaceous and Jurassic rocks are folded together
TRIASSIC	455	Micaceous and graphitic shale, conglomerate, arkose, and pyroclastic rocks
PERMIAN AND OLDER	285	Shale, limestone, chert, volcanic and pyroclastic rocks

IGNEOUS ROCKS

ACID	Extrusive	Triassic kertophyre, rhyolite and associated tuff in West Sarawak. Tertiary dacite, lava, and tuff in East and Central Sarawak
	Intrusive	Pre-Tertiary granite, Tertiary granite, microgranite, and gold-bearing dacite
INTERMEDIATE AND BASIC	Extrusive	Triassic and Pre-Triassic andesitic and basaltic lava and tuff in West Sarawak. Palaeogene basalt, lava, and tuff near Tatau; Neogene and Quaternary andesitic and basaltic lava and tuff in East Sarawak.
	Intrusive	Diorite, dolerite, and andesite mostly of Tertiary age; a little gabbro and norite occur in West Sarawak

C. Climate

The characteristics of the climate of Sarawak have been discussed in Section III.

D. Vegetation

The vegetation is evergreen tropical rain forest. The forest is very rich in species, containing an estimated 3,000 different kinds of trees. A typical feature is, that the upper canopy of the forest is dominated by species of the Dipterocarpaceae family. Under different local conditions different types of forest can be distinguished. These vegetation types are: beach forest, peat-swamp forests, swamp forests, riparian forests, kerangas forests, mangrove forests, and mossy-forest at higher altitudes.

The present knowledge of the forests of Sarawak has been described by F.G. Browne: Forest Trees of Sarawak and Brunei, 1955.

E. The Soil Associations

1. Yellow Latosols

The Yellow Latosols occur on parent materials of an acid nature, rich in silica, and comparatively poor in iron and aluminium compounds, such as acid sediments, acid igneous rocks, and metamorphic rocks. High rainfall seems to favour their development.

In Sarawak, Yellow Latosols are found in the hills and mountains on sloping to very steep hill sides in close association with Yellow Podzolic soils. The hills and mountains largely consist of sedimentary rocks of

Neogene to "Older than Permian" age which are made up mainly of sandstones and shales, but also include metamorphic and acid igneous rocks. The hills of "Intermediate and Basic" andesitic and basaltic lava and tuff near Kutching and Serian appear to have mainly Yellow Latosols and Yellow Podzolic soils. These rocks often are strongly metamorphosed and silicified.

The Sarawak Yellow Latosols are very porous, very friable soils having little texture differentiation within the profile. No clay coatings on ped planes or in pores have been observed. Often a thin AO surface layer of fine roots with partly decomposed organic matter and some bleached quartz grains is present. The A horizons usually have yellow colours, those of the B Horizons are yellow, brownish-yellow or reddish-yellow. The C horizon shows a weak or prominent mottling of yellow, white and red. The structure is single grain, weak fine crumb, or weak fine sub-angular blocky. Concretions are absent in some profiles, but they occur in others in the lower B and the C horizons. The available chemical data indicate that the Yellow Latosols have very low cation-exchange-capacities and base-saturation-percentages. The soils may be considered to be virtually devoid of plant nutrients. The reaction is very strongly or extremely acid, the pH varying from 4 to 5. The low base-exchange-capacities indicate the presence of kaolinitic clays and a low content of organic matter.

According to texture, 2 sub-divisions have been made:

- (a) Sandy Yellow Latosols: loamy sand and sandy loam soils.
- (b) Heavier-Textured Yellow Latosols: sandy clay loam and clay soils.

Profile descriptions

(a) Sandy Yellow Latosols

Profile 386/389 D (201/204)^x

Location: Sungei Likau area; traverse No. 6, 60 chain

Topography: Undulating to rolling terrain with long dipslopes rising 20° towards east; some 40 metres above sea-level

Vegetation: Fairly poor lowland Dipterocarpaceae forest

A00 : The floor is well-covered by broad leaves

201 A0 : 3 - 0 cm : Mat of fine roots with partly decomposed leaves and dark reddish-brown granular mor; at the bottom, 1 cm of light grey medium and fine sand is adhered; sharply overlying.

202 A1 : 0 - 12 " : Moist yellow (10YR 7/6) fine loamy sand to sandy loam; many pores up to 0.5 mm wide and some 4 mms wide pores of old root passages with dark brown organic coatings and remnants of roots; very friable; most of the larger tree roots are confined to this horizon; boundary abrupt

x) 386/389 D is the collectors number; 201/204 is the laboratory number

- 203 B1 : 12 - 100 cm : Moist yellow (10YR 7/6) fine loamy sand to sandy loam; very friable; pores up to 0.3 mm wide are present; few roots, only a single larger root proceeds into this layer, generally roots do not go beyond a depth of 35 cms, most roots run parallel with the surface; dark brown organic coatings in old root passages.
- 204 B3 : 100 - + " : Moist, brownish-yellow (10YR 6/6), very weakly light red mottled fine sandy loam with many dark red, hardened concretionary fragments, mostly up to 0.5 cm thick plates, up to 8 cms large; no roots

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)							Texture class
			c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay	
202	0- 12	A1	10.00	1.34	55.09	23.61	80.04	12.79	12.02	1. sand/s. loam
203	12- 100	B1	10.03	1.33	50.71	28.19	80.26	11.76	14.21	1. sand/s. loam
204	100- +	B3	12.02	2.84	52.67	19.01	76.54	15.11	14.03	1. s. loam

No.	pH	Org. %	N %	C/N	Exchangeable cations m.e./100 g.				CEC m.e. %	Base satn. %
					Ca	Mg	K	Na		
202	14.3	0.84	0.02	42	0.19	nil	0.18	0.24	4.1	15
203	14.9	0.30	0.02	15	0.13	nil	0.10	0.16	2.6	15
204	14.8	0.15	0.02	8	0.16	nil	0.17	0.16	3.2	15

General remarks

The pit is situated on a 20° sloping dip slope of pure fine sandstone rock. The soil is permeable; run-off is limited because of the presence of the surface organic mat; soil drainage is only moderate because of seepage water. Mottling starts at a depth of 1 metre. Periodic aeration is sufficient to keep the iron oxidized to this depth. The mottling and the formation of concretions point to periodic wetter conditions below a depth of 1 meter.

The enumeration of commercial trees gave 2 meranti, 1 keruing, and 2 other Dipterocarpaceae trees to the acre.

(b) Heavier-Textured Yellow Latosols

Profile 992/996

Location: Limbang Valley area between Ukong and Danau

Topography: The pit is situated on a low ridge side with a 10° slope, 3 metres elevated above swamp level

Vegetation: Secondary tree growth with some old trees that have been left standing during clearing

- 992 A1 : 0 - 5 cm : Very pale brown (10YR 7/4, dry; moist yellowish-brown 10YR 5/4) silty clay; somewhat humus; very friable; crumb structure; slightly plastic and slightly sticky
- 993 A3 : 5 - 28 " : Yellow (10YR 8/6, dry; moist yellowish-brown 10YR 5/6) silty clay; friable; weak fine to medium subangular blocky structure; pores present; fair number of roots
- 994 B2 : 28 - 55 " : Yellow (10YR 8/6, dry; moist yellowish-brown 10YR 5/8) clay; friable; slightly plastic; more compact; many small concretions of ferruginous gravel or fine sandstone and shale; fair number of roots
- 995 B3 : 55 - 75 " : Very pale brown (10YR 7/4, dry; moist yellowish-brown 10YR 5/6) clay with more concretionary gravel and pieces of sandstone and shale.
- 996 C : 75 - + " : Very pale brown silty clay with light grey (10YR 7/1, dry) specks and some yellowish-brown (10YR 5/8, dry) mottles; fairly firm; fragments of shale and sandstone present; roots present

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)					Texture class
			c. and m.s.	f.s.	T.s.	silt	clay	
992	0 - 5	A1	2.2	8.8	11.0	40.9	45.0	Silty clay
993	5 - 28	A3	2.3	10.2	12.5	43.8	44.7	silty clay
994	28 - 55	B2	4.1	17.8	21.9	37.9	45.4	clay
995	55 - 75	B3	6.3	6.9	13.2	38.4	50.3	clay
996	75 - +	C	5.7	10.9	16.6	42.4	44.5	silty clay

No.	pH	Org. %	N%	C/N	P ppm	Exchangeable bases m.e./100g.				CEC	Base s
						Ca	Mg	K	Na		
992!	4.2!	3.69!	0.29!	12!	6!	0.61	0.62	0.29	0.18	12.9	13
993!	4.6!	1.20!	0.13!	9!	2!	0.39	0.26	0.09	0.08	12.8	6
994!	4.4!	0.54!	0.09!	6!	tr!	0.44	0.10	0.09	0.07	10.6	7
995!	4.9!	0.40!	0.09!	4!	2!	0.44	0.21	0.10	0.15	10.5	9
996!	4.9!	0.30!	0.07!	4!	tr!	0.39	0.10	0.11	0.17	11.9	7

Profile 356/359 D (176/179)

Location: Long nawei in the Rajang river area beyond Belaga
 Topography: Very steep hill land in the Palaeogene formation; the pit is on a 30° sloping site at the upper end of a 40° sloping hillside; the elevation is estimated at some 60 metres above sea level
 Vegetation: Good quality hill forest

- 356 A1 : 0 - 2 cm : Brown to dark brown (7.5YR 4/2, moist), some humus present; fine sandy clay loam; boundary abrupt
- 357 A3 : 2 - 35 " : Yellow (10YR 7/6, moist) fine sandy clay loam; the soil is weakly mottled by yellow spots and by slightly darker spots with more humus; crumb structure; very porous; large number of pores; no coatings; many roots; boundary abrupt
- 358 B2 : 35 - 75 " : Brownish-yellow (10YR 6/8, moist) fine sandy clay loam; somewhat more compact; crumb structure; slightly plastic and slightly sticky; very many pores up to 1 mm wide; fair number of roots
- 359 B3 : 75 - + " : Reddish-yellow (5YR 7/8, moist) fine sandy clay loam with red and grey weathered fragments of fine sandstone; pores present; less roots

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)						Texture class
			c.s.	m.s.	f.s.	T.s.	silt	clay	
356	0 - 2	A1	0.12	8.03	41.01	49.16	21.88	26.41	sandy clay loam
357	2 - 35	A3	0.18	7.17	47.17	54.52	23.02	25.91	sandy clay loam
358	35 - 75	B2	0.18	3.08	51.09	54.35	21.79	29.79	sandy clay loam
359	75 - +	B3	0.99	5.77	49.68	56.44	25.70	24.52	sandy clay loam

No.	pH	Org. C%	N%	C/N	P ppm	Exchangeable bases m.e. /100 g.				CEC	Base satn. %
						Ca	Mg	K	Na		
356	3.4	5.61	0.34	17	35	0.25	0.19	0.31	0.31	24.6	4
357	4.1	1.27	0.14	9	11	0.23	nil	0.25	0.16	10.7	6
358	4.2	0.46	0.03	15	3	0.13	nil	0.12	nil	6.4	4
359	4.5	0.26	0.04	9	2	0.11	nil	0.14	nil	5.7	4

Natural vegetation and suitability for agriculture

The stand of primeval forest on the Sandy Yellow Latosols is generally poor, whereas that on the Heavier-Textured Yellow Latosols is good. The suitability of the Sandy Yellow Latosols for agriculture must be considered as low. On suitable sites, with more gentle slopes and deeper soils, they may prove to be suitable for the cultivation of rubber and fruit trees, which will need heavy applications of fertilizers. For clean-cultivation crops they seem to be unsuitable because of the erosion hazard and the extreme poverty. The Heavier-Textured soils may prove to be suitable for rubber, fruit trees, coconut, and food crops. They also will need heavy fertilization to provide sustained yields.

A slope gradient of 30 degrees must be considered to be the ultimate permissible for cultivation, except for the cultivation of hill padi in special areas.

2. Red-Yellow Podzolic Soils

The Red-Yellow Podzolic soils occur in Sarawak in close association with the Yellow Latosols. They also are found on well-drained hill sides with gentle to very steep slopes. The Red-Yellow Podzolic Soils in Sarawak are well-drained soils with a distinctly eluviated, lighter-coloured and lighter-textured A horizon over a heavier B horizon. In many cases the increase in clay content with increasing depth is fairly gradual; and in many cases it is not possible to distinguish a well-defined A2 horizon. In fact, many of the soils in Sarawak are not typically developed and appear to be intergrades to Yellow Latosols.

The soils generally have many pores until the B21 or B22 horizon, i.e. until a depth of some 50 to 90 centimetres. Usually the colours of the A horizon are light brownish-grey or pale brown (moist). Those of the B horizon are yellow, reddish-yellow, or brownish-yellow. Weak mottling usually begins in the lower part of the B horizon at a depth of some 50 to 70 centimetres. The C horizons are generally prominently mottled with white, light grey, brown, reddish-yellow and red colours. Concretions have been found to occur in several profiles in the lower B or C horizons, but in most profiles no concretionary material was found. The texture of the A horizons usually varies from loamy fine sand to fine sandy loam; the B horizon usually has a sandy clay loam texture; and the C horizon is either clay loam, sandy clay or clay. The structure of the A horizon and of the upper part of the B horizon is often weak medium sub-angular

blocky. The deeper layers generally are massive. Weak clay coatings in pores and on ped planes have been observed in some profiles, but are lacking in others. It is noticeable that until now no Red Podzolic soils have been found in Sarawak and Brunei. All the studied profiles had either yellow, brownish-yellow, or reddish-yellow B horizons, and are, therefore, Yellow Podzolic soils. This, most likely, is caused by the very wet climatic conditions, as it has been found in other parts of the world that wetter climatic conditions favour the development of the yellow varieties of these soils. Also, when comparing the Sarawak Yellow Podzolic soils with Yellow Podzolic soils elsewhere, it seems likely, that the Sarawak soils fit into the extremely leached and acid, chemically extremely poor, range of the Great Soil Group.

Apart from Red-Yellow Podzolic soils, intergrades to Yellow Latosols and to Grey Hydromorphic Soils have been found to occur, the latter in localities with wetter soil conditions. Thus, the following sub-divisions have been made:

- (a) Red-Yellow Podzolic Soils
- (b) Red-Yellow Podzolic Soils transition Yellow Latosols
- (c) Red-Yellow Podzolic Soils transition Grey Hydromorphic Soils

Profile descriptions

(a) Red-Yellow Podzolic Soils

On the basis of profile characteristics the studied profiles have been grouped as follows:

- (1) Normal Sarawak Red-Yellow Podzolic Soils
- (2) Light-Textured Red-Yellow Podzolic Soils
- (3) Imperfectly drained Red-Yellow Podzolic Soils
- (4) Concretionary Red-Yellow Podzolic Soils

(1) Normal Red-Yellow Podzolic Soils

Profile 471/477 D (274/280)

Location: Andalau Forest Reserve in Brunei State
Topography: Steep hilly land; the pit is situated on a 15° slope near the top of a steep ridge; the elevation is estimated at some 70 metres above sea level
Vegetation: Very good quality forest

A00 : Ground well covered by a 2 cm thick layer of broad leaves, twigs, fruits and wood fragments; the lower 1 mm adheres to the ground and is interwoven with many very fine roots

A0 : Layer of some 1.5 cm thickness consisting of a net-work of very fine roots with partly decomposed leaf, fruit and wood remnants and some fine granular mor; layer is wet and contains some bleached white quartz grains; 1 cm thick layer of loose, soft, humus sand.

