A SOIL SURVEY OF BRUNEI, BRITISH BORNEO

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A Soil Survey of Part of Brunei, British Borneo

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CONTENTS

MAPS

PENGUKURAN TANAH DI-BRUNEI, BRITISH BORNEO

-oleh G. Blackburn dan R. M. Baker

Pengukuran tanah ini telah di-jadi kan dasar atas ranchangan pendudokkan oleh Kerajaan Brunei. Kurang lebeh 30,000 acre di-daerah dekat Brunei Town dan kurang lebeh 30,000 acre lagi telah di-pereksa dekat Tutong Valley. Tetapi pemereksaan dekat Tutong itu tidak berapa teliti. Oleh sebab ada-nya banyak kesukaran yang pernah di-hadapi dalam rimba *tropic*, maka pekerjaan membuat peta (atau kar) tanah di-daerah itu tidak dapat di-jalan kan dengan sa-tepat²-nya. Tanah yang mengandong barang² tambang (*mineral*) telah di-bahagi dalam 5 jenis, menurut pembahagian di-daerah sa-tempat (*local*) itu. Kebanyakkan tanah ia mengandong "*yellow acid*" dan termasok dalam class "*podzol*". Dan keluasan satu² jenis tanah itu dapat di-taksir dari pertunjukkan peta tanah itu. Peta tanah itu menunjuk kan:

(1) jenis tanah di-tiap² titik sa-panjang garis lintang (*traverse line*) dengan jarak, dan 20 hingga 40 rantai,

(2) bukit churam, lereng sedang, dan tanah datar (rata), dan paya. Di-kebanyakkan tanah rendah terdapat paya yang dalam dan mengandongi "*acid peat*". Kebanyakkan tanah pegunongan terlalu churam dan tidak subur untok pertanian tetap.

Keterangan tentang sifat² tanah, serta hasil² pemereksaan dari chontoh tanah dalam *laboratory*, telah di-ketahui; dan ini di-perbinchangkan di-samping keterangan tentang kegunaan tanah itu. Peta daerah ada di-beri beserta dengan "*sectional diagram*" sepanjang jalan rentis dekat Brunei Town. Kesimpulan dan penesehatan terutama ada di-daftar di-akhir laporan. Tanah 30,000 acre yang di-pereksa dekat Brunei Town itu tidak meliputi daerah luas yang sesuai untok pertanian tetap dan pertanian kechil. Kebanyakkan dari tanah² yang tersebut sudah kini di-perguna kan untok penanaman getah dan tambuhan lain. Nasehat² (*recommendations*) telah di-beri untok memaju kan pekerjaan berkenaan tanah di-Brunei.

Bab Yang Ke-Tujoh

Pengukuran tanah di-daerah Brunei Town dan pemereksaan tanah di-Tutong Valley, menunjokkan bahwa tanah² yang subur untok mengeluar hasil pertanian telah di-perguna kan. Hanya 2000 acre tanah subur di-Lamunin saja belum di-perguna kan.

Pembahagian tanah yang telah di-ukur ini ia-lah 4 jenis tanah yang menunjok kebanyakkan tanah² yang berbukit tinggi, tanah yang berbukit sederhana dan tanah² paya. Tanah berbukit tinggi itu tidak sesuai untok pertanian tetap; tetapi, seperti telah tertunjuk dalam peta tanah, tanah yang tersebut itu mengandongi tanah yang baik (seperti tanah *Class 3*) dan sangat subur untok berkebun getah. Tanah² paya yang berguna sekali ada-lah tanah² paya yang di-sekeliling tanah² paya besar dan di-sepanjang lembah^{2} kechil. Sebahgian dari tanah jenis ini sedang di-perguna kan untok berkebun getah dan kadang^{2} untok berhuma padi. Banyak petani mendiri kedudokkan tetap di-tanah ini. Kebanyakkan tanah yang mengandongi daun^{2} burok (*peat*) tidak dapat di-pergunakan untok berchuchok tanam oleah sebab susah di-keringkan dan di-hampiri.

Tanah yang berbukit sederhana itu pada masa ini menunjokkan banyak kebolehan untok di-perkembang dan untok di-jadi kan pertanian^{2} kechil (*small holdings*). Ranchangan penempatan semula (*resettlement scheme*) di-Simpang Muara itu telah di-tuboh kan di-atas tanah dari jenis ini. Kawasan^{2} kechil dari tanah yang sedemikian maseh ada terdapat di-Jalan Berakas di-sebelah timor dan di-sebelah barat, tetapi kebanyakkan tanah yang paling berguna di-sepenjang Jalan Muara telah di-miliki orang. Kawasan^{2} lain yang sesuai pertanian^{2} kechil adalah berdekatan dengan kampong^{2} di-sebelah barat-daya dan di-kebun getah Gadong. Menurut peta tanah, tanah *Class 4* meliputi daerah^{2} di-sepanjang jalan rentis di-tanah yang berbukit sederhana ini; di-beberapa tempat dalam daerah ini terdapat juga tanah *Class 3* dan *2*, tetapi bidang tanah dari jenis^{2} ini tidak-lah berapa besar. Dari itu, kebanyakkan tanah yang kini di-perguna untok pertanian kechil, ada-lah sama baik atau pun kurang baik dari tanah yang telah di-diami di-Simpang Muara.

Kechuali bagi kawasan Lamunin di-Lembah Tutong (Tutong Valley) yang kini sedang di-pereksa dengan selanjut-nya oleh Kerajaan Brunei, maka jarang sekali terdapat tanah rata yang sesuai untok pertanian. Lain^{2} kawasan bagi di-dudoki (*settlement*) di-Brunei boleh di-dapati dengan mengambil tindakan memereksa dan mengukor tanah di-seluroh Negeri. Pertolongan dan nasehat harus di-minta dari orang tempatan yang mengetahui tentang kedudokkan dan keadaan tanah pertanian yang subur di-daerah^{2} mereka.

Mas'alah *social* yang bersangkutan dengan pemindahan pendudok dari satu kesatu tempat, dan menempatkan semula mereka di-atas satu tempat belum lagi di-sebut kan. Soal ini mungkin akan mengganggu gerakkan perkembangan di-luar bandar.