274 A1 : 0 - 3 cm : Dark brown (7.5YR 3/2, moist) humus sandy loam in a net-work of roots; fine crumb structure; abrupt boundary

- 275 A2 : 3 - 20 cm : Light yellowish-brown (10YR 6/4, moist; dry pale yellow 2.5Y 7/4 dry) sandy loam; some light yellowish-brown and yellow splotching; soft and fairly loose in place; very friable; weak, fine crumb structure;
- 276 A3 : 20 - 60 " : Yellow (10YR 7/6, moist) sandy loam; somewhat more compact than A2; very slightly plastic and very slightly sticky; very many fine pores; no coatings; many black, old root remnants; many roots; clear boundary
- 277 B21 : 60 - 110 " : Reddish-yellow to brownish-yellow (7.5YR 7/8 - 10YR 6/6) sandy clay loam; slightly plastic and slightly sticky; fine pores present; weak grey and brown clay coatings in some larger, old root passages; fair number of roots; black root remnants present
- 278 B22 : 110 - 150 " : Reddish-yellow (7.5YR 7/8, moist) sandy clay loam; compact; friable; slightly more plastic and sticky than horizon above; few, fine pores; some roots; some grey clay coatings along old root passages
- 279 B23 : 150 - 220 " : Reddish-yellow (7.5YR 7/8, moist) sandy clay loam with weak yellowish-red and very pale brown mottling; compact; friable; very slightly plastic and very slightly sticky; few, fine pores; roots present
- 280 C : 220 - + " : Prominently pale yellow and red mottled sandy clay loam; roots penetrate beyond 250 centimeters

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)								Texture class
			c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay		
274	0 - 3	A1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	s. loam
275	3 - 20	A2	2.34	26.63	40.95	7.21	77.13	10.67	15.83	n.a.	s. loam
276	20 - 60	A3	2.09	25.28	40.84	7.44	75.65	10.12	17.58	n.a.	s. loam
277	60 - 110	B21	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	s. cl. loam
278	110 - 150	B22	1.18	20.98	38.29	8.12	68.57	8.42	27.04	n.a.	s. cl. loam
279	150 - 220	B23	1.27	20.65	37.68	8.57	68.17	9.77	26.13	n.a.	s. cl. loam
280	220 - +	C	0.86	20.21	37.37	7.56	65.90	12.03	30.77	n.a.	s. cl. loam

Chemical Data (Bogor, Indonesia)

No.	Depth in cms	Hor.	Particle size distribution (percent)									Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay		
240	0 - 3	A1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
241	3 - 40	A3	0.0	0.6	17.9	17.9	17.9	54.3	19.5	26.2	s. cl. loam	
242	40 - 60	B1	0.0	0.4	27.8	8.6	19.2	56.0	18.7	25.3	s. cl. loam	
243	60 - 180	B22	0.0	0.3	12.9	10.4	13.0	36.6	20.8	42.6	clay	
245	190 - +	C	0.1	0.2	6.9	6.7	8.7	22.6	19.7	57.7	clay	

No.	pH	Org.m. %	N %	C/N	P205 %		K20 %		CaO %		MgO %	
					25%HCl	2%ci.ac.	25%HCl	2%ci.ac.	25%HCl	25%HCl		
241	4.32	0.79	0.026	17	0.002	tr.	0.006	0.004	0.026	0.002		
242	4.25	0.47	0.018	14	0.002	tr.	0.008	0.004	0.038	0.004		
243	4.38	0.40	0.021	11	0.001	tr.	0.006	0.003	0.017	0.012		
245	4.32	0.30	0.019	9	0.002	0.001	0.014	0.007	0.051	0.006		

(4) Concretionary Red-Yellow Podzolic Soils

Profile 296/301 D

Location: Gunung Kandai area

Topography: Undulating terrain; the pit is situated on a 4° sloping site; estimated elevation is 20 metres above sea level

Vegetation: Poor quality forest with mosses on the lower part of boles and dead wood

- 296 A0/A1 : 0 - 3 cm : Mat of roots, leaf remnants and fine mor, with 2 or 3 cm layer of adhered grey and yellow splotched loam
- 297 A2 : 3 - 28 " : Yellow loam with weak grey and yellowish-brown mottles; friable; many roots
- 298 B21 : 28 - 50 " : Light yellowish-red and light brown mottled clay loam; friable; compact in place; medium angular-blocky structure; fair number of roots; wavy boundary
- 299 B22cn : 50 - 75 " : Light brown clay loam with very many more or less hardened concretions and quartzite fragments up to 2 cm in size; firm in place; some roots present

- 300 B/Ccn : 75 - 110 cm : Light grey, light red, dark red, and yellowish-brown mottled clay loam; hard dark red laterite concretions and quartzite fragments present; fine platy structure
- 301 C : 110 - + " : Light grey, very pale brown, red and dark red mottled silt loam; fine platy with nearly vertical trend; few hard concretionary fragments present; some fine roots

General remarks

The platiness has been inherited from the parent material which may be a steeply folded phyllite. The soils also may be a Ground-Water Laterite which has originally developed in a plain with poor drainage conditions.

Chemical data (Bogor, Indonesia)

No.	Depth in cms	Hor.	Particle size distribution (percent)								Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay	
297	3 - 28	A2	1.0	2.9	9.5	8.6	19.6	41.6	40.2	18.2	loam
298	28 - 50	B21	1.2	1.9	7.2	6.1	16.6	33.0	38.3	28.7	cl. loam
299	50 - 75	B22cn	10.9	7.1	5.6	2.3	8.6	35.4	31.8	32.8	cl. loam
300	75 - 110	B/Ccn	6.4	6.0	6.2	2.6	7.0	28.2	41.9	29.9	cl. loam
301	110 - +	C	4.4	8.5	6.2	1.2	3.3	23.6	53.5	22.9	silt loam

No.	pH	Org. m. %	N %	C/N	P2O5 %		K2O %		CaO %	MgO %
					25% HCl	2% ci. ac.	25% HCl	2% ci. ac.		
297	4.34	0.88	0.039	13	0.003	0.001	0.004	0.002	0.040	0.049
298	4.21	0.40	0.020	11	0.003	tr.	0.003	0.001	0.064	0.026
299	4.61	0.40	0.030	8	0.003	tr.	0.004	0.001	0.044	0.017
300	4.68	0.65	0.062	6	0.003	tr.	0.005	0.002	0.046	0.031
301	4.61	0.28	0.065	2	0.003	tr.	0.006	0.003	0.074	0.034

General remarks

The B22cn horizon has 22.3 percent of the soil consisting of gravel, and the B/Ccn horizon 16.4 percent.

Natural vegetation and suitability for agriculture

On the Normal Red-Yellow Podzolic Soils of the steep or sloping hill sides the stand of the forest is good or very good. The forest stand is poor on the light-textured soils with a 60 centimeters thick sandy or sandy loam upper layer; the same is true of the soils with imperfect drainage conditions. The suitability for agriculture also is thought to depend on the texture, the heavier-textured soils being better suited for agriculture. As with the Yellow Latosols, these soils will be best suited for the growth of rubber and fruit trees on slopes not exceeding 30 degrees. Terracing and drainage measures to control the erosion hazard will be needed. As the soils are chemically extremely poor, they will need heavy fertilization.

(b) Red-Yellow Podzolic Soils transition Yellow Latosols

Introduction

Some profiles have been grouped with the Red-Yellow Podzolic soils transition Yellow Latosols as they show distinct relation to the Yellow Latosols. The following profile is considered to be representative.

Profile 482/488 D (283/289)

Location: Andalau Forest Reserve in Brunei State; compartment 6
Topography: Steep hill land; the pit is situated on the higher side of a 35° sloping hill side; the elevation is estimated at some 70 metres above sea level
Vegetation: Very good quality Dipterocarpaceae forest

283	A0	:	1 - 0 cm	:	Mat of fine roots with partly decomposed leaf remnants and little, dark reddish-brown fine granular mor (F-layer); the mat is weakly laminated and fairly tough; there is a fauna of very small white ants, spiders etc.; white quartz grains are present, brought up by these animals; abrupt boundary; many roots extending into A1
284	A1	:	0 - 15 "	:	Light yellowish-brown (10YR 6/4, moist) sandy loam; very friable; weak fine crumb structure; very porous; many roots
285	A3	:	15 - 60 "	:	Brownish-yellow (10YR 6/6, moist) sandy clay loam; very porous; many roots
286	B21	:	60 - 110 "	:	Reddish-yellow (7.5YR 7/8-6/6, moist) sandy loam to sandy clay loam; very friable; somewhat more compact than A3; weak fine crumb structure; very porous; many roots
287	B22	:	110 - 170 "	:	Reddish-yellow (5YR 6/8-7-5YR 6/8, moist) sandy clay loam; somewhat more compact than B21; pores present; fair number of roots

- 288 C1 : 170 - 280 cm : Moist, mottled major light red (10YR 6/8), minor pale yellow (2.5Y 7/4) sandy clay loam with few white specks; massive and stiff; some very fine pores; very slightly plastic and very slightly sticky; fair number of roots; in places dark purplish-red soft sandy concretionary material with small hard concretions
- 289 C2 : 280 - + " : Mottled pale yellow and reddish-yellow sandy loam to sandy clay loam with minor white and light red colours; friable; no concretionary material

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)								Texture class
			c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay		
284	0 - 15	A1	1.89	21.52	45.79	11.53	80.73	9.02	16.32	sandy loam	
285	15 - 60	A3	1.41	20.24	44.47	11.75	77.87	7.98	24.07	s. clay loam	
286	60 - 110	B21	1.47	19.00	44.88	10.71	76.06	8.28	21.96	s.loam/s.cl.1.	
287	110 - 170	B22	1.30	19.08	42.56	11.84	74.78	9.42	25.65	s. clay loam	
288	170 - 280	C1	1.85	10.93	36.95	13.88	63.61	15.74	30.31	s. clay loam	
289	280 - +	C2	1.13	8.77	45.16	16.25	71.31	14.08	22.95	s.loam/s.cl.1.	

No.	pH	Org. %	Total N %	C/N	P ppm	Exchangeable bases m.e./100 g.				CEC	Base satn. %
						Ca	Mg	K	Na		
284	4.1	0.85	0.05	17	4	0.18	nil	0.17	nil	4.0	9
285	4.2	0.43	0.03	16	3	0.13	nil	0.06	nil	2.6	7
286	4.1	0.21	0.01	21	1	0.09	nil	0.10	nil	1.9	10
287	4.3	0.13	0.02	7	1	0.16	nil	0.03	nil	2.2	9
288	3.8	0.17	0.03	6	1	0.11	nil	0.06	nil	3.7	5
289	4.0	0.10	0.03	3	1	0.16	nil	0.16	nil	2.6	12

(c) Red-Yellow Podzolic Soils transition Grey Hydromorphic Soils

Some profiles have been found on gentle slopes with less rapid external drainage, and show signs of prolonged wetness in the profile.

Profile 302/308 D

- Location: Gunung Kandai area
 Topography: The pit is situated in undulating terrain on a 5° slope
 Vegetation: Fairly poor quality forest

- 302 A0 : 1.5 - 0 cm : Mat of roots and granular mor
- 303 A1 : 0 - 25 " : Grey loamy sand; many roots
- 304 A2 : 25 - 50 " : Moist, pale yellow sandy loam with yellowish-brown and brown mottles; pores of old root passages have dark grey coatings; no roots
- 305 B21g : 50 - 70 " : Moist, pale yellow, red and minor light grey mottled clay loam; compact and stiff; plastic and sticky
- 306 B22cn : 70 - 87 " : Moist, pale yellow gravelly clay with red mottles; the soil has 51.4% of gravel consisting of hard lateritic concretions, of irregular shape, dark red coloured, platy, up to 1 cm in size; the layer is compact and dense; clear boundary
- 307 C : 87 - 150 " : Pale yellow, white and red mottled sandy clay loam
- 308 D : 150 - 200+ " : Prominently white and red mottled silty clay with some brownish-yellow mottles; plastic and non-sticky

Chemical data (Bogor, Indonesia)

No.	Depth in cms	Hor.	Particle size distribution (percent)									Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay		
303	0 - 25	A1	4.7	16.2	25.7	13.8	18.8	78.2	15.4	6.4	l. sand	
304	25 - 50	A2	7.1	15.0	23.7	9.7	15.7	71.2	23.4	5.4	s. loam	
305	50 - 70	B21g	7.0	6.7	8.4	6.7	9.0	37.8	22.8	39.4	cl. loam	
306	70 - 87	B22cn	1.4	3.1	4.9	3.4	7.6	20.4	35.9	43.7	clay	
307	87 - 150	C	8.0	6.8	17.6	7.8	9.7	49.9	27.0	23.1	s.cl.loam	
308	150 - 200+	D	0.2	0.8	1.9	2.6	5.9	11.4	47.0	41.6	s. clay	

No.	pH	Org. m. %	N %	C/N	P2O5 %		K2O %		CaO %	MgO %
					25% HCl	2% ci. ac.	25% HCl	2% ci. ac.	25% HCl	25% HCl
303	4.80	1.69	0.040	24	0.008	0.004	0.003	0.002	0.044	0.037
304	4.80	0.46	0.008	33	0.003	tr.	0.005	0.003	0.058	0.021
305	4.47	0.34	0.017	11	0.003	tr.	0.005	0.003	0.034	0.026
306	4.60	0.12	0.019	4	0.002	tr.	0.005	0.003	0.055	0.032
307	4.44	0.91	0.025	21	0.002	tr.	0.006	0.003	0.040	0.038
308	4.75	0.36	0.025	8	0.003	0.001	0.008	0.005	0.074	0.066

3. Low Humic Gley Soils

In Sarawak, Low Humic Gley soils occur in flat river flood plains with swampy conditions or with imperfect drainage. They have also been found on Quaternary terrace remnants where they occur in association with Humus Podzols and other Hydromorphic soils. The parent materials are silt, clay, and some fine sand, originating from the sandstone-shale formations. The flat river flood plains suffer generally from impeded drainage because of the presence of low and narrow river levees along the banks of the main rivers as well as of the affluents descending from the hills. Apart from occasional high floods, most rivers annually flood their banks for only very short periods of a few days; flooding also is caused by water backing up in side streams, with the consequent overflowing during periods of heavy rainfall. But, the greater part of the swamp water is provided directly by rainfall; this is a further reason for the extreme acidities and the highly leached status of the soils.

Generally the soils of the flood plains are clays, silty clays, or clay loams with slow or very slow permeability. The soils have a thin, humus A horizon of a friable consistence and a fine crumb structure; and a massive, mottled or pure white or light grey subsoil with fine pores over massive, plastic and sticky, dense silty clay or clay. The soils occur in localities which are permanently wet, with the water-table near or at the surface; or with a fluctuating water-table at depths varying from nil to over 150 centimeters. The soil-drainage conditions appear to have great influence on the structure, consistence and permeability. The permanently water-saturated layers are massive, have no pores, and appear to be very slowly permeable.