Pertanian tetap di-kebun^{2} kechil (*small holdings*) di-Brunei boleh di-adakan di-kawasan^{2} yang terhad berdekatan dengan Bandar Brunei (Brunei Town) tetapi berapa besar-nya kawasan^{2} yang di-miliki itu, tanaman yang sangat sesuai, bagi kawasan itu dan baja yang harus di-gunakan belum lagi dapat di-tentukan. Maka tidak dapat di-elakkan kebiasaan beraleh tanaman akan menjadi mustahak untok beberapa tahun lagi. Chara berchuchok tanam ini adalah sangat memakan tenaga dan merbahaya kepada kekayaan^{2} bumi, terutama sekali dalam kekurangan tanah untok pertanaman, tetapi ini sudah terjadi 'adat menanam makanan di-atas tanah yang tidak sesuai untok pertanian tetap, dan ia-nya adalah chara hidop bagi masharakat yang bersatu dan tegoh. Di-Belgian Congo perchubaan^{2} telah di-buat untok memperbaiki peralehan tanaman ini dengan mengurang jarak masa bertanam dengan menanam tumbohan yang boleh menyuborkan tanah itu kembali seperti biasa dan dengan memakai alat jentera (*machine*). Chara ini boleh di-choba di-Brunei; lain^{2} jalan untok memperbaiki peralehan tanaman adalah sedang di-jalankan di-Sarawak (Miller 1956).

Perkara² penting yang terhasil dari pengukuran tanah adalah di-rengkaskan seperti berikut:

(1) Kebanyakkan kawasan² yang sudah di-ukuri itu tidak dapat menyokong pendudok sebanyak yang di-taksirkan oleh Kerajaan Brunei.

(2) Tanah dari darjah yang baik telah di-pergunakan untok berkebun gatah, kebun² kechil atau kawasan² kedudokkan semula (*resettlement areas*) dan peta tanah menunjokkan ada kawasan² tambahan kechil yang sesuai bagi di-perkembangkan.

(3) Chara Kedayan membahagi jenis tenah ialah chara yang bagus bagi mengenalkan tanah² tempatan.

(4) Menurut keadaan yang sekarang ini peralehan tanaman tidak begitu berbahaya.

(5) Lereng bukit harus di-tingkati dan tanaman harus di-susan menurut tingkat dan lengkongan bukit itu, kalau tumboh²han hendak di-tanam di-atas lereng itu.

(6) Keterangan tentang jemis tanah akan memudah penentuan jenis baja yang di-kehendaki, tetapi perchobaan² harus di-lakukan di-kebun, dengan memakai tumbohan yang di-kehendaki itu.

(7) Menambak paya yang dalam untok bertanam padi paya nampak-nya tidak dapat terhasil dan membuang belanja yang terlalu besar.

(8) Ampangan ayer yang chukop adalah di-kehendaki untok menanam padi paya dengan bagus-nya.

(9) Satu pemereksaan yang besaran bagi seluroh Negeri untok menentukan chara² dan jalan² bagi memeliharakan kesuboran tanah, mahu pun dengan menanam pohon² yang tertentu atau pun menchampuri ternakkan binatang² dengan berchuchok tanam. (*Ecological survey*) akan menolong menanda kawasan² yang sesuai bagi pertanian di-peta.

(10) Ranchangan² muka bumi (*base plans*) dan gambaran dari udara (*air survey*) yang di-ukur katakan satu inchi = 20 rantai, adalah di-kehendaki bagi membuat peta yang betul.

(11) Pengukuran tanah sekarang ini hanya dapat di-jalankan dengan mengikut jalan rentis.

A SOIL SURVEY OF PART OF BRUNEI, BRITISH BORNEO

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Summary

This survey was made as the basis for a proposed Government resettlement scheme in Brunei. About 30,000 acres were inspected near Brunei Town and a similar area in the lower Tutong valley was covered in less detail. The difficulties associated with surveying in tropical jungle prevented the accurate mapping of soil boundaries. The mineral soils, mainly acid yellow earths and podzols, were divided into five classes according to a local classification, and the extent of each class can be estimated from the soil map which shows (1) soil classes at points along traverse lines 20 to 40 chains apart and (2) steep hills, moderate slopes, flat land, and swamps. Large areas of deep acid peat swamps occupy most of the lowland and much of the hill country is too steep or infertile for permanent agriculture.

Descriptions are given of the characteristic soils, together with results from laboratory examination of soil samples, and these are discussed with reference to land use. Maps of each area are presented, also sectional diagrams of typical *rentis* lines near Brunei Town. The main conclusions and recommendations are listed at the end of the report. The 30,000 acres examined near Brunei Town do not include a large area suitable for permanent agriculture on small holdings; most of the suitable land is already used for rubber and other crops. Recommendations are made for further work in connection with land use in Brunei.

I. INTRODUCTION

Brunei is a State under British protection on the north-west coast of Borneo; its area is 2226 sq. miles and the population in 1956 was about 65,000. Most of the people live near the coast, especially in the urban districts of Kuala Belait—Seria (36,000) and Brunei Town (16,000). Oil is the chief industry; in 1955 oil production in Brunei was valued at more than £A.42,000,000 and royalties to the State exceeded £A.5,000,000.

Until recently food, particularly rice, was grown by village people for their own use and the State was largely self-supporting. Now, however, many of these people are employed in the oil industry at Seria and in the extensive public works programmes, and local food production cannot meet the demand.

The Brunei development plan for the period 1953–58 includes schemes to help food production, and the government wishes to provide small holdings for the thousands of families still living on the water village over the Brunei River. One of these schemes at Mulaut is designed to increase the area of wet *padi*‡ land.

Another proposal for resettlement on small holdings led to the soil survey of an area near Brunei Town. In 1955 the Division of Soils, C.S.I.R.O., was asked through the Commonwealth Department of External Affairs to make a soil survey

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‡See Appendix I for a glossary of vernacular names and terms.