The soil layers with a fluctuating water-table are indicated by distinct or prominent mottling of yellowish-brown, brown, or reddish-yellow in a white or light grey matrix. The permanently wet layers usually are white, light grey, or dark grey without mottling. In some cases, however, prominently mottled layers are found which are permanently water-saturated. This can probably be explained by the absence of organic matter in such layers. Where the soil is rich in organic matter which will, under anaerobic conditions, act as a reductive agency and reduce iron oxides to soluble ferrous compounds. These are either partially retained in the soil, causing dark grey, greenish or bluish colours to develop, or are wholly removed with seepage water, leaving a pure white or light-grey coloured, non-mottled soil. Where no organic matter is present, the

ferruginous mottles, that have been formed previously under periodical wet and dry soil conditions, appear to be persistent under permanently water-logged conditions.

The biological activity in these extremely acid soils seems to be very limited, resulting in a very slow decomposition of organic materials, so that often remnants of wood and roots are found throughout the soil or only in the deeper layers.

As a rule, the Low Humic Gley soils have no or only a thin AO surface mor layer. With increasingly poor drainage conditions the normal sequence is: soils with mottled upper layers grade into non-mottled, light-coloured soils which grade into Half Bog and Bog Soils with peat-swamp forest vegetations.

Profile descriptions

Profile 458/461

Location: Jelalong river in the Kebulu Protected Forest
 Topography: Flat river flood plain
 Vegetation: "Empran" (river alluvial) forest with tall trees, many of which have stilt roots

- 458 A1 : 0 - 7 cm : Moist, brown silty clay loam in a network of roots
- 459 C1g : 7 - 32 " : Dark grey, weakly yellowish-brown mottled silty clay loam; massive structure; dense; plastic and sticky; many, mostly horizontal roots
- 460 C2g : 32 - 80 " : Light grey and yellowish-brown mottled-clay loam; dense and tough; roots present
- 461 C3g : 80 - + " : Light grey, prominently reddish-brown mottled clay loam

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)					Texture class
			c.s.	f.s.	T.s.	silt	clay	
458	0 - 7	A1	2.3	10.7	13.0	50.6	37.1	silty clay loam
459	7 - 32	C1g	4.5	12.6	17.1	48.7	39.9	silty clay loam
460	32 - 80	C2g	0.2	30.9	32.9	38.9	36.8	clay loam
461	80 - +	C3g	1.3	23.1	24.4	48.3	29.6	clay loam

No.	pH	Org.	Total	C/N	P	Exchangeable bases		m.e./100g. Total
		C%	N%			Ca	Mg	
458	4.7	2.13	0.29	8	4	2.5	4.0	18.8
459	4.3	1.05	0.17	6	2	0.7	3.5	15.1
460	4.2	0.14	0.08	2	1	0.6	2.3	10.8
461	5.2	0.08	0.05	2	1	0.4	1.3	10.7

Profile 997/1001

Location: The Limbang river valley near Ukong village
Topography: Flat river alluvial at an estimated elevation of some 10 or 15 metres above sea level
Vegetation: A dense secondary growth of small trees, ferns, Cyperaceae and palms of some 5 years old

- 997 A : 0 - 18 cm : Very pale brown (10YR 7/4, dry; 10YR 5/3 brown, wet) silty clay; friable; crumb structure; plastic and slightly sticky; very many roots
- 998 B21g : 18 - 50 " : White (2.5Y 8/2, dry) distinctly mottled reddish-yellow (7.5YR 6/6, dry) clay; massive structure; many very fine pores and some larger old root passages; clay skins in root passages and on major ped planes; slight or moderate plasticity and stickiness
- 999 B22g : 50 - 125 " : White (2.5Y 8/2, dry), reddish-yellow (7.5YR 7/6) mottled, wet (10YR 6/1) and (7.5YR 5/8) clay; very fine pores of about 1/5th mm wide; clay skins less distinct; plastic and sticky
- 1000 Cg : 125 - 150 " : Light grey (10YR 7/1, dry; grey 10YR 5/1, wet) clay; plastic and sticky
- 1001 D : 150 - + " : Light grey to grey (10YR 6/1, dry; dark grey 10YR 4/1, wet) silty clay with remnants of leaves and woody material; this is the former bottom of an ox bow lake

The water-table was found at a depth of 65 centimeters.

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)			Texture class
			sand	silt	clay	
997	0 - 18	A	3.5	41.2	59.1	silty clay
998	18 - 50	B21g	0.3	35.1	71.0	clay
999	50 - 125	B22g	0.2	34.8	70.0	clay
1000	125 - 150	Cg	0.1	27.7	75.6	clay
1001	150 - +	D	0.0	44.9	55.4	silty clay

No.	pH	Org. m. %	Total N %	C/N	P ppm	Exchangeable bases m.e./100g.				CEC	Base satn. %
						Ca	Mg	K	Na		
997	4.4	2.15	0.23	9	4	0.83	0.73	0.17	0.16	16.0	12
998	5.0	0.71	0.09	8	2	0.34	0.81	0.09	0.20	13.9	10
999	4.9	0.68	0.11	6	2	0.49	0.77	0.10	0.20	11.9	13
1000	4.8	2.38	0.19	13	28	0.75	1.12	0.12	0.20	20.1	11
1001	4.8	9.20	0.25	37	19	0.38	1.50	0.17	0.22	29.2	8

Profile 1027/1029

Location: Limbang river valley near Ukong village
 Topography: Flat river alluvial
 Vegetation: A secondary growth of Cyperaceae, ferns, weeds and low shrubs mainly of Melastoma
 Drainage: Wet marsh land with the water-table flush with the surface

- 1027 A : 0 - 15 cm : Grey (10YR 5/1, dry; dark grey 10YR 3/1 wet) silty clay; rich in organic matter; soft mud with very many living roots; dry hard and unbreakable by hand
- 1028 A/Cg : 15 - 50 " : Light grey (10YR 7/1, dry; dark greyish-brown 10YR 7/2 wet) silty clay; rich in organic matter; plastic and very sticky; when dry hard but breakable
- 1029 Cg : 50 - + " : White (10YR 8/1, dry) with spots of light brownish-grey (10YR 6/2) colours due to finely divided organic matter; silty clay; plastic and sticky; when dry a very distinct soapy feel of the easily breakable clods; roots present

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)			Texture class
			sand	silt	clay	
1027	0 - 15	A	0.0	38.0	48.9	silty clay
1028	15 - 50	A/Cg	0.0	42.3	56.7	silty clay
1029	50 - +	Cg	0.0	39.9	58.3	clay

No.	pH	Org. m. %	Total N %	C/N	P ppm	Exchangeable bases m.e./100 g.				CEC	Base satn. %
						Ca	Mg	K	Na		
1027	4.4	23.25	1.58	15	32	1.06	1.19	0.58	0.26	49.7	6
1028	4.8	11.37	0.62	18	11	1.41	1.08	0.29	0.20	29.8	10
1029	4.2	7.50	0.42	18	12	1.50	0.93	0.10	0.20	20.7	13

Natural vegetation and suitability for agriculture

The natural vegetation is riparian forest containing many Shorea trees of several species which produce the illipe nuts, and some valuable timber trees. Most of the original forest has been destroyed by shifting cultivation.

The Low Humic Gley soils cover by far the greater part of the river flood plains, the balance being Alluvial Soils. It has been estimated previously in this report that these level lands of mineral soils cover some 3 percent of the total land surface, or about 900,000 acres. These soils are of the greatest importance for the agricultural development of Sarawak. Only little of this land is now intensively used. Drainage measures are primarily needed to make the land suitable for agricultural use. Where good drainage can be established, the soils are well suited for rubber plantations and for fruit trees such as durian, rambutan, bananas, and coconut palms. Larger areas are especially suited for the growth of oil palms. Moreover, these soils are typically suitable for the cultivation of sawah rice with proper drainage, and, where possible, irrigation. In between rice crops good crops of maize, sweet potatoes, beans, cucumber, and other vegetables can be grown on the sawahs. Till now, rice growing in these flat areas mostly has been done by the shifting cultivation system. In some areas, annual rice growing has been successfully carried out for long periods. In many localities, a common complaint of rice growers is that the rice shows an exceptional vegetative growth, but produces little or no grain. This is most certainly caused by the high organic matter content of many of these soils. Annual cropping,

with the growth of secondary crops between rice plantings, will have a beneficial effect, as it will lead to a better decomposition of the organic matter.

Proper management, including fertilization, will greatly improve the productivity of these soils. Much research on fertilization problems will be necessary, including that of the minor elements. At the very low level of bases in many of these soils, the balances among calcium, magnesium, and potassium could be upset very easily. Most of the plant nutrients in the soils seem to be contained in the organic matter which will decrease rapidly after intensive cultivation.

4. Grey Hydromorphic Soils

In Sarawak, the Grey Hydromorphic soils have been found until now on the Quaternary terrace remnants in the lowland and on some high mountain plateaux, in close association with the Humus Podzols and the other hydromorphic soils of the "Kerangas" soil association. They have developed over finer-textured sediments such as sandy clay loams and sandy clays; whereas the Humus Podzols are formed in sandy parent materials.

These soils usually have a well-developed, 2 to 5 centimeters thick AO surface layer of dark reddish-brown matted mor. The profiles studied have a light grey silt loam or silty clay A horizon varying in thickness from 10 to 25 centimeters; a white, heavier, and usually prominently brownish-yellow mottled B horizon with some grey clay coatings and often some dark, organic, coatings on ped planes and in old root passages. They occur on level to strongly rolling terrain. The external drainage varies from very slow to medium. Surface run-off is negligible because of the presence of the surface mor layer, but lateral drainage over the B horizon occurs in sloping terrain. The internal drainage varies from slow to very slow, depending upon the texture and permeability of the B and C horizons. Although in some localities a permanently high water-table was found, the soil-drainage conditions are generally better than those of the associated Humus Podzols with a slowly permeable humus-podzol B horizon at little depth. In most cases, no water-table was found in the Grey Hydromorphic soils. However, because of the wet climate, the presence of the surface mor layer, and the slow permeability, the soils are, for most of the time, moist or wet.

Many typical profiles have been studied in the Gunung Pueh, the Sarawak Mangrove, the Sempadi, and the 6th-Mile Forest Reserves.

Profile descriptions

Profile 102/104 D

Location: Sarawak Mangrove Forest Reserve
Topography: Level terrain on a terrace some 3 metres elevated above the mangrove mud flat
Vegetation: Fairly good quality kerangas forest with meranti, keruing, ru ronang, sempilor, rattan, lianes, nibong palm etc.

Drainage: External drainage is slow, and the internal drainage seems to be very slow and impeded. The water-table occurs at a depth of 15 cm below surface. Lateral water movement seems also to be very slow, as a nearby gully was dry and did not receive any seepage water from the water-saturated soil.

- 102 A0 : 3 - 0 cm : Mat consisting almost entirely of roots with some smeary mor in the lower part
- 103 A2g : 0 - 13 " : White (10YR 8/1, dry; light grey 10YR 7/2, moist) organic matter containing silt loam; very many roots
- 104 B21g : 13 - 23 " : White silty clay; very compact and dense; impermeable
- B22g : 23 - + " : White, prominently brownish-yellow (10YR 6/6, dry) mottled silty clay loam; dense and impermeable

Chemical data (Bogor, Indonesia)

No.	Depth in cms	Hor.	Particle size distribution (percent)									Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay		
103	0 - 13	A2g	0.0	0.3	1.4	1.0	5.6	8.3	75.8	15.9	silt loam	
104	13 - 23	B21g	0.0	0.3	1.2	0.8	7.1	9.4	61.1	29.5	silty clay	

No.	pH	Org. m. %	N %	C/N	P205%		K20%		CaO% 25% HCl	MgO% 25% HCl
					25% HCl	2% ci. ac.	25% HCl	2% ci. ac.		
103	4.13	2.99	0.040	42	0.003	0.001	0.002	0.001	0.017	0.008
104	4.15	0.30	0.013	13	0.002	0.001	0.006	0.002	0.055	0.009

Natural vegetation and suitability for agriculture

The natural forest is "kerangas" forest. The stand varies locally, depending on the drainage conditions. Generally, the forest stand is somewhat better than on the associated Humus Podzols; and the forest has more commercial trees such as meranti (*Shorea* sp.) and keruing (*Dipterocarpus* sp.) than is common in the "kerangas" forest of the Humus Podzols.

For agriculture, the soils seem to be, although extremely acid and poor in plant nutrients, somewhat better than the Humus Podzols. When occurring in level terrain they could be used for wet-rice cultivation. Rubber also may grow on these soils with proper drainage and fertilization.

Grey Hydromorphic Soils transition Half Bog Soils

In localities with very poor drainage and a permanently high water-table transitions between the Grey Hydromorphic soils and the Half Bog Soils are formed; characterized by a thick AO mor surface layer. This may be the case where the low terrace ridges transgress into the adjacent low-lying swamp, or in flat and sunken areas on top of the ridges. The forest in these localities is very poor, open, low, stunted "kerangas" forest, with most of the trees having stilt and knee roots.

5. "Humus Grey Hydromorphic" soils

The name "Humus Grey Hydromorphic" soils has been given by the expert to a group of soils which have important characteristics in common with both the Humus Podzols and the Grey Hydromorphic soils; but which, on the other hand, are distinguished from those soils to such a degree as to justify their classification in a separate major group of soils.

The "Humus Grey Hydromorphic" soils are, as are the Humus Podzols, characterized by a humus-podzol B horizon, but there is a marked difference in the mode of deposition of the translocated organic matter derived from the AO surface mat and the A1 horizon. In the Humus Podzols the organic matter has been deposited in a well-defined, usually hard or "firm to friable", humus-podzol B horizon which is only a little heavier in texture than the sandy-A horizon, is free of iron, and has a thickness - at least in the associated Humus Podzols - varying from 5 to 30 cms. The "Humus Grey Hydromorphic" soils have friable sandy clay loam B horizons which are usually prominently brown or yellowish-brown mottled by iron oxides and which have conspicuous dark brown to black, very coarse organic mottles and streaks, and continuous organic coatings along large ped planes and in old root passages. This organic deposition proceeds to a considerable depth into the B/C horizon. On the other hand, the Grey Hydromorphic soils are in many respects similar to the "Humus Grey Hydromorphic" soils, but they lack the conspicuous deposits of organic matter in the mottled B and C horizons.

"The Humus Grey Hydromorphic" soils have a well-developed, 2 to 5 centimeters thick, AO mor surface layer. They have a light grey, illuvial A horizon of loamy sand or sandy loam texture, varying in thickness from 10 to 25 centimeters. The A horizon is underlain by the white sandy clay loam B horizon with the ferruginous mottling and the organic deposits described above.

The "Humus Grey Hydromorphic" soils occur on Quaternary terrace remnants in the lowland and on high mountain plateaux with "kerangas" forest vegetation; and are found in association with Humus Podzols and Grey Hydromorphic Soils. They occur on level to rolling terrain. The parent rocks in these areas are unconsolidated siliceous sediments of various textures. The texture of the parent materials appears to be the most decisive factor in determining which of the three associated Great Soil Groups will develop. Humus Podzols tend to be prominent on the light-textured, sandy materials. The Grey Hydromorphic Soils develop over heavier-textured parent materials such as sandy clay loams and sandy clays; whereas the "Humus Grey Hydromorphic" soils generally are intermediate in this respect.

Transitions of these soils to both Humus Podzols and Grey Hydromorphic Soils have been found. The conspicuous organic mottling and coatings of the "Humus Grey Hydromorphic" soils are frequently found in Humus Podzols in the B22h or in the B/C or C horizons below the typically hard or firm B21h horizon. When the development of the typical humus-podzol B horizon becomes weaker the Humus Podzols grade into typical "Humus Grey Hydromorphic" soils. With decreasing deposition of organic matter in the subsoils the "Humus Grey Hydromorphic" soils grade into the Grey Hydromorphic Soils. Thus, the following sub-divisions have been made:

- (a) "Humus Grey Hydromorphic" Soils
- (b) "Humus Grey Hydromorphic" Soils transition Humus Podzols
- (c) "Humus Grey Hydromorphic Soils" transition Grey Hydromorphic Soils

Profile descriptions

(a) "Humus Grey Hydromorphic" Soils

Profile 64/67 D

Location: Gunung Pueh Forest Reserve

Topography: A broad terrace about 6 metres elevated above swamp level; the terrain is gently undulating to undulating; the pit is situated in a 5° to 10° sloping site

Vegetation: A better type of kerangas forest

- A00 : 2 cm of loose litter, leaves, twigs, etc.
- A0 : 3 - 0 cm : Matted mor consisting of a network of fine roots with partly decomposed plant debris and dusky red granular mor
- 64 A2 : 0 - 12 " : Light grey to grey (10YR 7/1-6/1, dry; greyish-brown 10YR 5/2, moist) soft, loamy fine and very fine sand
- 65 B21 : 12 - 48 " : White (7.5YR 8/0, dry; light brownish-grey 2.5Y 6/2, moist) fine sandy clay loam or loam with dark brown organic coatings on planes and root passages; fair number of roots; hardens somewhat on drying; abrupt boundary
- 66 B22 : 48 - 60 " : White (7.5YR 8/0, dry; light brownish-grey 2.5Y 6/2, moist), prominently brownish-yellow (10YR 6/6) mottled heavier fine sandy clay loam with dark brown and black organic coatings; few roots; hardens somewhat on drying; brownish-yellow mottles turn red on ignition
- 67 C : 60 - + " : Color same as B22; fine sandy clay loam with many rounded, dark grey, hard and weathered gravel (phyllite?) up to 2 cm in size; compact

(b) "Humus Grey Hydromorphic" Soils transition Humus Podzols

Profile 273/276 D

Location: Sempadi Forest Reserve

Topography: Undulating to rolling terrain; the pit is situated on a 20° slope dipping towards the East

Vegetation: Poor kerangas forest

- 273 A0 : 5 - 0 cm : Dark reddish-brown (2.5YR 2/4, moist) laminated mat of fine roots mixed with fine granular, greasy mor; some sand grains adhered to the bottom
- 274 A2 : 0 - 12 " : Pinkish-grey (5YR 6/2, moist) medium and coarse sand; very friable; roots present
- A3 : 12 - 15 " : Light brown and grey splotched transitional layer; very porous; some small earthworms present; fair number of fine roots
- 275 B2h : 15 - 30 " : Greyish-brown to brown (10YR 5/2-5/3, moist; pinkish-grey to pale brown 7.5YR 6/2-10YR 6/3, dry) humus sand, somewhat compact; friable; roots present
- 276 B/C : 30 - + " : White (10YR 8/0, moist) sandy loam, light brownish-grey and red mottled sandy loam; dark brown organic coatings and some brownish-grey clay coatings; roots present

Chemical data (Bogor, Indonesia)

No.	Depth in cms	Hor.	Particle size distribution (percent)									Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay		
274	0 - 12	A2	0.6	16.0	57.5	7.2	3.3	91.8	6.0	2.2	sand	
275	15 - 30	B2h	0.6	14.5	57.0	8.8	6.6	87.5	9.2	3.3	sand	
276	30 - +	B/C	0.0	11.3	52.6	4.5	6.1	74.5	14.5	11.0	sandy loam	

No.	pH	Org. m.%	Total N%	C/N	P2O5%		K2O%		CaO%	MgO%
					25% HCl	2% ci. ac.	25% HCl	2% ci. ac.		
274	5.59	0.66	0.017	22	0.004	0.001	0.005	0.004	0.055	0.008
275	4.51	1.42	0.028	29	0.002	0.001	0.016	0.007	0.033	0.116
276	4.79	0.32	0.011	17	0.002	0.001	0.015	0.004	0.052	0.058

6. Humus Podzol Soils (Ground Water Podzols)

In Sarawak, the Humus Podzols are found on low ridges and flats of alluvial deposits and on Old-Quaternary or Late Pliocene, Pre-Glacial terraces in the lowlands, and in the Tertiary of older sandstone hills, both at low elevations and at high altitudes. The relief of the Quaternary Terraces, which mostly are dissected by erosion, is level to rolling, and the Humus Podzols found here are on slopes varying from nil to 10 degrees. In the sandstone hills they have been found at lower elevations on level terrain and on slopes with gradients up to 20 degrees; at high altitudes they occur on strongly dissected very steep hill land. The parent materials are sandstones, loose sands, loamy sands and sandy loams.

All Ground Water Podzols in Sarawak have podzol-B horizons consisting of mineral matter with humus, and are wholly free of iron. Therefore, they are all pure Humus Podzols.

The Humus Podzols are found in association with Grey Hydromorphic soils, "Humus Grey Hydromorphic" soils, and, to a less extent, with Low Humic Gley soils. The distribution of these soil groups is largely dependent on the texture differences of the parent materials, the Hydromorphic soils having developed over finer-textured materials: i.e. heavy sandy loams, sandy clay loams, and sandy clays.

Although flat areas with very poor drainage conditions occur in Humus Podzol areas, generally the external drainage conditions are favourable. The Pre-Glacial terraces are, as a rule, somewhat elevated above the surrounding land. Sometimes they comprise large, continuous stretches, but frequently small patches are found as "dry" islands in the peat-swamps and mangrove swamps. Moreover, the terraces often are strongly dissected and gullied. In the hills, the Humus Podzols usually cover sloping sites. Still, most of the soils are usually wet because of poor internal drainage induced by the presence of the slowly or very slowly permeable B horizon which hampers the infiltration of water. The wet soil conditions are also greatly induced by the presence of the matted-mor surface layer which prevents run-off and lessens the evaporation of soil water. In some localities there may be a permanently or periodically high, fluctuating water-table in the solum or in the C horizon, but in most soils there is, at present, no such water-table. On some raised beaches with thick sand deposits, the soils are very deep and have much better internal drainage. Here the temporary or permanent perched water-tables over the B horizon lie much deeper than is the case in the soils with the hardpan at little depth.

It seems that in many cases the greater part of the drainage occurs by lateral movement through the A horizon. Much of the finely divided organic matter derived from the A₀ and A₁ horizons is carried away to the streams with this lateral moving water which, as in the case of the peat-swamp areas, is a dark brown colour.

Intergrades between the Humus Podzol soils and the "Humus Grey Hydromorphic" soils have been found. In localities with very poor drainage and a permanently high water-table, intergrades between the Humus Podzols and the Bog Soils develop; these are characterized by a thick A₀ peat surface layer.

Profile description

The complete soil profile of the Humus Podzols in Sarawak has the following schematic composition:

- A₀ : Matted mor surface layer
- A₁ : Light grey, somewhat humus sand
- A₂ : White sand
- A₃ : A thin layer of brown and grey streaked and mottled, somewhat humus sand or loamy sand with an accumulation of horizontal roots
- B_{21h} : Prominently dark brown to black coloured, firm to hard-cemented loamy sand or sandy loam with humus; in the top few cms this horizon may be black
- B_{22h} : Brown, yellowish-brown and pale brown coloured, firm to friable loamy sand or sandy loam with humus; usually somewhat finer-textured than the B_{21h}
- B/C : Pale yellow or white sandy loam or sandy clay loam with many dark brown to black, organic coatings on large ped planes and in old root passages, and, usually, with ferruginous mottling
- C : White to pale yellow sand, sandy loam, sandy clay loam, or hard sandstone

Several of these horizons may be lacking. Sub-horizons may be absent in the B horizon, and often the A₃ horizon is lacking. Also, the B horizon may lie directly over the C or D horizon.

The humus-podzol B horizon may be either very hard, hard, very firm, or soft and friable. The thickness of the A and B horizon varies widely.

The main features of importance for classification are:

- (1) the thickness of the matted-mor surface layer
- (2) the depth of the humus-B horizon below the mineral surface
- (3) the consistence and the thickness of the humus-B horizon which may vary from very hard to soft and friable
- (4) the presence or absence of sub-horizons within the B horizon
- (5) the presence or absence of a B/C horizon
- (6) the presence or absence of a C horizon below the B or the B/C
- (7) the presence or absence of an A₃ horizon
- (8) the presence or absence of a thin black top layer in the B horizon

Taking into consideration the importance of the Humus Podzols for forestry and agriculture, the main features for defining major sub-groups are:

- (1) the thickness of the matted-mor surface layer. This reflects drainage conditions; the thickness of the peat mat appears to determine the regeneration of tree species; the thickness of the peat mat defines the sequence of Humus Podzols - Bog Soils as follows:

- (a) thickness of AO-less than 10 cms: Humus Podzols
 - (b) thickness of AO-10 to 30 cms : Humus Podzols transition
Bog Soils
 - (c) thickness of AO-over 30 cms : Bog Soils
to be sub-divided into:
 - AO 30 to 150 cms: Shallow Bog Soils
 - AO over 150 cms: Deep Bog Soils
- (2) the depth of the Bh below the mineral surface; this feature is of great importance for soil drainage conditions and root penetration
- (a) Bh at less than 25 cms : Shallow Humus Podzols
 - (b) Bh at 25 to 100 cms : Normal Humus Podzols
 - (c) Bh at over 100 cms : Giant Humus Podzols
- (3) the consistence of the Bh, which may be hard, firm or friable, is also of great importance for soil drainage and root penetration; this feature can be used for defining major sub-groups within the above-mentioned divisions in the Humus Podzols

The other features can serve to determine lower categories such as soil series. Within the soil series, soil types can be distinguished on the texture of the A horizon and on minor differences in thickness of the AO peat mat. Soil phases can be defined at all levels on slope and relief conditions.

(a) Shallow Humus Podzols

Shallow Humus Podzols occur locally in rocky terrain in the sandstone hills, both at low and high altitudes. The vegetation a very poor, open, low, and stunted "kerangas" forest. Especially the conifer "sempilor" (Dacrydium elatum Roxb. Wall.) has been found on these shallow soils.

The Shallow Humus Podzols have a well-developed AO surface mat of roots with dark reddish-brown or dusky red mor, varying in thickness from 5 to 12 centimeters. The sandy A horizon usually is only 10 to 20 centimeters; it rests on a weakly developed humus-podzol B horizon or B/Dh, which, as a rule, is no more than the upper few centimeters of the hard sandstone in which organic matter has been deposited, forming dark bands and streaks.

The soil-drainage conditions are poor. Notwithstanding the often steep slopes, the shallowness of the soil over the slowly permeable sandstone rock, the presence of the thick AO surface peat layer, the high and well-distributed rainfall, and the forest cover result in continuous wet or moist soil conditions. There is much lateral movement of water through the A horizon over the rock, carrying with it most of the finely divided organic matter; this explains the weak development of the humus-podzol B horizon in these soils.

Profile description

Profile 337/339 D

Location : Linau-Balui Plateau

Topography: Very steep hilly land; the pit is situated at the higher part of a 45° slope; some 1,000 metres above sea level

Vegetation: Poor, open, montane mossy-forest

- 337 AO : 5 - 0 cm : Dusky red (10YR 3/3, moist) matted mor
- 338 Al : 0 - 10 " : Pinkish-grey (7.5YR 6/2, dry; light brownish-grey 10YR 6/2, moist) loamy sand; wavy boundary
- 339 B/Dh : 10 - + " : Hard, platy sandstone with broken bands and streaks of humus-impregnated material of light yellowish-brown (10YR 6/4, dry) colour; turns white on ignition

(b) Normal Humus Podzols

Normal Humus Podzols are distinguished from Shallow Podzols and Giant Podzols, mainly on the basis of the depth of the humus-podzol B horizon. This depth varies in this group of soils from 25 to 100 centimeters below the surface of the Al horizon.

Within this group three sub-divisions can be made:

Soils with a hard to firm B2lh pan at a depth varying from 25 to 45 centimeters

Soils with a hard to firm B2lh pan at a depth varying from 60 to 100 centimeters

Soils with a firm to friable Bh at a depth of 50 to 70 centimeters

Soils with a hard to firm podzol B horizon at a depth varying from 25 to 45 centimeters

These are the soils found on the Pre-Glacial terraces and on sandstone ridges in the Tertiary sandstone hills. They occur in association with the other Great Soil Groups of the "Kerangas" soil association, i.e. the Grey Hydromorphic soils, the "Humus Grey Hydromorphic" soils, and the Low Humic Gley soils. Especially on the terraces, where there is much variation in the texture of the sediments, these Great Soil Groups are often found rapidly interchanging and in an intricate pattern.

The drainage conditions in these areas are generally poor. Intergrades to Bog Soils develop where there is a permanent water-table near the surface. In some places with wet soil conditions

the Bh was not hardened, and these soils intergrade to sub-division 3.

In the great number of profiles studied, the Bh pan was invariably found at depths varying from 25 to 45 centimeters.

Profile descriptions

Profile 37/42 D

Location: Gunung Pueh Forest Reserve

Topography: Level to gently rolling terrace; the pit is situated in a 5° to 10° sloping site

Vegetation: Poor kerangas forest; very open and thin with many poles; many Casuarina Sumatrana trees; mosses on boles and floor

- A00 : 2 cms of loose litter of leaves, needle-leaves, twigs etc.
- 37 A0 : 8 - 0 cm : Mat of roots and dusky red granular mor
- 38 A1 : 0 - 18 " : Light grey (5YR 7/1, dry; greyish-brown 10YR 5/2, moist) soft medium and fine sand; many roots
- 39 A2 : 18 - 26 " : White (7.5YR 8/, dry; light grey 10YR 7/2, moist) loamy medium and fine sand; single grain structure; layer is compact and wet-through; some roots; abrupt boundary
- 40 A3 : 26 - 30 cm : Wet layer of very coarse mottled black, dark grey, and dark brown, soft loamy sand with some horizontal roots; brown to dark brown (7.5YR 4/2, moist), dominantly pinkish-grey (7.5YR 6/2, dry) with white patches
- 41 B21h : 30 - 40 " : Dominantly brown to dark brown (7.5YR 4/4, moist), mixed brown and very pale brown (7.5YR 5/4 and 10YR 7/4, dry) layer of very firm, somewhat cemented, humus, heavy loamy medium and fine sand; many black and dark reddish-brown organic coatings on ped surfaces and organic remnants in old root passages; no living roots; turns pure white on ignition
- 42 B22h : 40 - + " : Very compact, firm layer of sandy loam with the typical granulated appearance of a fine sandstone; light yellowish-brown to brownish-yellow (10YR 6/4-6/6, moist) very pale brown (10YR 8/3-8/4, dry); the material breaks into large peds with continuous organic coatings of strong brown (7.5YR 5/8, dry); many black and dark brown remnants of organic matter in old root passages; some grey clay coatings in old root passages; the material is generally fairly easily breakable, but in places very hard and unbreakable; very slightly plastic and sticky, on drying the material becomes harder; no living roots

General remarks

The A2 and A3 horizons were thoroughly wet, and water was seeping from these layers into the pit. The permeability of the Bh horizon seems to be very slow, and drainage takes place largely by lateral movement through the A horizon. The organic remnants in the B22h horizon indicate very slow decomposition in this environment. These organic remnants are remains of a former forest vegetation when the Humus Podzol had not yet been developed.