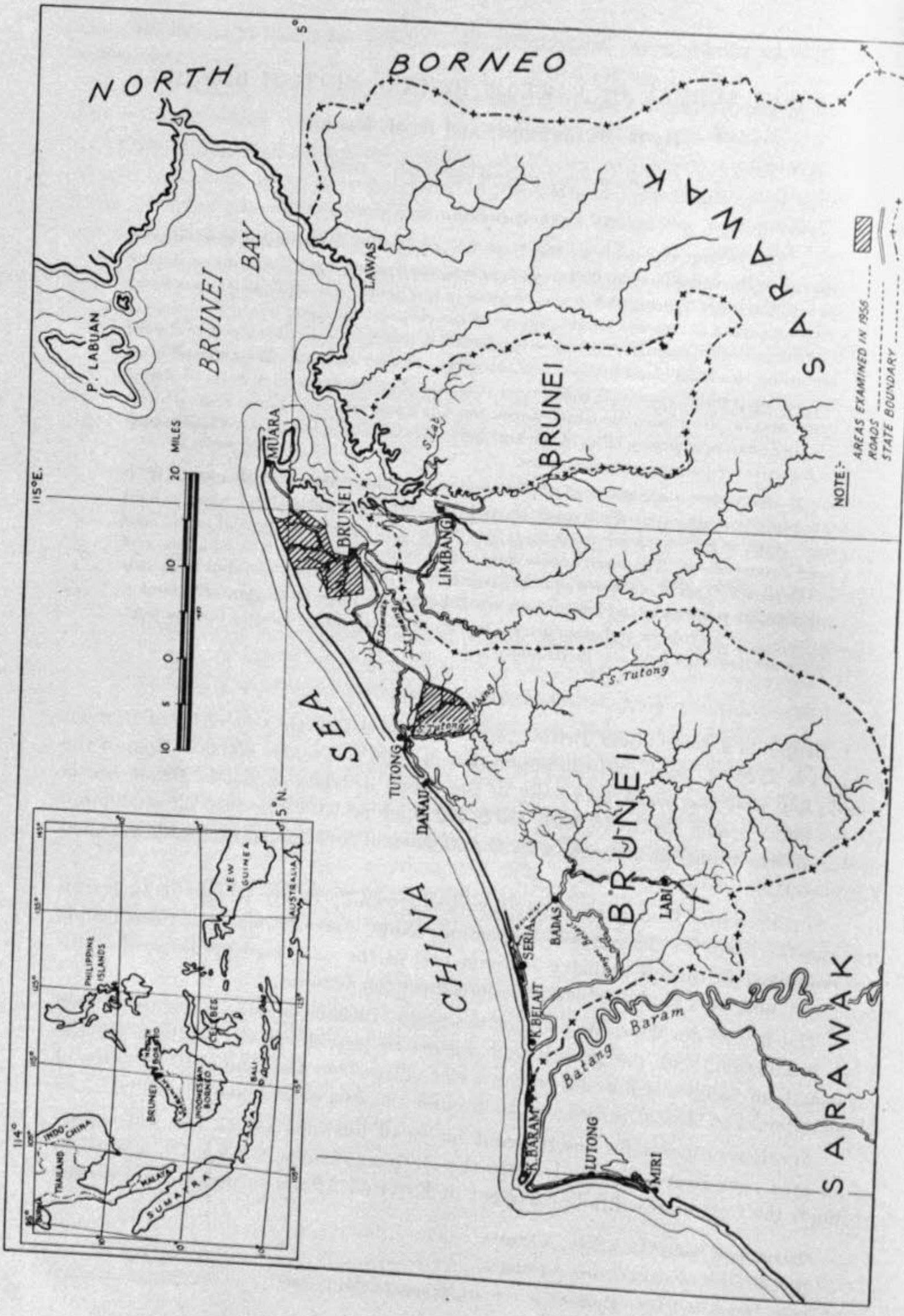

Fig. 1.—Locality map of Brunei showing areas inspected.

for the resettlement scheme. In February 1956 a brief inspection of suggested areas was made by Dr. C. G. Stephens of the Division and preparations were then made for a soil survey of approximately 30,000 acres near Brunei Town. The systematic examination of this area along *rentis* lines was made from June to August 1956 and a brief inspection was also made of an equally large area in the lower Tutong valley. These areas are shown on the locality map (Fig. 1).

The climate of Brunei is tropical and the abundant rainfall is marked by short periods of intense rainfall. This creates a severe erosion hazard on the sandier soils, as shown on the unprotected road sides (Fig. 2). Most of the State is covered by primary rain-forest growing both in the rugged hilly interior and on the swamp lands near the coast.

Fig. 2.—Short periods of intense rainfall cause severe roadside erosion on unprotected sandy soils near Berakas beach.

Rice, sago, and fish are the major foods in Brunei. A large part of the primary forest has been cut down for shifting cultivation, mainly for rice, near Brunei Town. Sago production is important in some areas, particularly along rivers. Fish are caught along the coast and in the main rivers; the Malay community of the large water village at Brunei Town is traditionally associated with fishing. The shifting cultivation on the smaller hills (Fig. 3) and valleys has supported people in the scattered small villages. Permanent small holdings have become important only recently; much of the land adjoining the main roads is now occupied in this way and there are a few places where land has been subdivided by the government for resettlement by people from Brunei Town. The largest of these areas, near the Berakas and Muara Roads, is known as the Simpang-Muara resettlement area. A large part of the better land close to the town is occupied by rubber plantations, the only type of permanent agriculture carried out successfully over a long period. The use of small holdings for stable agriculture is a new development in Brunei and there is little experience to show what methods will be most successful.

II. Topography and Geology

The surveyed area near Brunei Town consists essentially of low steep hills and swamps. It is bounded on the south-east and south-west by higher and much dissected hills and on the north-west by the China Sea. The highest point is Bukit Tabur Bintang, 290 ft above the sea. In the northern parts most of these hills have

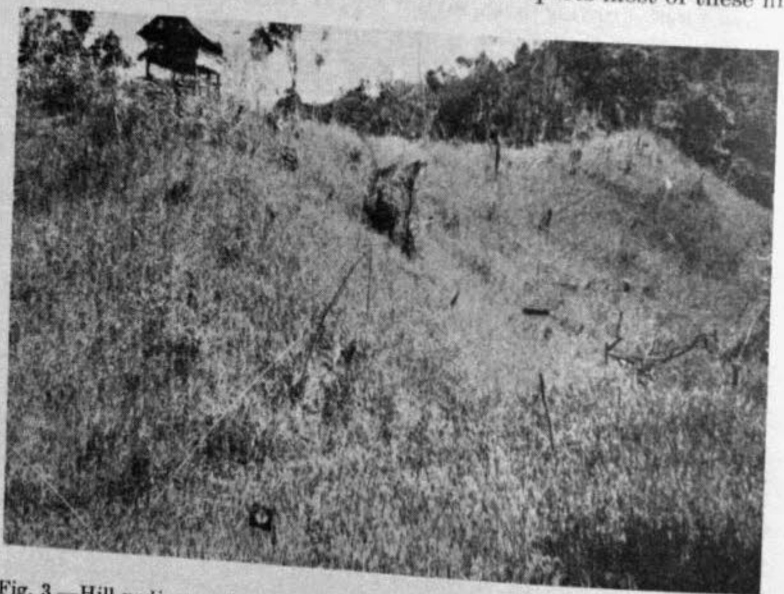

Fig. 3.—Hill *padi* on a short steep slope close to the Muara Road follows several years of secondary jungle.

slopes of more than 30 per cent., and many of the slopes are too steep for cultivation. Some of the razorback ridges show signs of erosion even under natural forest. In the southern part the slopes are much more reasonable and although there are many steep areas most of the hilly land could be cultivated. The sequence of low steep hills and swamps is shown in Figures 4, 5, and 6, representing cross sections along *rentis* lines.

The low hills have been formed by dissection of folded Tertiary clays and sandstones. White sands on lower hills and terraces represent marine sand deposits at former high sea-levels. More recent alluvial deposits occur as small clay hills, as river flats, or as layers of clay or silt over or in the peat.

Drainage to the north occurs through a network of swamps, leading to the sea via Sungei Mangsalut; drainage to the south is through a tributary system of Sungei Brunei. Many of the smaller streams are only ill-defined links between one swamp and the next.

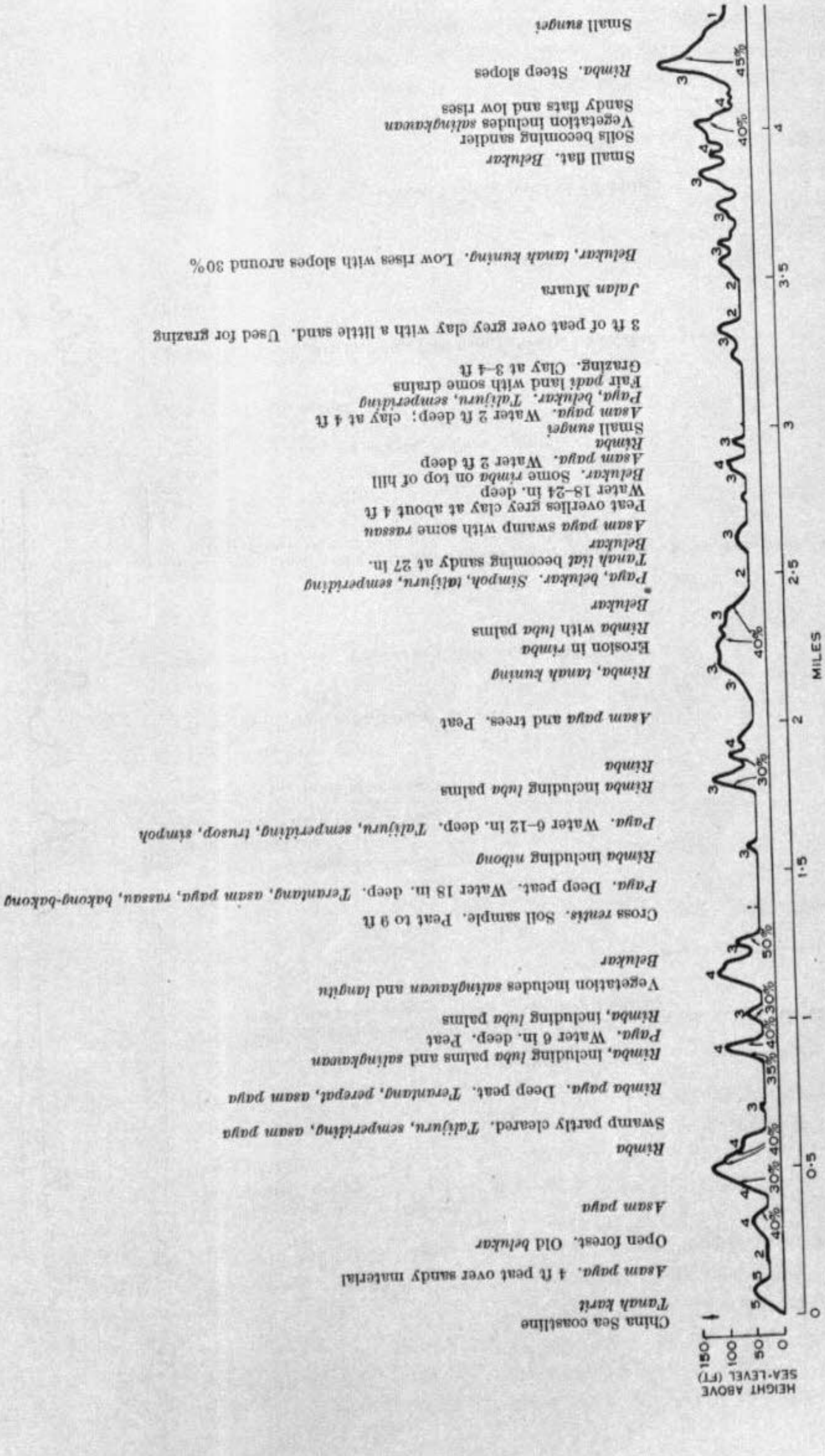

Fig. 4.—Cross section along *rentis* C.