Chemical data (Bogor, Indonesia)

No.	Depth in	Hor.	Particle size distribution (percent)							Texture class	
			v.c.s.	c.s.	m.s.	f.s	v.f.s.	T.s.	silt clay		
38	0 - 18	A1	n.a	n.a	n.a	n.a	n.a			sand	
39	18 - 26	A2	0.0	3.3	47.9	14.4	18.9	84.5	11.2	4.3	loamy sand
40	26 - 30	A3	0.0	3.2	54.8	6.6	19.2	83.8	14.0	2.2	loamy sand
41	30 - 40	B21h	0.0	3.3	44.2	13.5	18.3	79.3	13.1	7.6	sandy loam
42	40 - +	B22h	0.0	4.3	52.4	9.1	10.9	76.7	12.6	10.7	sandy loam

No.	pH	Org.m. %	N %	C/N	P205%		K20%		CaO%
					25%HCl	2%ci.ac.	25%HCl	2%ci.ac.	
38	15.05	1.53	0.036	24	0.003	0.001	0.011	0.009	0.014
39	16.25	0.29	tr.	-	0.002	0.001	0.006	0.005	0.069
40	14.35	2.32	0.027	49	0.011	0.001	0.008	0.007	0.019
41	14.00	3.17	0.031	58	0.002	0.001	0.006	0.004	0.016
42	14.52	1.85	0.010	-	0.002	0.001	0.032	0.003	0.021

Profile 285/290 D

Location : Sempadi Forest Reserve
 Topography: Gently undulating terrain
 Vegetation: Kerangas forest

- 285 A0 : 3 - 0 cm : Matted mor; dark reddish-brown (2.5YR 2/4, dry)
- 286 A1 : 0 - 9 " : Light grey (10YR 7/1, dry; brown 7.5YR 5/2, moist)
 medium and fine sand

- 287 A2 : 9 - 27 cm : White to light grey (10YR 8/0 - 7/1, moist pinkish-grey (5YR 7/2) with weak pinkish-white (5YR 8/2) splotches; loamy medium and fine sand;
- 288 B21h : 27 - 42 " : Prominently brown to dark brown (10YR 4/3, dry), dark brown to black, hard-cemented humus sandy loam (moist); the harpan is difficult to break by hand, when dry it breaks fairly easily; the material turns white on ignition
- 289 B22h : 42 - 62 " : Light yellowish-brown (10YR 6/4, dry) and very pale brown (10YR 7/4, dry), prominently brown to dark brown and light yellowish-brown (moist); sandy loam texture; black organic streaks in old root passages; in place the material is firm, when removed-friable; hardens on drying; turns white on ignition
- 290 Cl : 62 - + " : White (10YR 8/1), light grey (5Y 7/2, moist) sandy loam; compact; slightly plastic and slightly sticky; many dark brown and black organic streaks in old root passages up to 7 mms thick; brownish-yellow, ferruginous veins; friable; massive; the material breaks into irregular lumps; fine granulated appearance like a fine sandstone

General remarks

The roots are almost entirely confined to the A1 horizon, i.e. to the top 9 centimeters of the soil.

Chemical data (Bogor, Indonesia)

No.	Depth in	Hor.	Particle size distribution (percent)								Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay	
86	0 - 9	A1	0.0	0.0	32.9	23.9	30.0	86.8	11.8	1.4	sand
87	9 - 27	A2	0.0	0.0	40.0	14.5	28.0	82.5	16.2	1.3	loamy sand
88	27 - 42	B21h	0.0	0.0	18.9	25.1	23.9	67.9	24.1	8.0	sandy loam
89	42 - 62	B22h	0.0	0.0	24.4	16.9	24.6	65.9	22.6	11.5	sandy loam
90	62 - +	Cl	0.0	0.0	16.3	20.6	25.7	62.6	32.1	5.3	sandy loam

No.	pH	Org. m%	N %	C/N	P205%		K20%		CaO%	MgO%
					25%HCl	2%ci.ac.	25%HCl	2%ci.ac.	25%HCl	25%HCl
86	4.14	2.98	0.061	28	0.005	0.003	0.005	0.004	0.096	0.014
87	4.68	1.17	0.010	67	0.002	tr.	0.005	0.003	0.079	0.016
88	4.25	9.40	0.046	117	0.007	tr.	0.005	0.003	0.047	0.026
89	4.50	6.95	0.047	85	0.003	0.002	0.004	0.003	0.048	0.027
90	4.60	0.56	0.004	80	0.016	0.001	0.006	0.004	0.084	0.013

Soils with a hard to firm Bh pan at a depth varying from 60 to 100 centimeters

These soils have been found in several localities on raised beaches and sand terraces where the sand covering over the Tertiary strata is comparatively thin. Parent materials are well-sorted sands, mainly of medium and fine texture. The drainage conditions are best described as imperfect, but they are distinctly better than those of the soils above.

The profile has a well-developed, 5 to 12 centimeters thick, matted-mor surface layer; a 20 to 30 centimeters thick, light brownish-grey A1 horizon of medium or medium-fine sandy texture; a light grey or white, 30 to 100 centimeters thick, A2 horizon; a thin A3 horizon with an accumulation of roots; and a hard, thick, dark brown to black humus-podzol B horizon.

Profile descriptions

Profile 398/402 D (211/215)

Location : Semilajau area
Topography: Gently undulating terrain; raised beach terrace some 8 meters elevated above sea level
Vegetation: Kerangas forest of somewhat better type

- 211 A0 : 12 - 0 cm : Matted mor surface layer; the thickness varies from 12 to 20 centimeters
- 212 A1 : 0 - 23 " : Light brownish-grey (10YR 6/2, dry; grey to greyish-brown 10YR 5/1 - 5/2, moist) fine sand; humus; very many roots; boundary irregular
- 213 A2 : 23 - 73 " : Light grey (10YR 8/2, dry; pale brown (10YR 6/3, moist) fine sand; compact; very few roots
- 214 A3 : 73 - 83 " : Moist dark brown (7.5YR 3/2), dry brown to dark brown (10YR 4/3), grey and black mottled fine sand; more horizontal roots than A2
- 215 B2h : 83 - + " : Dark reddish-brown (5YR 3/2, dry; black 7.5YR 2/0, moist) humus-sand hardpan; turns white on ignition; easily breakable when dry

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)							Texture class
			c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay	
12	0 - 23	A1	0.04	4.37	77.80	8.44	90.65	3.59	8.76	sand
13	23 - 73	A2	0.06	5.31	82.30	8.77	96.44	3.63	6.44	sand
14	73 - 83	A3	0.27	8.62	75.03	5.89	89.81	3.99	15.30	loamy sand
15	83 - +	B2h	1.76	21.44	48.82	5.69	77.71	3.14	22.36	s. clay loam

No.	pH	Org. C%	Total N%	C/N	P ppm	Exchang. Ca	bases m.e./100 g.			CEC	Base satn %
							Mg	K	Na		
12	3.8	4.12	0.06	69	11	0.69	0.55	0.36	0.71	6.1	38
13	6.1	0.20	0.01	20	2	0.71	nil	0.14	0.34	0.7	100
14	4.4	3.44	0.03	115	tr.	0.20	nil	0.30	0.55	11.3	9
15	2.9	11.00	0.09	122	1	0.32	0.26	0.33	0.76	44.8	4

Soils with a firm to friable Bh at a depth of 50 to 70 centimeters

These soils have been found in the Anduki Forest Reserve on recent, low-lying beach sands. The drainage conditions are very poor, and there is a permanently high or a fluctuating high water-table.

The profile is characterized by a very thin A0 surface layer of fine roots with some leaf remnants and mor, a usually very thin A1 horizon, a bleached A2 horizon of a thickness of 50 to 60 centimeters, and a compact but friable humus-B horizon.

Profile description

Profile 462/464 D

Location : Anduki Forest Reserve in Brunei State

Topography: Flat terrain with cradle-knoll micro-relief; recent beach sand area bordered inland by an extensive peat-swamp and towards the shore by slightly higher sand ridges

Vegetation: Good forest composed of tree species which are typical for fresh water swamps and kerangas; the principal canopy is wholly formed by the crowns of "kapur paya" (Dryobalanops rappa Becc.); in the ponded depressions there is a ground flora of sedges, Thorasticum bencanum; elsewhere the ground flora is sparse

Drainage: Drainage towards the sea is impeded; the area is transversed by a number of streams running parallel to the coast for long distances before reaching the sea; these rivers drain part of the great inland swamp and they carry dark brown water; the water-table is high; the depressions are usually ponded; elsewhere the water-table was found at depths varying between 0 to 75 centimeters

A0 : 1 - 0 cm : A net-work of fine roots with partly decomposed plant debris

462 A1 : 0 - 5 " : A net-work of roots with very pale brown (10YR 8/3, dry; dark reddish-grey 10YR 4/1, moist) humus loamy sand

463 A21 : 5 - 30 " : Pinkish-grey (7.5YR 6/2-7/2, dry; moist 5YR 6/2) medium and fine sand with pockets of pure white sand; irregular boundary

464 A22 : 30 - 70 " : White, (10YR 8/1, dry and moist) medium and fine sand

- B2h : 70 - + " : Dark brown and black coloured, friable to firm; sand-humus podzol B

General remarks

The pit is situated on a slightly higher stretch of land; dark brown water seeps from the sides and accumulates on top of the B horizon. Roots plentiful to a depth of 30 centimeters. Some roots extend into the B horizon.

(c) Giant Humus Podzols

These are soils of raised beaches and sand terraces, mostly of Pre-Pleistocene age, occurring in the lowlands at elevations between 5 and 50 meters above sea level. These raised beaches often form large, continuous stretches of flat or nearly level land, rising steeply from the surrounding swamp level or abutting against higher Tertiary hills. The sands form rather thick coverings over Tertiary or older rocks or mudstone derived from mangrove mud.

The soils have a well-developed, 3 to 10 centimeters thick, A0 matted-mor surface layer; a 10 to 25 centimeters thick, A1 horizon of medium sandy texture and with "pepper and salt" shading; a white medium sandy A2 horizon which is over 100 centimeters thick and which may reach a thickness of several meters. This A2 horizon overlies a very thick, dark brown to black humus-podzol B horizon. The soil consists of well-sorted sand of medium texture, only in rare cases containing some fine gravel. The thick podzol B horizon is fairly homogeneously dark brown to black coloured and, compared with the Normal Humus Podzols, seems to have a high content of organic matter.

The podzol-B horizon often rests on top of either Tertiary or older bedrock or on loose sand with locally interbedded films and bands of silt and clay. Thus, the thickness of the profile is, in many cases, determined by the thickness of the sand covering over the older deposits. The podzol B horizon has been developed from the bottom of the sand deposit upwards.

Generally, the soil-drainage conditions in these deep soils are much better than those in the Shallow and Normal Humus Podzols. In places, the drainage conditions in the thick sand covering may be such that no podzol B horizon develops but that the fine organic matter is removed from the soil by drainage water. This may be the case in some areas of the Marudi terrace and near Bintulu, where road cuts exposed very thick layers of sand without a sign of a podzol-B horizon. If no podzol-B horizon is present, the soils may be considered to be Regosols.

Profile description

Location : The Badas Terrace near the railway station at Badas in the State of Brunei

Topography: The pit is situated on the flat terrace; the elevation is estimated at some 20 meters above sea level; the terrace stands some 15 meters above the surrounding land

Vegetation: Good forest mainly of "bindang" (Agathis alba) the height of the trees is some 30 to 35 meters; the girth up to 2.5 meters; the under storey is rather variable in height and inclined to be low; the ground flora has small tree seedlings, small palms and some "lambas" (Gomphrandra lanceolata) mosses occur on the ground and on the lower part of boles, especially on the west sides.

AOO : 2 cms of litter consisting almost exclusively of bindang leaves, twigs and fruits

453 A01 : -10 - -8 cm : Mat of roots with very dark, partly decomposed fragments of leaves, fruits etc. and a little mor (F layer)

454 A02 : -8 - 0 " : Dark red greasy mor (2.5YR 3/6, moist) in a mat of roots; some F material and some white quartz grains (H layer)

455 A11 : 0 - 5 " : Very pale brown (10YR 8/3, dry; dark reddish-grey 10YR 3/1, moist), humus, soft, loose medium and fine sand in the lower part of the root mat; weak fine crumb structure; very many large and fine roots, mostly horizontal; wavy (5 cms vertically) boundary

- 456 A12 : 5 - 15 cm : Pinkish-grey (7.5YR 7/2, dry and moist) medium and fine sand; pepper and salt; single grain structure; many roots mainly up to 5 mm thick and many of them horizontal
- 457 A21 : 15 - 30 " : Pinkish-grey (5YR 7/2, dry; moist light grey 5YR 7/1) medium and fine sand
- 458 A22 : 30 - 115 " : White (2.5Y 8/, moist 7.5YR 8/) soft medium and fine sand; fairly loose; fair number of vertical roots; abrupt boundary
- 459 A23 : 115 - 255 " : White medium and coarse sand; more compact than A22; roots few, some large vertical roots bend sharply to horizontal at a depth of 170 cms; larger roots are surrounded by a ring of pinkish-grey sand similar in colour to the A12 horizon; with increasing depth the soil becomes wetter and at a depth of 180 cms the soil is wet and dark brown, humus water seeps from the sides; deeper some brown, organic splotches
- 468 Bh : 255 - 400 " : Sampled from nearby exposure in cliff face; by boring in the soil pit the Bh was found at the depth of 255 cms; the water-table occurred at a depth of 245 cms and is perched on top of the Bh; dark brown cemented humus-sand pan breakable by hand; some root remnants
- 469 Bi : 400 - 401 " : A thin layer with a more or less hardened reddish-yellow ferruginous sheet varying in thickness from 5 to 10 mms; in places there is, directly below the brown Bh, a very thin, but sometimes up to 15 cms thick, lens of greyish-yellow silty clay; the ferruginous sheet is either directly attached to the bottom of the Bh or to the bottom of the clay lens
- 470 C : 401 - + " : White, prominently coarse yellowish-red mottled, loose sand.

General remarks

The soil seems to be well-drained to a depth of 180 centimeters. The change of the soft and loose A22 horizon to the more compact A23 horizon is abrupt and has been found to occur in several profiles at a depth of some 115 centimeters. The A23 horizon is more moist than the layers above and becomes increasingly moist with increasing depth. Roots are present to a depth of 100 centimeters. Some roots penetrate much deeper, and have been seen deep in the Bh horizon. The health of the roots seems much better than that of roots in the poorly drained Shallow and Normal Humus Podzols.

Giant Podzols have been found on the Badas terrace, the Bukit Puan terrace, and the Tutong terrace in Brunei State, and on the Marudi terrace. They have also been observed near the Sungei Dalam Forest Reserve, and along the road from Bintulu to the Fuchou rubber plantations. They are expected to be found in other places on raised beaches where the sand covering is thick. In the embankment of the Sungei Tutong, a Giant Podzol profile is exposed with 6 meters of white, coarse and medium sand underlain by a 3 meters thick, dark brown sand-humus B horizon. Here also, a very thin ferruginous sheet was found underneath the Bh horizon.

As the Giant Podzols occur on raised beaches with well-sorted sandy materials, no such intricate interchange of these soils with other hydromorphic soils is found as is the case with the Shallow and Normal Humus Podzols, where the parent materials differ widely in texture.

General remarks on the Humus Podzol Soils

The Humus Podzol Soils are confined to areas with sandy parent rocks. Well-developed Humus Podzols with a humus-podzol B horizon and a white, leached, alluvial A horizon are only found on sandy parent materials, such as sand and sandy loam. "Humus Grey Hydromorphic" Soils, Grey Hydromorphic Soils, and Low Humic Gley Soils develop on parent materials which have an increasing amount of clay particles. There is no essential difference in soil-drainage conditions of these soil groups, which vary from imperfect to very poor. The development of the humus-podzol B horizon is most pronounced in sand because of the smaller total surface of the sand particles; this results in much thicker deposits of humus on them.

The accumulation of humus in a distinct horizon seems to be caused by hindrance to further vertical percolation of water; this is caused by a water-table or by very wet soil conditions due to less permeable underlying strata. In many profiles it was observed that the humus-B horizon had developed from the bottom upwards. Thus, the drainage conditions in the upper layers of the soil became increasingly worse. This will result in an increase of lateral water movement through the A horizon, carrying with it an increasing amount of humus; and it may be deduced that a stage will be reached when humus deposition on top of the Bh horizon comes to a stop. In most level to rolling areas, with fair to good external drainage conditions, this appears to be the case when the Bh horizon occurs at a depth varying from 25 to 45 centimeters. The Shallow Humus Podzols of the steeper and rocky terrains have a very high rate of lateral water movement and, locally, also of water seepage into cracks in the rock; this explains the poor development of the podzol B horizon in these soils.

Humus Podzol Soils, although hydromorphic soils and often developing in areas with high water-tables, appear to be persistent only under conditions of somewhat better external drainage. In low-lying areas, with a high water-table and in sunken terrains on top of terraces, the originally formed Humus Podzols grade into Bog Soils; ultimately developing "raised bog" formations.

The formation of the Bh horizon in the Giant Podzol Soils is not understood. In these deep and level soils there will be comparatively little lateral movement of water. The thick Bh horizon may be very old and be a relict of former times with different drainage conditions. In places, several thick Bh horizons are found, separated by white sand layers.

Natural vegetation and suitability for agriculture

The natural vegetation of the Humus Podzol Soils is the "kerangas" forest. "Kerangas" is the name by which the Dayaks indicate land with a typical forest vegetation and light-coloured, usually sandy soils. Other soils of kerangas areas are the Grey Hydromorphic Soils, the "Humus Grey Hydromorphic" Soils and, to a less extent, the Low Humic Gley Soils. Together we may call these soils the "Kerangas" soil association. The forest and the kerangas lands have been described by Browne* **.

The typical ecological conditions have resulted in a forest which is comparatively poor in tree species. Although the forest of the kerangas areas is of a specific unique type, there are marked local differences in the development of the forest as a whole or in certain tree species which are related to differences in soil characteristics. Of great importance is the development of the peat surface layer, in itself an indication of the drainage conditions. Soil-drainage depends on the external drainage, the thickness of the A horizon, and the permeability of the B and C horizons. Very poor kerangas forest is found on the Shallow Podzols, which are more or less continuously wet because of shallowness. Typically, small Dacrydium elatum trees often occur on these soils. The forest also is very poor on the Normal Humus Podzols with a slowly permeable Bh, at a depth varying from 25 to 45 centimeters, which also are wet in the A horizon for most of the time. In both these soil groups roots are very shallow, being confined to the surface mat and the upper 10 centimeters of the A horizon. These forests are stunted, low and thin, and with a very open canopy. The areas have a marked cradle-knoll micro-relief caused by the many fallen trees. Distinctly better are the kerangas forests on the Humus Podzols with the Bh horizon at a depth varying between 50 and 100 centimeters. These are mostly the soils of raised beaches with comparatively thin sand coverings. The soil-drainage conditions are somewhat better because of the greater thickness of the A horizon. Here the forest usually has a number of larger-size trees such as meranti and keruing; also the typical Casuarina Sumatrana trees are much taller. The cradle-knoll micro-relief is less pronounced. Also the Grey Hydromorphic Soils and the "Humus Grey Hydromorphic" Soils have a somewhat better type of kerangas forest, except in places with very poor drainage.

* F.G. Browne; Forest Trees of Sarawak and Brunei

** F.G. Browne; Kerangas Lands of Sarawak, The Malayan Forester, 1952.

The somewhat improved drainage conditions in these soils are caused by the better permeability of the B and C horizons. By far the best kerangas forest is found on the Giant Podzols which have much better drainage conditions in the thick A horizons. There is no cradle-knoll micro-relief in these areas. Here, heavy Agathis alba trees are conspicuous.

Much further research on the relationships of soil and vegetation is needed. As a follow-up of the soil investigations of the expert, the Research Branch of the Forest Department began a study of the composition of the kerangas forests in selected sample plots in the surveyed areas.

Agriculturally, it is likely that the Humus Podzols can only be used in small localities near population centres for intensive vegetable growing with heavy manuring. Primarily the kerangas areas present a forestry problem. Many of the lowland kerangas areas cover extensive terrains of level to rolling land with fairly good accessibility. For a domestic supply of construction timber, poles, and fuel they are of value, and must, therefore, be protected. Also, as a long-term project, the improvement of the forest stand by silvicultural measures is considered worthy of investigation. In the little explored upland kerangas areas there may be larger stands of the conifers Agathis alba and Dacrydium elatum which may be of commercial value in the future.

The forest on the Giant Podzol Soils is valuable as a source of Agathis alba timber. These terraces are best kept under forest. Clear cutting must be avoided, as regeneration of the forest after clear cutting will be very slow and the stand of poor quality.

7. Lithosols

Lithosols cover very extensive areas in Sarawak in the steep hills and mountains where the high rate of natural erosion prevents the development of deep soils. On hill sides, with slope gradients of 30 degrees, the Yellow Latosols and Red-Yellow Podzolic Soils usually are 70 or 80 centimeters deep. With increasing steepness the soils rapidly become more shallow. These steep soils are often stony because of loose rock fragments and outcropping bedrock. Most soils, with slopes of 45 degrees and more, are less than 40 centimeters deep, and very stony.

The Lithosols of the hills and mountains are frequently mottled because of wet soil conditions; these conditions are caused by rather slow permeability of the underlying rocks and by seepage water. In areas where dipslopes and escarp sides of the ridges are present, there often are significant differences in the soil characteristics of both hill sides.

The soils of the rocky limestone hills in West Sarawak also are Lithosols. Soils are only found in small depressions amidst the bare limestone rocks. These soils consist of a 5 to 10 centimeters thick mat of roots with black, humus loam containing hard fragments of limestone. The limestones are very hard and dense, recrystallized, and consist almost exclusively of calcium carbonate.

Profile descriptions

Profile 164/166 D

Location : Merurong area

Topography: Very steep hill land; the pit is situated on the dislope side of a ridge with a 45° slope; many outcrops of white, medium-grained sandstone, sandy shale and shale; many loose blocks of sandstone

Vegetation: Rather poor quality forest

- 164 A1 : 0 - 5 cm : Very pale brown (1OYR 7/3, dry; moist yellowish-brown 1OYR 5/4) sandy loam to loamy sand; somewhat humus; fine crumb structure; friable; porous; many outcrops of angular blocks of hard sandstone up to 1 meter in size, many loose sandstone boulders
- 165 A/C : 5 - 30 " : Very pale brown (1OYR 7/4, dry; moist brownish-yellow 1OYR 6/6) sandy loam; fine crumb structure; friable; many fragments of sandstone
- 166 C : 30 - + " : Large sandstone fragments with interbedded layers of soft, friable sandy loam; the layer extends for over 1 meter; the number of hard sandstone blocks increases with increasing depth

Profile 167/169 D

Location: The escarp side of the same ridge of profile 164/166 D; the pit is situated on a 25° to 30° sloping site; no rock outcrops here

- 167 A : 0 - 5 cm : Pale brown (1OYR 6/3, dry; moist brown to dark brown 1OYR 4/3) loam; somewhat humus; fine crumb structure; many roots
- 168 A/C : 5 - 45 " : Yellow (1OYR 8/6, dry; moist 1OYR 7/6) clay loam; friable, dry somewhat hardened, slightly plastic and slightly sticky; some grey, small shale fragments; fair number of roots
- 169 C : 45 - + " : Yellow (1OYR 8/6, dry; moist 1OYR 7/6) clay loam; many grey shale fragments up to 12 cms in size, and some sandstone fragments with red and brown colours

Chemical data (Bogor, Indonesia)

No.	Depth in cms	Hor.	Particle size distribution (percent)										Texture class
			v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay			
167	0 - 5	A1	0.0	0.0	3.5	9.3	35.3	48.1	31.8	20.1	loam		
168	5 - 45	A/C	0.0	0.0	2.0	5.7	24.3	32.0	38.7	29.3	clay loam		
169	45 - +	C	1.5	2.4	2.0	2.6	17.5	26.0	37.1	36.9	clay loam		

pH	Org.m. %	N%	C/N	P2O5		K2O		CaO	MgO
				25%HCl	2%ci.ac.	25%HCl	2%ci.ac.	25%HCl	25%HCl
4.66	6.44	0.243	15	0.019	0.007	0.027	0.020	0.024	0.024
4.34	1.21	0.087	8	0.007	0.002	0.013	0.007	0.054	0.022
4.40	0.67	0.062	6	0.011	0.001	0.017	0.005	0.024	0.067

General remarks

On the escarp side of the hill the shaly rocks have more influence on soil formation than on the dipslope side where the sandy rock strata are more prominent. The escarp soil is somewhat better developed and heavier-textured. Also the vegetation is somewhat better.

Natural vegetation and suitability for agriculture

The Lithosols have no agricultural value. In general, soils with a slope of more than 30 degrees should not be used for agriculture because of the erosion hazard.

8. Alluvial Soils

Alluvial soils are little developed soils of recently deposited aqueous sediments. In Sarawak we can distinguish:

- a. River Alluvial Soils
- b. Soils of the Mangrove and Nipah swamps (Alluvial Clays)
- c. Recent Coastal Sands

a. River Alluvial Soils

The river alluvials form narrow strips along the lower reaches of rivers. These narrow strips of very slightly elevated levees rapidly

grade into the lower-lying river flood plain with Low Humic Gley Soils.

Although sandy varieties occur, usually the Alluvial Soils in Sarawak are clay loams, silty clays or clays. Often layers of different texture are found in the profile; also peat layers may be interbedded in the soil.

The available chemical data indicate that the soils are equally poor in plant nutrients and are as acid as the Yellow Latosols and Red-Yellow Podzolic Soils of well-drained hill sides. The Alluvial Soils from granite massifs have somewhat better chemical properties. Many Alluvial Soils are periodically flooded and suffer from water-logging, as is apparent by the mottling in the profile.

Profile descriptions

Profile 419/425

Location : Kebulu Protected Forest

Topography: Flat alluvial of the Sungei Bubang; the land is 4 to 6 meters elevated above normal river level; it is annually flooded for a period of a few days

Vegetation: Secondary forest of 30 to 40 years old

- | | | | | | |
|-----|-----|---|-------------|---|---|
| 419 | All | : | 0 - 5 cm | : | Moist brown to dark brown silty clay loam; fine crumb structure; slightly plastic and slightly sticky; very many roots |
| 420 | A12 | : | 5 - 20 " | : | Moist yellowish-brown silty clay loam; in places grey mottled; medium to fine crumb structure; friable; very many roots |
| 421 | 3 | : | 20 - 45 " | : | Weakly yellow, yellowish-brown and grey mottled silty clay loam; slightly firmer than A12; slightly plastic and sticky; very many roots |
| 422 | 4 | : | 45 - 90 " | : | Moist yellowish-brown silty clay loam; friable; slightly plastic, non-sticky; roots present |
| 423 | 5 | : | 90 - 150 " | : | Color same as 4; silty clay loam; moister; plastic; very slightly sticky; few roots |
| 424 | 6 | : | 150 - 200 " | : | Same as 5 |
| 425 | 7 | : | 200 - + " | : | Wet, grey prominently yellow mottled silty clay loam |

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)					Texture class
			c.s.	f.s.	T.s.	silt	clay	
419	0 - 5	A11	3.3	14.7	18.1	52.8	29.2	si. clay loam
420	5 - 20	A12	0.6	20.6	21.2	51.0	30.2	si. clay loam
421	20 - 45	3	0.7	19.0	19.7	46.9	37.0	si. clay loam
422	45 - 90	4	1.0	20.6	21.6	46.8	32.9	si. clay loam
423	90 - 150	5	0.6	6.6	7.2	52.1	40.9	si. clay/si. cl. 1
425	200 - +	7	0.5	8.9	9.4	49.7	37.8	si. cl-loam

No.	pH	Org. %	Total N%	C/N	P ppm	Exchangeable bases m.e./100 g.		CEC
						Ca	Mg	
419	13.9	3.95	0.40	10	4	0.3	4.0	16.2
420	14.3	1.03	0.28	4	1	0.3	1.3	11.2
421	14.3	1.02	0.20	5	1	0.2	0.9	10.8
422	14.6	0.73	0.10	7	1	0.4	0.5	9.8
423	14.6	0.56	0.16	3	1	0.3	1.2	11.8
424	14.7	0.38	0.15	4	1	0.3	1.6	9.8
425	14.5	0.71	0.15	5	2	0.7	1.1	10.7

Natural vegetation and suitability for agriculture

Most of the original riparian forest has been felled for agricultural purposes.

Agriculturally, the Alluvial Soils, together with the related Low Humic Gley Soils of the river flood plains, are of the greatest importance. The alluvial plains have been roughly estimated to cover some 3 percent of the country, or about 900,000 acres. Little of this land is now actually intensively used.

The transition from River Alluvial Soils to Low Humic Gley Soils is gradual. The levee soils are somewhat better drained, and, because of that, have more homogeneously yellow or brownish-yellow coloured subsoils than the mottled Low Humic Gley soils. They usually contain more silt and fine sand than the adjacent Low Humic Gley soils which have developed over sediments deposited at greater distances from the river.

Nearly all Alluvial Soils need drainage, and often flood control or some other type of measures, before they can be successfully used. The drainability depends largely on the elevation of the levees above the river level. When the land is very low and bordered by extensive peat swamps, drainage often requires expensive constructions.

The Alluvial Soils of the river levees are often used for rubber plantations and for fruit trees such as bananas, durian, rambutan, and others. Along the Limbang and Trusan rivers coconut trees are grown in larger numbers. The fruiting seems generally to be poor and the trees would greatly benefit from manuring. Rubber plantations along many rivers are very poor; this is mainly due to indifferent management, including inadequate drainage. The Alluvial Soils could also be used for the cultivation of sawah rice with proper drainage, and, where possible, irrigation. They can also produce good crops of sweet potatoes, maize, cassava, beans, cucumber, and vegetables. These crops are best grown on raised beds or ridges.