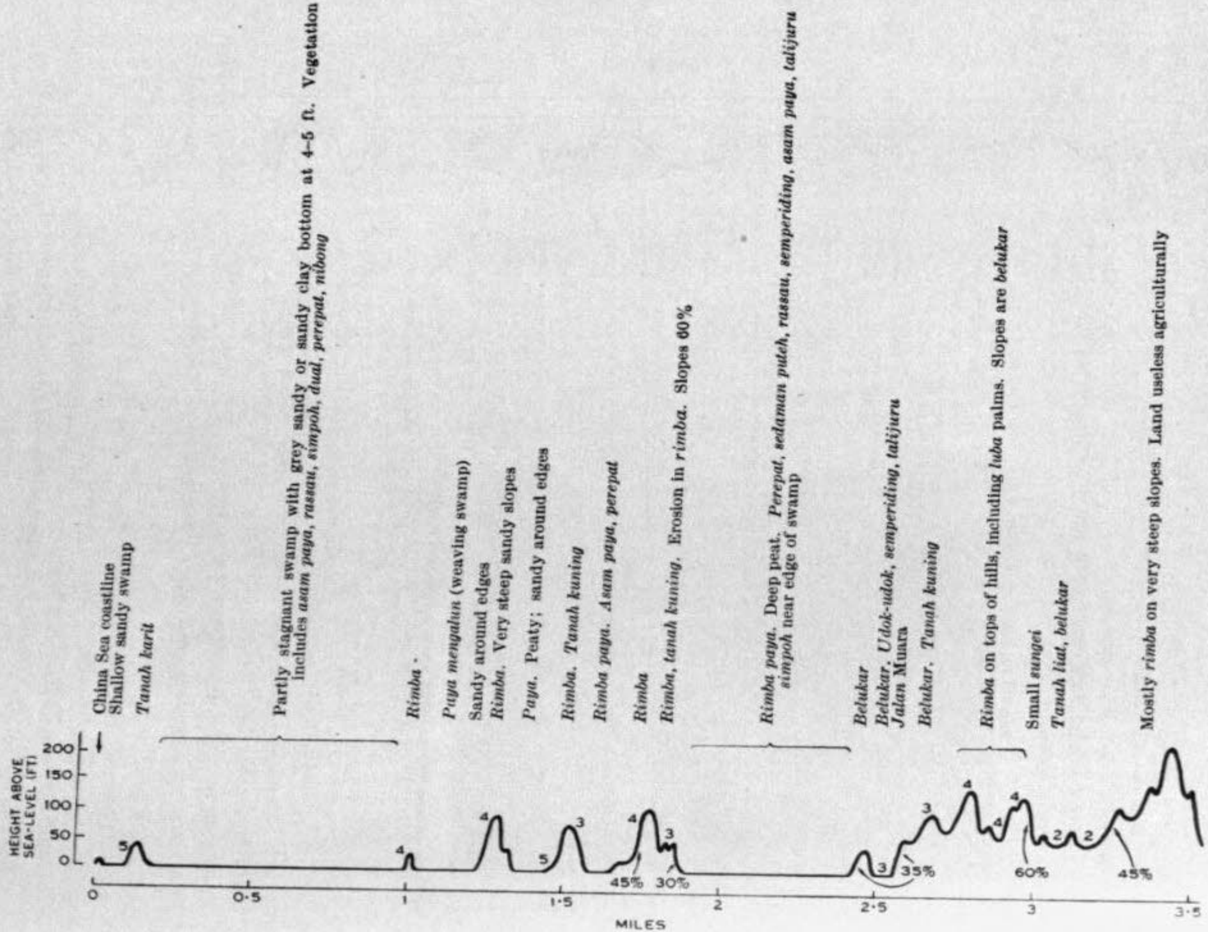

Fig. 5.—Cross section along *rentis* J.

In the Tutong valley most of the area is peat swamp forest. The higher hills on the east and south-east of this valley represent the same formation near Brunei Town. Low sandy hills and terraces, as at the town of Tutong and west of Tutong River, represent deposits at former high sea-levels. Alluvial deposits by tributaries of the Tutong River occur in the small valleys and along the fringe of the higher hills. Levee banks are noticeable along the main channels; the highest banks, up to 6 or 10 ft above the river, occur along the Tutong River. The land slopes gradually down away from the river bank into the swamps. The only areas used for cultivation are the levee banks, the low isolated hills and the alluvial soils in tributary valleys.

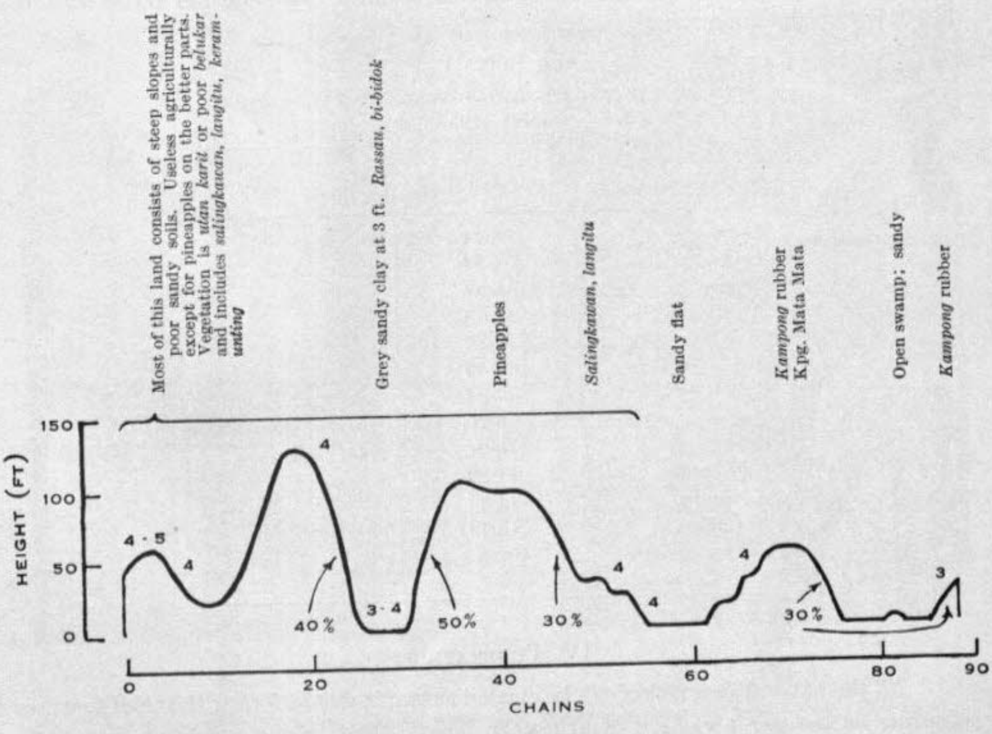

Fig. 6.—Cross section along *rentis* II.

Apart from the cobble beds at Berakas beach and isolated cobble beds elsewhere in the State there are no hard stones and rocks; much of the material for road making must be imported.

III. Climate

The climate is tropical. The main features are abundant rainfall, high temperatures and humidity, and lack of wind. There are no distinct seasons.

The normal daily temperature varies from 76°F to 86°F and seldom exceeds 90°F. Minimum temperatures below 70°F are almost unknown in the coastal lowlands. Early morning mists are prevalent in the valleys but the hours from 9 a.m. to 3 p.m. are generally sunny and hot; this is the period of rapid evaporation and cloud formation. Much of the rain comes from evening thunderstorms. No records are available for the intensity of rainfall but high intensity rains of short duration are common.

The average annual rainfall exceeds 100 in. Although Brunei escapes the monsoons the wettest period is from September to the middle of January, during the time of the north-east monsoons. However, there is no distinct dry season and no month averages less than 6 in. of rain. The rainfall records for the Kilanas Agricultural Station, several miles west of Brunei Town, are given in Table 1; they may be regarded as typical of the area—details are given in Appendix II. During the period 1937–55 the highest rainfall recorded at Kilanas was 131·7 in. in 1945, and the lowest 73·4 in. in 1941.

TABLE 1

MEAN RAINFALL AT KILANAS AGRICULTURAL STATION, BRUNEI (1937–55)

Month	Rainfall (in.)	Rainy Days
January	8·64	16
February	6·82	13
March	6·46	12
April	7·75	15
May	7·87	16
June	8·46	13
July	7·04	12
August	8·20	15
September	10·04	15
October	11·89	19
November	11·84	20
December	13·43	18
Year	108·4	184

IV. VEGETATION

All the natural vegetation can be classed as tropical rain-forest, the chief feature of which is the great variety of evergreen trees. Most of the surveyed area near Brunei Town has at some time been cleared and used for shifting cultivation; thus secondary forest (*belukar*) is seen in all stages of growth. The primary forest contains little undergrowth, owing to the exclusion of light by the thick canopy. Secondary forest has more undergrowth, especially in the first 10–20 years, and access through it is extremely difficult.

The natural forest has been divided by Browne (1955) into three divisions: lowland heath forest or *kerangas*; swamp forest; and lowland dipterocarp forest.

Kerangas forest is easily recognized by its poor growth. The trees are fairly small, the canopy is thin and not continuous. Undergrowth is prominent and there there are even patches without trees. *Aru* (*Casuarina sumatrana*) is a distinctive tree of this forest. The soils commonly associated are podzols formed in coarse sands mostly of marine origin.

The swamp forest is represented by the tall forest growth often found on deep acid peat, as in the Tutong valley and near Seria (Fig. 7). In this forest the trees may reach 100 ft or more and include a great variety of species. *Kapur paya* (*Dryobalanops rappa*), *terantang* (*Campnosperma*), and *jelutong* (*Dyera*) are three representative trees. The swamp forests in the surveyed area near Brunei Town seem to be intermediate between mangrove forests and true peat swamp forests. The main species in these swamps are *terantang*, *perepat* (*Sonneratia caseolaris*), *rassau* (*Pandanus*), and *bakong-bakong* (? *Crinum*). Other swamps are virtually free of trees and consist of dense thickets (Fig. 8) of the *asam paya* palm (*Zalacca conferta*).

Fig. 7

Fig. 8

Fig. 7.—A drain near the light railway across the Badas peat swamp near Seria. The trees in the background may reach 100 ft or more.

Fig. 8.—A dense impenetrable thicket of *asam paya* between the Berakas and Muara roads, on *rentis* F.

The lowland dipterocarp forest has been cleared from most of the surveyed areas other than very steep slopes and fruit islands (*pulau buah*). For the whole of Brunei however it is the main vegetation community; the fact that it contains so many species of the one plant family—Dipterocarpaceae—is regarded by Browne (1955) as evidence that Brunei may have been the original home of these trees.

Brunei has considerable forest resources: 75 per cent. of the territory has a cover of primary forest, of which 42 per cent. is permanent forest reserve. Because of the revenue from oil, little effort is made to use this asset, whereas in the neighbouring territories of Sarawak and British North Borneo forestry is an important industry.

Where shifting cultivation is practised many characteristic regrowth plants occur. The most common of these are the sedges *talijuru* and *semperiding* (? *Cyperus* or *Scleria*), coarse tropical grasses *batong-batong* and *lalang* (*Imperata cylindrica*), and the shrub *udok-udok* or Straits rhododendron (*Melastoma*). The two ferns *salingkawan* (*Gleichenia*) and *langitu* (*Pteridium aquilinum*) are prominent in regrowth on sandy soils.

The cultivated plants include rubber (*Hevea brasiliensis*), *padi*, *cassava*, pineapples, coconuts, and various fruit trees and vegetables.

Fig. 9.—View north-west along *rentis* O, between the Berakas road and the coast. The *rentis* crosses 2-year old secondary forest, with primary forest in the distance.

V. Soils

(*a*) *The Survey of the Area near Brunei Town*

The field work in Brunei consisted mainly of a soil survey of about 30,000 acres in the districts of Muara, Berakas, and Gadong. All of this land is within a 10-mile radius of Brunei Town; detailed knowledge of the soils was required in preparation for resettlement of local people on small holdings.

Parallel *rentis* lines, 20 or 40 chains apart, were cut to give access (Fig. 9), and these lines were pegged and surveyed by the Survey Department, Brunei, so that all inspection points could be plotted on a map. The vegetation between *rentis* lines proved so dense, except in rubber plantations and small holdings, that detailed observations were mainly restricted to these lines.

The information obtained by examinations along *rentis* lines refers mainly to the mineral soils above permanent water level; the description of a Malayan survey of peat swamps by Coulter, McWalter, and Arnott (1956) shows why the swamps must be treated differently: "There was a very strong tendency after the initial enthusiasm of the first two hours of the day, for almost the entire attention to be devoted to the 'battle for survival'. The going may be described as climbing out of a hole, over the top of a large buttress root and falling down a hole on the other side. Under these conditions variations in soil are easily missed and in fact cannot be seen because of the covering of water." Similar conditions were found in Brunei; some variation was provided by the lack of buttress roots in swamps consisting of dense spiny palms such as *asam paya*.

The aerial photographs of the district, taken some years ago, were not useful for detailed soil mapping. Because of the dense vegetation and constantly changing pattern of shifting cultivation recent photographs are essential and they must be of large scale for detailed mapping.

Fig. 10.—Pineapples on a 50 per cent. slope near Kpg. Gadong Rimba. Surface litter prevents erosion on the sandy Class 4 soil.

The soil survey was based on

- description and classification of soils along *rentis* lines;
- finding the boundaries of swamps and the depth of the peat layer;
- determining the boundaries of steep hilly land with limited use for crops.

After the field work was completed the boundaries of swamps and steep hills were traced out on aerial photographs, and these were copied onto the base map of the area derived from military maps at the scale 1:25,000.

The map shows

- division of the area into four types of land;
- location of *rentis* lines, roads, *kampongs*, *sungeis*, and certain tracks;
- classification of soils along *rentis* lines and at other inspection points;
- information on depth of peat in swamps.

The four types of land shown on the map are

(1) high hills with slopes of more than 30 per cent. (17 degrees). This land (Fig. 10) is very liable to damage by soil erosion if forest vegetation is permanently removed;

(2) lower hills with more moderate slopes and undulations. This includes much land suitable for crop production if a number of quite practicable soil conservation measures are used;

(3) flat land adjoining *sungeis*, suitable for cultivation without protection against erosion, though liable to occasional flooding;

Fig. 11.—On *rentis* H in a peat swamp of *perepat*, *terantang*, and *rassau*. The peat is 12 ft deep.

(4) swamps under water permanently or for long periods of the year (Fig. 11). Most of these have thick deposits of peat but near the edges of the swamps the peat is usually thin and overlies silty or clay material.

The *rentis* lines are identified by letters and by Roman numerals. All known *kampongs* in the area are shown on the map and these indicate the centres of population. The existence of a *kampong* is a good sign that cultivation, especially shifting cultivation, occurs in the locality. The Gadong rubber estate is the largest rubber plantation in the district but other large areas of rubber lie to the north and south of the airstrip and there are also many small plantings. Bridle paths, suitable for bicycle traffic, exist in the Gadong district and there are several important foot-tracks giving access to *kampongs* such as Kpg. Bedaras and Kpg. Terunjing.