With adapted fertilization the Alluvial Soils are capable of producing very satisfactory harvests.

b. Soils of the Mangrove and Nipah swamps (Alluvial Clays)

The limited areas of mangrove and nipah tidal swamps have silty clay and clay soils. Most of these are, as yet, not reclaimable. Poisonous cat's clay has been observed to occur in the deeper layers and on crab mounds.

The chemical data of a sample of these clays are:

Particle size distribution (percent)								Texture	pH	Org.	N%	C%
v.c.s.	c.s.	m.s.	f.s.	v.f.s.	T.s.	silt	clay	class	!	!	!	!
0.0	0.1	0.05	0.05	0.2	0.4	35.2	64.4	clay	7.65	4.53	0.171	15

P205		K2O		Ca	MgO
25% HCl	2% ci. ac.	25% HCl	2% ci. ac.	25% HCl	25% HCl
0.051	0.021	0.176	0.099	0.419	0.032

c. Recent coastal sands

The recent coastal sands generally form low and very narrow strips of beach sand along the coast. They have an adapted vegetation of species that can grow on pure sand and that are not normally found in other forests. Most familiar is the "Ru laut" (Casuarina equisetifolia); others are Calophyllum inophyllum, Hibiscus tiliaceus, Thespesia populnea, Pongamia pinnata, Terminalia catappa, Planchonella obvata, Barringtonia asiatica and Hernandia ovigera (according to F.G. Browne, Forest Trees of Sarawak and Brunei).

Profile descriptions

Profile 460/461 D

Location : Near the Anduki Forest Reserve in Brunei State; the pit is situated 80 meters from the beach
Topography: Level to very gently undulating ridge some 1 to 2 meters elevated above the highest beach line.
Vegetation: Mainly Casuarina equisetifolia trees and a few ferns

- AOO : 1 - 0 cm : Needle-leaves of Casuarina
- 460 A2 : 0 - 20 " : White (10YR 8/2, moist) medium and fine sand
- 461 B/C : 20 - + " : Reddish-yellow (7.5YR 6/6, moist) prominently coarse brown mottled sand

The water-table occurs at a depth of 75 centimeters

A boring at 50 meters from the beach gave:

- A : 0 - 10 cm : Grey sand
- B/C : 10 - 30 " : Brown, ferruginous sand
- C : 30 - + " : White (2.5Y 8/2) beach sand

These profiles are of interest as they show the high rate of mobility of iron. With increasing acidity the iron compounds are wholly removed from the soil and a Humus Podzol develops in these sands. This is accompanied by a change in the vegetation and the early formation of an AO surface peat mat.

9. Bog Soils

The Bog Soils of Sarawak are the soils of the peat-swamp areas covered by swamp forests of different types. The areas cover some 12 percent of the country. As a rule, the Bog Soils of Sarawak consist completely of organic matter. It is a deposit of acid humus with a large amount of boles, branches, twigs and roots which usually are well-preserved.

The expert crossed several extensive peat swamps, but, apart from determinations of the thickness of the peat deposit and of the textural character of the mineral soil underneath, no further studies were made.

The peat deposits of Sarawak are similar to the extensive peat swamp areas in Indonesian Borneo and Sumatra described by Elisabeth Polak*. They are of the "raised bog" type, and are comparable with the European "high-moors". They are of the ombrogene, oligotrophe type, extremely acid and poor in plant nutrients.

Mr. J.A.R. Anderson, Forest Research Officer in Sarawak, intends to publish a work on the ecology of the peat swamp forests which will include details on the chemical composition of the peat soils, and on the origin, structure, and development of the typical raised bog formation.

As a rule, in Sarawak the soils are over 150 centimeters deep. Usually their depth varies between 2 and 7 meters, but locally they are still deeper. There is usually no appreciable peripheric zone of shallow peat in the raised bog areas. Apparently the bog rises rapidly from the surrounding land.

Shallow peat soils are comparatively scarce. They are found in some larger areas in the Nonok and Maludam Peninsulas where land accretion is going on; consequently the peat formation is in a young stage of development. Limited areas of shallow peat also can be found inland in localities where, because of changes in the river course, peat development has more recently started.

In general, the peat deposits are underlain by clay or silty clay substrata.

It is proposed that the Bog Soils be divided into:

- Deep Bog Soils - more than 150 centimeters deep
- Shallow Bog Soils - less than 150 centimeters deep

In several recent river flood plain areas, mineral and organic deposits alternate in the soils. Such soils are best called "peaty".

Natural vegetation and suitability for agriculture

The peat swamp forests have been described by Browne in "The Forest Trees of Sarawak and Brunei". Several zones can be distinguished in the raised bog areas; these are probably related to the drainage conditions and the thickness of the peat deposit.

* E. Polak, Ueber Torf and Moor in Niederländisch, Indien 1933.

Many peat-swamp forests produce valuable timber, both for export and local use.

The difficulties of reclaiming the raised bog areas have been the reason that many of these areas over the world are still out of agricultural production. Where there is a very high pressure for land, some of the areas are being reclaimed.

The reclamation comprises mainly: (1) drainage, and (2) de-acidification and fertilization. Drainage is done by digging a large canal with side canals. Because of the large number of hard boles and wood fragments, the use of machinery has till now proved to be unfeasible. The canals have to be dug in stages so as to prevent a too rapid drainage of the land; this would result in rapid shrinking of the peat and in irreversible drying which makes the material unsuitable for crop growth. In the next stage, together with the top layer of the peat, the forest is felled and burned. After this, the land can be planted to annual crops such as pineapple and maize. Rice can be planted only on very shallow peat deposits as this crop has to root in the clay substratum or it is sterile. After several years of planting annual crops and of burning the top layer of the peat, the land can be planted with rubber and coconut trees. At this stage, the rapid shrinking of the first years of drainage is more moderate, and the felling of trees less severe. Still, shrinking by drying and oxidation will never come to a complete standstill in these organic soils. The plantations of rubber and coconut trees have a comparatively short lifetime and a low production. With the use of lime, nitrogen, phosphate, potassium, copper sulphate, and possibly other minor elements, the well-drained and well-prepared Bog Soils should yield reasonably well. Much study will be required to assess the technical and economical feasibility of reclamation of these soils.

In Sarawak, the expert considers the deep-peat soils as unsuitable for agriculture for a long time to come. The shallow peat soils are more promising, although they also will require very careful reclamation measures and heavy fertilization. To a less extent, the same problems as in the actual peat soils present themselves in the "peaty soils". Uneven surface by shrinking will give trouble with sawah cultivation.

10. Linau-Balui Soils, Brown Latosols, and related Hydromorphic Soils

These are the soils of the Linau-Balui Plateau, and of the smaller Kebahor and Bukit Kajang Plateaux in the Upper Rajang area. These plateaux are situated at elevations between 600 and 1,200 meters above sea level. They have been built up by several flows of basaltic lava which took place in Neogene and possibly Quaternary times.

Locally the relief is flat, undulating or rolling; in other places it is strongly dissected very steep hill land. The basalt lava is wholly impervious. The climate is presumably very wet throughout the year and the air-humidity is very high. The forest varies markedly with the soil-drainage conditions. On the flat and undulating land, with imperfect or very poor drainage, poor, open and low forest is found having "kerangas" physiognomy; but most likely not having the floristic composition of kerangas forest. On better drained, sloping sites, moderate and good-quality forest is found. In the strongly dissected areas, which are situated at higher elevations and have been built up by older lava flows, the forest is of the poor, montane, mossy-forest type.

Based on drainage conditions the following groups can be distinguished:

Poorly drained soils

These soils occur on level terrain with swampy conditions and hard basalt at shallow depth. In places, outcrops of basalt occur. The soil consists of a layer of olive grey or olive coloured silty clay or clay, which is underlain by hard basalt at a depth varying from nil to some 50 centimeters.

Imperfectly to poorly drained soils

These soils occur on level to gently sloping terrain. They are grey and olive coloured silty clay and clay soils.

Profile description

Profile 352/355 D (172/175)

Location : Linau-Balui Plateau; at an elevation of some 700 meters above sea level

Topography: Undulating terrain; the pit is situated on a 5° slope

Vegetation: Fair forest with "kerangas" physiognomy

Drainage : Imperfect drainage conditions

- 352 All : 0 - 5 cm : Net-work of roots with dark greyish-brown (10YR 4/2, moist) clay; very humus; fine and medium crumb structure; abrupt boundary
- 353 A12g : 5 - 30 " : Olive (5Y 5/3, moist) clay; humus; crumb structure; many roots
- 354 A/Cg : 30 - 80 " : Olive (5Y 5/3, moist) clay; crumb structure; roots moderate
- 355 C : 80 - + " : Grey (5Y 5/1, moist) clay loam with hard, weathered basalt gravel; roots moderate

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)					Texture class	
			c.s.	m.s.	f.s.	T.s.	silt clay		
352	0 - 5	A11	12.68	5.82	3.88	22.38	20.11	56.32	clay
353	5 - 30	A12	8.35	11.50	13.90	33.75	18.34	54.37	clay
354	30 - 80	A/Cg	7.65	3.79	11.32	22.76	25.72	55.43	clay
355	80 - +	C	10.27	7.33	16.82	34.42	32.61	39.00	clay loam

No.	pH	Org. C%	N %	C/N	P ppm	Exchangeable bases m.e./100g				CEC	Base satn. %
						CaO	MgO	K	Na		
352	3.9	6.51	0.86	8	37	0.76	1.45	1.69	1.51	47.9	11
353	4.9	3.53	0.24	15	7	0.25	nil	0.54	0.54	22.1	6
354	4.2	1.09	0.10	11	3	0.13	nil	0.34	0.18	13.5	5
355	4.0	0.67	0.04	17	16	0.20	0.25	0.71	0.24	16.3	9

Imperfectly to moderately well-drained soils

These soils have been found on gently sloping to steep terrain. They have brown to dark brown, olive-brown, or light olive-brown colours in the subsoil.

Profile descriptions

Profile 340/344 D (161/165)

Location : Linau-Balui Plateau; at an estimated elevation of 750 meters above sea level
Topography: Nearly level, very gently sloping terrain with long, smooth slopes
Vegetation: Fairly good quality hill forest with, in places, many heavy trees such as oak and damar. The canopy is fairly open. The ground flora is sparse. Surface roots and lower parts of boles are covered by mosses
Drainage : Imperfect soil drainage conditions

- 340 A1 : 0 - 10 cm : Layer of very many roots with very dark greyish-brown (2.5Y 3/2, moist) sandy clay loam; crumb structure; very friable; very humus; some hard fine gravel of weathered basalt; abrupt boundary
- 341 A3 : 10 - 30 " : Very dark greyish-brown (2.5Y 3/2, moist) clay; crumb structure; some sand and fine gravel

- 342 B1 : 30 - 55 cm : Dark olive-grey (5Y 3/2, moist) clay loam; crumb structure; slightly plastic and slightly sticky; more fine gravel and some hard stones of weathering basalt
- 343 B3 : 55 - 75 " : Main colour light olive brown (2.5Y 5/4, moist); clay loam; with many red, brown, pale brown, yellow and white weathered, hard and soft small rock fragments; roots present; abrupt boundary
- 344 C : 75 - + " : Layer of hard and soft, weathered basalt; in places, the vesicular structure, which locally occurs in the basalt lava, is present; the main colours are red, yellow, brown, grey and white; pockets with smeary clayey material with inclusions of harder material are present; moderate amount of fine roots

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)					Texture class
			c.s.	m.s.	f.s.	T.s.	silt clay	
340	0 - 10	A1	36.63	5.77	6.48	48.88	20.37 30.32	sandy clay loam
341	10 - 30	A3	13.45	5.65	12.77	31.87	26.06 43.21	clay
342	30 - 55	B1	27.83	4.77	8.04	40.64	22.20 36.98	clay loam
343	55 - 75	B3	11.35	10.14	19.97	41.49	25.93 27.46	clay loam
344	75 - +	C	26.03	9.24	18.01	53.28	30.53 32.49	loam

No.	pH	Org. C%	N %	C/N	P ppm	Exchangeable bases m.e./100 g.				CEC	Base Satn. %
						CaO	MgO	K	Na		
340	4.2	6.19	0.34	18	9	0.22	0.14	0.43	0.06	23.7	4
341	4.3	2.04	0.13	16	2	0.14	nil	0.21	0.02	14.6	3
342	4.4	0.89	0.05	18	3	0.12	nil	0.21	0.09	10.1	4
343	4.1	0.83	0.03	28	tr	0.14	nil	0.25	0.07	20.0	2
344	4.3	0.40	0.02	20	1	0.30	nil	0.23	0.06	12.5	5

Profile 328/331 D (152/155)

Location : Linau-Balui Plateau; at an estimated elevation of 1,000 meters above sea level

Topography: Strongly dissected, very steep hill land with 40° to 60° slopes and ravines of about 40 meters depth; the soil pit is situated on a 35° sloping site

Vegetation: Mossy, montane forest with open canopy; the trees are usually thin and many have high stilt roots; the floor and the trees are covered by mosses

- 328 A11 : 0 - 5 cm : Net-work of roots with dark grey, strongly humus loam; soft and very friable; wet smeary; fine crumb structure
- 329 A12 : 5 - 17 " : Light olive-brown (2.5Y 5/4, moist) clay; friable wet smeary; in places, yellowish-weathered fragments of basalt occur; roots moderate; irregular boundary (vertical variation within 15 to 25 cms)
- 330 C1 : 17 - 45 " : Weathering layer with the typical vesicular structure of the basalt lava; yellow, brown, grey and white colours are dominant; brown rings occur which probably are remnants of ferruginous weathering crusts of basalt blocks and stones; few roots
- 331 C2 : 45 - + " : Weathering layer with prominent grey, basaltic, colour; material is rather soft, crushable and smeary; white specks and in places red colours; very few roots

General remarks

This steep soil is a stony phase. The whole soil is moist to wet. It is of interest that in this very wet area there is no "mor" surface layer. Under these conditions, a "mor" surface layer would undoubtedly have developed over soils derived from siliceous parent materials. The soil reaction of these basaltic soils is equally as acid as that of the soils derived from sandstones and shales. It may be that the difference in the type of vegetation causes the difference in accumulation of surface organic matter.