(b) *The Survey of the Area near Tutong*

The area of about 30,000 acres bounded by the Kuala Abang Road, the Brunei–Tutong Road and the Sungei Tutong was inspected briefly but no attempt was made to map the soils of this district. Inspections were made along the motor roads, by boat along S. Tutong and S. Bekiau, and on foot along several tracks. The main object of the work was to gain knowledge of unused swamp areas, possibly suitable for agriculture. The various traverses together with subsequent interpretation of aerial photographs provided information for the map of the lower Tutong valley which shows the large area between the S. Tutong and S. Bekiau as swamp forest with deep peat. Settlement is restricted to the well-drained areas such as levee banks of S. Tutong, the hills, and the ground in the valleys of tributaries such as S. Abang and S. Lamunin. An area of not less than 2000 acres in the valley drained by S. Abang and S. Lamunin warrants further attention for settlement.

(c) *Classes of Soil in Brunei*

The descriptions of soil profiles (the vertical sections to a depth of several feet) were classified according to a local system.* Five soil classes shown on the map by numbers 1 to 5 correspond with those recognized by local cultivators. The classification has been in use for a long time, possibly hundreds of years, and is a useful way of distinguishing the soils. The five classes emphasize the relative values of soils for growing rice and also other crops. These classes are separated mainly on surface soil features such as colour, and content of sand and clay. The nature of the vegetation, whether primary or secondary, is also taken into account. Subsoil features are recognized as important; for example a soil of the first class has a subsoil of clay which is nearly white and very sticky—if sand or yellow patches are detected in the subsoil it could not belong to this class. The poorer classes of soil, 4 and 5, are much more variable than Classes 1 and 2; thus various sandy soils may all be referred to as Class 5 soils on account of their poor value for rice production.

The five classes refer only to mineral soils, the peats being considered separately. The use of the local system should be encouraged because the names are familiar and refer to fairly distinct profiles. In the absence of any other published descriptions of local classes the following descriptions may provide a standard for future work; they should agree generally with the experience of Brunei people.

Class 1.—In the local language this is mostly spoken of as *tanah bakar*, "burning soil"—apparently referring to the black, as if burnt, appearance of the surface soil. The whole profile is clay. The surface is black, distinctly granular and crumbly, and shows evidence of worm activity. In fact worm casts are to be expected in this class. At about 4 to 6 in. below the surface there is a gradual but distinct change to a light grey or near white, plastic or sticky clay. Sand is not detected in the clay nor is there any evidence of yellow patches or mottling. The soil occurs near edges of

*The Kedayan people near Brunei Town are the source of this system. They are the local agriculturists and are credited with the introduction from Java of a superior method of rice cultivation. It is not known whether other peoples in Brunei—Malays, Chinese, Dusuns, and Dayaks—make use of this system of soil classification.

swamps or hills, or on flat land near *sungeis*. It is not subject to permanent flooding but the subsoil apparently always remains in a moist condition. Occasional small patches of the soil were seen but it is not common.

Class 2.—This includes clay soils not quite as fertile or moist as *tanah bakar*. The surface is usually dark brown rather than black and is not so distinctly granular and crumbly. The subsoil clay shows light grey and yellow colours, indicating variation in moisture and air content, probably due to partial drying out of the subsoil.

The soil occurs in low situations, above the level of permanent swamps. These soils are also rather rare and occur in small patches.

Class 3.—This includes yellow-brown or brown clay loam and clay soils found mainly in fairly well-drained places. The clay subsoils are red and yellow. There is some sand in the subsoil but not enough to alter the texture to sandy clay or sandy clay loam.

The description of one example of this class is as follows:

Depth (in.)	
0–3	Dark brown granular clay loam with many fine roots.
3–6	Yellowish brown clay loam.
7–12	Brown, red, and grey clay showing vertical cracks.
12–18	Light reddish brown stiff clay with grey and red inclusions. There are some pieces of plate-like ferruginous gravel.
18–30	Light grey, yellowish brown, and light red sticky clay.
30–44	Light grey and light yellow clay with occasional red patches.

The above soil occurs on the top of a hill 20–30 ft above swamp level. Young secondary regrowth of shrubs, trees, and grass indicated recent use of the site for cultivation, probably hill rice.

Class 4.—This class includes all the more sandy soils, whether on hills or flats, having subsoils of clay, sandy clay, or sandy loam. The surface soils are variable in clay content, being either sandy loam, fine sandy loam, or fine sandy clay loam. Subsoils always contain more clay than the surface soils and have yellow and light red colours.

Examples of this class are:

Profile A

Depth (in.)	
0–3	Grey-brown fine sandy loam, mellow and crumbly, with plant roots and wood ash.
3–8	Grey-brown to light yellow-brown fine sandy loam, mellow and crumbly, with plant roots; gradually changing to
8–16	Light yellowish brown mellow fine sandy loam; gradual change to
16–24	Light brownish yellow fine sandy loam, mellow; gradual change to
24–36	Bright yellow-brown with occasional red mottling, fine sandy loam; distinct change to
36–45	Bright yellow-brown friable sandy clay loam with occasional red and light yellow fine diffuse mottling.

This soil occurs on the upper slope of a high hill with jungle vegetation. There was evidence of recent cultivation on similar soil nearby.

Profile B

Depth (in.)	
0–3	Grey-brown mellow crumbly fine sandy loam with fine plant roots.
3–12	Grey-brown and light grey with brown veins, mellow crumbly fine sandy loam; gradual change to
12–24	Yellow stiff loam with light grey inclusions; gradual change to
24–45	Bright yellow-brown, light grey and light red mottle clay loam, friable and cloddy.

This soil occurs on moderate slopes of low level hills with a vegetation of old secondary jungle which does not form dense growth.

Class 5.—This is referred to as *tanah karit*, meaning stingy, unproductive soil. The term *kerangas* used in reference to infertile forest soils in Borneo certainly applies to all this class and possibly also to the most sandy members of Class 4. In this report *tanah karit* is applied to the loose light-grey or white sands with a dark brown compact sand layer in the subsoil, but it is known that the term is applied in a general way to the most sandy soils growing rather open forest or even a treeless stand of shrubs.

An example of the soils allotted to this class is as follows:

Depth (in.)	
0–2	Dark grey-brown sand under organic litter.
2–6	Light brown sand.
6–13	Very light brown to very light grey loose sand.
13–15	Very light grey and brown mottled compact sand.
15–24	Yellow-brown very compact sand with occasional small pieces of waterworn rock (sandstone).
24–45	Brown firm sand.
45–54	Dark brown compact sand.
54–60	Very dark brown to black very compact sand ("coffee rock").
60–63	Dark grey-brown sand, sodden at water level.