Chemical Data

No.	Depth in cms	Hor.	Particle size distribution (percent)						Texture class
			c.s.	m.s.	f.s.	T.s.	silt	clay	
329	5 - 17	A12	4.51	2.96	4.62	12.09	26.06	65.14	clay
330	17 - 45	C1	22.67	12.77	12.62	48.06	35.55	20.73	loam
331	45 - +	C2	13.80	5.29	9.39	28.48	45.52	31.32	clay loam

Chemical data (Cont'd)

No.	pH	Org.m. %	N %	C/N	P ppm	Exchangeable bases m.e./100g.				CEC	Base stn.%
						Ca	Mg	K	Na		
329	4.5	2.42	0.17	14	2	0.17	nil	0.22	0.24	15.2	4
330	4.7	0.35	0.01	35	1	0.17	nil	0.42	0.06	13.0	5
331	4.4	0.30	0.03	10	1	0.24	nil	0.43	0.33	12.2	8

Profile 324/327 D (149/152)

Location : Linau-Balui Plateau; at an estimation of some 700 meters above sea level

Topography: Undulating to rolling terrain

Vegetation: Fairly poor quality forest

- 324 AO : 1 - 0 cm : Thin mat of fine roots with partly decomposed leaf remnants
- 325 A1 : 0 - 25 " : Olive-brown (2.5Y 4/4, moist) sandy clay loam; humus; crumb structure; many pores; roots abundant
- 326 B1 : 25 - 50 " : Olive-brown (2.5Y 4/4, moist) clay; friable; somewhat more compact; pores present; slightly plastic and slightly sticky; some brown, weathered basalt fragments; few grains of clear (basaltic) quartz of 2 mms size; abrupt boundary
- 327 B/C : 50 - + " : Yellowish-brown (10YR 5/6, moist) clay; slightly plastic and slightly sticky; pores present; many hard fragments of brown and white weathered basalt up to 10 cms in size; roots moderate; at a depth of 100 cms a boring gave red and grey coloured smeary weathered material, and many hard, weathered basalt fragments

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)						Texture class
			c.s.	m.s.	f.s.	T.s.	silt	clay	
325	0 - 25	A1	33.35	9.28	7.99	50.62	17.33	34.10	sandy clay 10
326	25 - 50	B1	10.14	8.21	21.13	39.48	20.72	44.43	clay
327	50 - +	B/C	19.31	4.94	10.82	35.07	23.38	44.59	clay

Chemical data (Cont'd)

No.	pH	Org.m. %	N %	C/N	P ppm	Exchangeable bases m.e./100g.				CEC	Base stn.%
						Ca	Mg	K	Na		
325	5.0	5.71	0.35	16	6	0.25	0.21	0.62	0.44	23.3	7
326	4.9	1.90	0.07	27	1	0.19	nil	0.26	0.18	12.6	5
327	4.6	0.84	0.07	12	1	0.17	nil	0.17	0.29	9.4	7

Moderately well-drained soils

Profile 345/349 D (165/169)

Location : Linau-Balui Plateau; at an elevation of some 850 meters above sea level

Topography: Rolling to steep terrain; the pit is situated on a 30° slope

Vegetation: Good quality hill forest with many tall trees

- 345 All : 0 - 3 cm : A net-work of roots with some dark brown (7.5YR 3/2, moist) humus loam; friable; wet smeary; fine crumb structure
- 346 Al2 : 3 - 12 " : Dark yellowish-brown (10YR 4/4, moist) humus clay; very friable, rather loosely packed; wet smeary; crumb structure; abundant roots; abrupt boundary
- 347 B3 : 12 - 50 " : Dark yellowish-brown (10YR 4/4, moist) clay; friable; somewhat more compact than Al2; wet smeary; medium subangular blocky structure; some larger pores of former root passages are present without coatings; slightly plastic and slightly sticky; hard and soft-breakable red, brown, yellow and white coloured, weathered basalt fragments which are mostly platy up to 0.5 cm thick
- 348 B/C : 50 - 75 cm : Dark yellowish-brown (10YR 4/4, moist) clay with fragments of weathered basalt; more moist than B3
- 349 C : 75 - + " : A moist to wet layer of weathered basalt with red and yellowish-brown colours; roots penetrate deeply into this layer

Chemical data

No.	Depth in cms	Hor.	Particle size distribution (percent)						Texture class
			c.s.	m.s.	f.s.	T.s.	silt	clay	
346	3 - 12	A12	38.48	2.90	3.52	44.90	15.16	41.93	clay
347	12 - 50	B3	9.79	2.08	5.93	17.80	25.58	59.53	clay
348	50 - 75	B/C	12.06	3.53	8.06	23.65	27.79	50.22	clay
349	75 - +	C	36.78	7.57	10.80	55.15	20.49	26.89	sandy clay loam

No.	pH	Org.m. %	N %	C/N	P ppm	Exchangeable bases m.e./100g.				CEC	Base stn.%
						Ca	Mg	K	Na		
346	4.1	6.51	0.33	20	7	0.26	nil	0.55	0.12	23.0	4
347	4.7	1.81	0.11	17	1	0.17	nil	0.27	0.37	14.9	5
348	4.9	0.77	0.06	13	1	0.19	nil	0.31	0.16	12.1	5
349	5.0	0.39	0.03	13	1	0.22	nil	0.15	0.01	7.5	5

Suitability for Agriculture

The volcanic plateaux are inaccessible and lack large rivers. This will make settlement difficult. When of sufficient depth, the soils may prove to be suitable for the growth of crops such as tea, coffee, and vegetables including potatoes. Field experiments are needed to assess the feasibility of cultivation under the climatic conditions. A more detailed survey of the soils is needed to prepare a land use suitability map as a basis for further research.

X. SOME GENERAL REMARKS ON THE SOILS OF SARAWAK

The extremely wet climate has been largely decisive in producing highly leached very acid soils containing very low amount of plant nutrients. Without doubt the character of the natural vegetation has been of great influence in producing these soils. It appears that all the soils have kaolinitic clays with low exchange-capacities. Moreover, the content of exchangeable bases is invariably low.

The usually highly siliceous character of the rocks - rich in quartz and low in feldspars, hornblendes and micas, - has been another reason for the production of soils poor in lime, magnesia, potassium, phosphorus, and comparatively poor in iron compounds. Those soils derived from intermediate and basic igneous rocks, such as the Triassic and Pre-Triassic andesitic and basaltic lava and tuffs in West Sarawak and the Neogene and Quaternary andesitic and basaltic lavas and tuffs of the volcanic plateaux in East Sarawak, are very strongly acid and equally poor in plant nutrients due to the wet climatic conditions. Also, the soils derived from recent river alluvials, such as the Low Humic Gley soils and the Alluvial Soils, have no better chemical properties due to the acid character of the sediments. It appears that only some granitic soils of the lower slopes of the granite massifs and of the narrow alluvial strips along the rivers rising in these massifs have a somewhat higher content of plant nutrients because of the presence of fresh minerals such as biotite and feldspars. The mangrove clays have better chemical properties because of additions of elements from the sea-water.

Generally, much of the plant nutrients present in the soils appear to be contained in the organic matter. In the soils of the hills, the upper layer containing a higher percentage of organic matter is usually very thin, often less than 2 centimeters; in the river valley soils, the organic matter containing topsoil is somewhat thicker. In most soils, the organic matter cannot provide a source of plant nutrients for a long time. The hill padi crop largely grows on nutrients provided by the ash of the burned forest, which makes available part of the elements stored in the trees over very long periods.

It is clear that, for sustained good yields of annual or perennial crops, well-balanced fertilization is necessary. Much research is needed. Because of the very low level of plant nutrients, the application of one or several elements may well upset the intake of others and cause damage by a deficiency of minor elements.

Apart from the purely organic peat soils, there are several areas where the organic matter content of the soils of the river flood plains appears to be too high for a good harvest of wet rice. A high content of organic matter is generally not considered beneficial for rice growth. It has the effect of stimulating vegetative growth with very little or no grain. A more intensive, annual use of the same land for wet rice, combined with the growing of secondary crops in between rice crops, may reduce the organic matter content of such soils and have a beneficial effect. Efficient drainage, both during the rice planting and the fallow

period in case no secondary crop is grown, would also result in a decrease in the organic matter content; especially if the growth of ferns, Cyperaceae and grasses of the fallow period could be burned instead of worked into the soil.

Within the limitations of soil formation, as conditioned by the wet climate and the character of the parent rocks, the topography and the soil-drainage conditions have largely determined the soil units used (series, types and phases). In some cases, the influence of specific vegetation types also seems to be a determining influence; this is apparent in the formation of Bog Soils and the development of several types of Humus Podzols.

A classification of the soils of Sarawak for practical purposes must give great attention to the topographic and drainage conditions. Soil slope, relief, including the characteristics of shape, length and pattern of slopes are of great practical issue and should be expressed in the classification. It is important whether or not a landscape is built up of a system of low steep hills and ridges, or of long hill sides with similar slope gradients. On similar parent rocks, the slope of the soil generally coincides with the soil depth. Slope is of great importance for erosion, both natural and after cultivation. Under the severe rainfall conditions erosion and erosion control must be given great attention in Sarawak.

Except in detailed surveys it will not be possible to define soil series and soil types as described in the Soil Survey Manual. For a soil classification suitable for practical use, broader units will have to be defined. For the hill soils the following characteristics are important:

- (a) The depth of the soil over
 1. weathered rock penetrable for roots
 2. hard dense rock unpenetrable for roots
- (b) The relief, including slope, shape, length and pattern.
- (c) The texture: generally the stand of the forest is better on heavier-textured soils; it is expected that these soils also have greater possibilities for agricultural use.
- (d) The degree of podzolization in the profile.
- (e) The thickness and properties of separate horizons in the profile, such as structure and colouration.
- (f) Chemical and mineralogical features, including the occurrence of concretions.

For classifying the soils of the river alluvials the main features are:

- (a) The texture of the separate soil layers.
- (b) The build-up of the profile by different layers.
- (c) The organic matter content.
- (d) The drainability as determined by the elevation above river level and the position in regard to peat swamps.
- (e) The flood hazard.
- (f) Tidal influences.

MAP 1 - LOCATIONS OF RECONNOITRED AREAS

Legend

1955/1956 "Kerangas" soil investigations

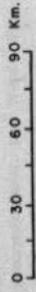
1. Gunung Pueh Forest Reserve
2. Sungai Sebat-Tembaga Area
3. Gunung Kandai Area
4. Sempadi Forest Reserve
5. Sarawak Mangrove Forest Reserve
6. Muara Tebas Area
7. Sungai Likau Area
8. Sungai Similajau Area
9. Gunung Kajang Volcanic Plateau
10. Kebhor Volcanic Plateau
11. Linau-Balui Volcanic Plateau
12. Merurong Area
13. Lambir and Sungai Dalam Forest Reserves
14. Marudi Forest Reserve
15. Batu Belah Forest Reserve
16. Labi-Bukit Teraja Area
17. Anduki Forest Reserve
18. Badas Terrace
19. Andulau Forest Reserve
20. Tutong Terrace
21. Berakas Forest Reserve
22. Lawas Area

1959 soil investigations

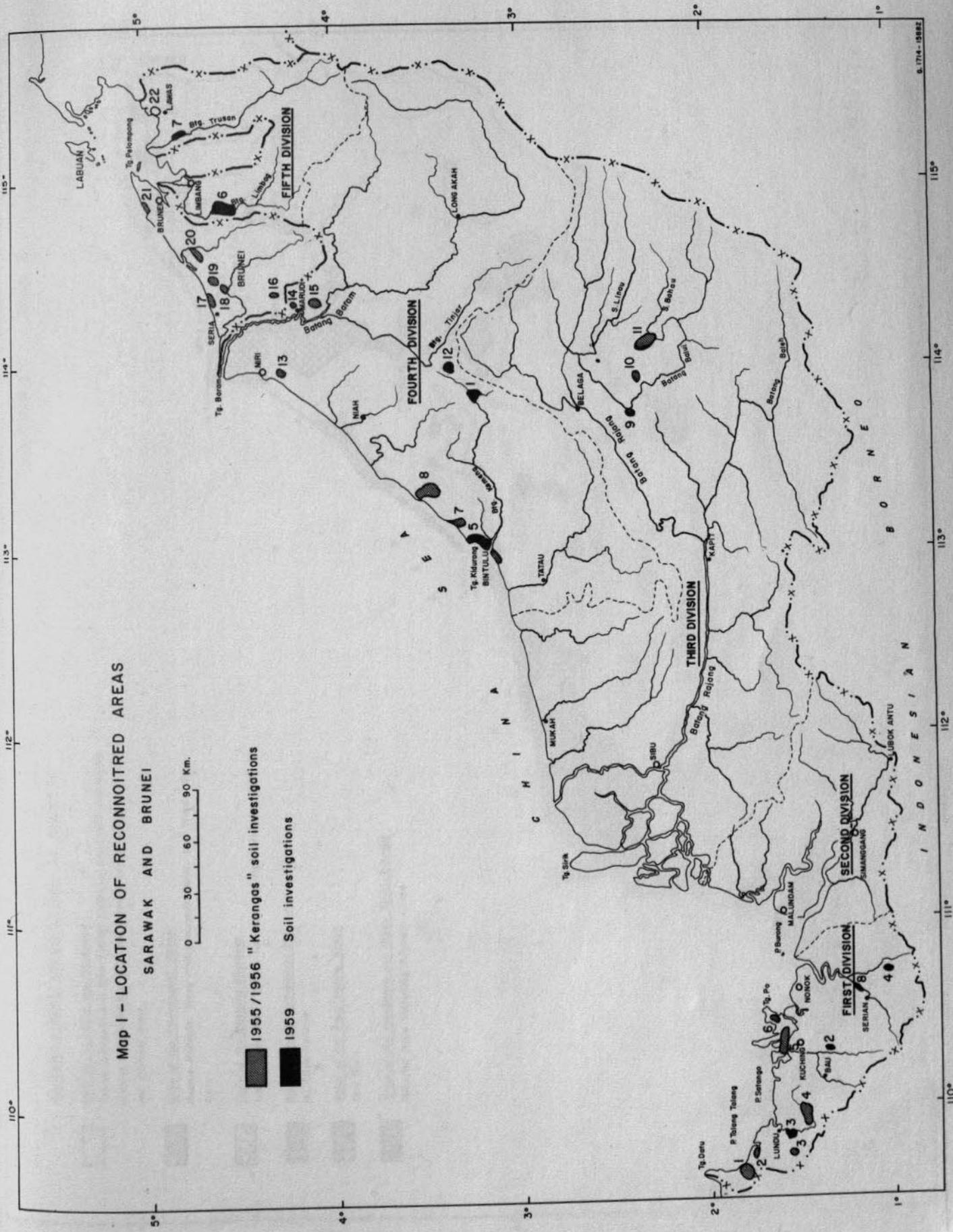
1. Kebulu Protected Forest; resettlement scheme
2. Semengko Forest Reserve; hill-padi experiment
3. Sebandi - Sungai Pasir Reserve Area; wet-padi experiment
4. Balai Ringing Area; hill-padi experiment
5. Bintulut Coastal Area; coconut planting scheme
6. Limbang River Valley; oil palm introduction scheme
7. Trusan River Valley; cocoa introduction scheme
8. Serian irrigation project

Gunung	Mountain
Bukit	Hill
Sungai	River
Batang	River
Tg Tanjong	Cape
P Pulau	Island

Map I - LOCATION OF RECONNOITRED AREAS
SARAWAK AND BRUNEI



- 1955/1956 "Kerangas" soil investigations
- 1959 Soil investigations



SARAWAK - Map 2

GENERAL SOIL ASSOCIATIONS OF SARAWAK

-  Soils of the Hills and Mountains
-  Yellow Latosols and Red-Yellow Podsolc Soils with inclusions of Grey Hydromorphic Soils and Low Humic Gley Soils, Lithosols and Alluvial Soils
-  Soils of the "Kerangas" Areas
-  Humus Podzols, Grey Hydromorphic Soils, Low Humic Gley Soils
-  Soils of the Basaltic Plateaux
-  Linau-Balui Soils, Brown Latosols and Hydromorphic Soils
-  Soils of the Acid-Volcanic Plateaux
-  No Observations
-  Soils of the Peat-Swamp Areas
-  Bog Soils
-  Soils of the Mangrove and Nipah Tidal Swamps
-  Alluvial Soils including Sulphate Clays