This soil occurs on a distinctly flat-topped sandy hill 50–100 ft above sea-level. Originally under forest, the site had been planted with rubber but the trees were of very poor quality, similar to those shown in Figure 12. The regrowth of native trees and fern showed that the rubber plantation was not regarded as sufficiently productive to justify control of regrowth. The loose sand and pieces of waterworn gravel in the soil indicate that the site is an old coastal beach deposit.

(*d*) *Peat*

For agricultural purposes peat may be distinguished from soil by the presence of at least 18 in. of partly decomposed plant material, and the presence of more than 65 per cent. organic matter in the dry material.

Peat swamps are common in the coastal parts of Borneo as well as in Sumatra and on the west coast of the Malayan peninsula. The depth of peat is as much as 50 ft in some parts (Polak 1950) but in the areas investigated in Brunei it was commonly no more than 12 ft at the centre of a peat swamp and often only 1–2 ft near the edge of a swamp.

In British Borneo peat swamps extend miles inland along the Rajang and Baram rivers in Sarawak (Roe 1954*a*) and in adjoining Brunei territory peat swamps are also very extensive along two major rivers, S. Belait and S. Tutong. Peat also covers large areas in the flat land near Mulaut, south-west of Brunei Town between the S. Limbang and S. Tutong. Most of the low-lying parts in the 30,000 acres inspected near Brunei Town consist of peat.

Several features of the peat areas are important:

(i) *Depth of Peat.*—Peat is unlikely to be of use for growing rice if the deposit is more than 4 ft thick. This depth was commonly exceeded in all the large peat swamps at distances of more than a few chains from surrounding land. The depth of peat was

Fig. 12.—Stunted, poor quality rubber on a hilltop with Class 4 soil in the Gadong rubber plantation.

measured with sticks and with the peat auger used when sampling the peat. The recorded depth of peat is shown at the inspection points along the *rentis* lines in the area near Brunei Town. It is estimated that from 1000 to 2000 acres in the north of the surveyed area consist of peat deeper than 4 ft, and another large area occurs near Brunei Town. In the lower Tutong valley an area of approximately 13,000 acres between S. Tutong and S. Bekiau is peat more than 4 ft deep. Other undetermined areas probably amounting to a few thousand acres of deep peat occur in the area between the Brunei–Tutong Road, the Kuala Abang Road, and S. Bekiau.

(ii) *Features of the Materials beneath the Peats.*—Both the physical features (texture) and chemical composition of the material beneath the peat are important if drainage and irrigation are contemplated. The occurrence of sands beneath one peat deposit in North Borneo intended for rice cultivation made water control impossible (Roe 1954*b*). Many peats in coastal swamps overlie deposits containing much sulphur as sulphide, derived from the sulphates deposited from sea water. Exposure of these deposits to the air creates an extremely acid condition in which plant growth is impossible. This condition is known in several parts of the world including Holland, Malaya, and Borneo and was regarded as a probable feature of the Brunei peats. The laboratory examination of samples, referred to in Section III(*g*), showed that the material beneath the large peat basins became strongly acid on exposure to air.

The presence of sand beneath the peat in the large basins is also indicated from the results of laboratory examination, but extensions of peat along narrow valleys often occur over silt or clay deposits.

(iii) *Features of the Peat.*—Peat commonly occurs in Brunei under a swamp forest vegetation and remains of trees are found at depth in some of the swamps. The presence of ancient logs and the stumps and roots of growing trees are a great hindrance to the cultivation of these swamps if they are drained. The most useful peats for drainage would therefore be those formed mainly from less woody plants such as the palms *asam paya*, *rassau*, or *bakong-bakong*. The chemical composition of the peat is discussed in another section.

(*e*) *The Distribution of Soils in the Surveyed Area near Brunei Town*

The map shows that large parts of the area are either steep hills or peat swamps. The steep hills occur especially to the north-west, south-east, and west of the area, in extensive ranges, but there are also isolated steep hills surrounded by peat swamps, in the area north-west of the *jalan* Muara. All the lowest land, along the S. Mangsalut and its tributaries and around the *sungeis* north of Brunei, consists of deep peat, some of which is covered by as much as 2 ft of alluvium, as in parts of the Berakas rubber plantation, and near the *jalan* Gadong. There are large areas with moderate slopes in the central part of the surveyed area between the *jalan* Berakas and *jalan* Muara. Another large area of moderately sloping land occurs in the western part along tributaries of S. Gadong. Lowland areas with little peat and containing mainly Class 3 and Class 2 soils are not extensive; they occur mainly in the west, along the upper reaches of *sungeis* draining towards S. Brunei. The lower hilly country with moderate slopes shows much soil variation over small distances, as in the land north of *jalan* Muara, where Class 2 and Class 5 soils occur close to each other. This soil variation occurs with changes from higher banks of infertile sands, representing ancient beach deposits, to lower areas of clay representing river deposits. Generally the Class 5 soils are beach sands, now occurring as benches or terraces fringing higher hills.

Information was collected on the depth of peat in swamps; this is shown on the map. It will be seen that the swamp areas extending upstream along narrower valleys of *sungeis* have the least depth of peat, and this explains the restriction of *padi* cultivation to the swampy places closest to dry land.

(*f*) *The Distribution of Soils in the Tutong Area*

Soils in this area appear little different from those seen near Brunei Town but the various proportions are quite different. This valley contains a large proportion of swamp forest with deep peat and some low-level sandy hills, apparently representing ancient coastal deposits. Well-drained alluvial soils occur on the levee banks of the S. Tutong. Along the banks of the river the land is higher and the soils rather more sandy than at a distance from the river where finer silt has been deposited from flood waters. At still greater distance the land becomes swampy (Fig. 13) and peat becomes extensive. Further away from the river are peat swamps where no flooding and deposition of mineral material occur. Soils of Class 1, 2, and 3 occur on some of the valleys of *sungeis* joining the S. Tutong. The Kuala Abang Road crosses the swampy fringe of the higher hills drained toward the S. Tutong; on this fringe the *sungeis* commonly flood over their banks but peat is restricted in occurrence. Some valuable areas of soil occur in the vicinity of Lamunin and have become the centre of a productive rice-growing area. The elevated areas are either extremely sandy with Class 4 and Class 5 soils, as at Tutong township, near Kpg. Pat Nunok, and at Kpg. Bekiau, or comprise soils formed from the older rocks of the area, on the higher hills further inland, near Kpg. Birau for example.

Fig. 13.—Buffaloes grazing on the levee bank of S. Abang. The forest in the background grows on the deep peat at a lower level than the levee bank.

(g) *Laboratory Examination of Soils and Waters*

Analyses were made to determine the acidity of various soils, peats, and waters; the clay and sand contents of various samples; the contents of plant nutrients: nitrogen, phosphorus, potassium, and calcium; and the trace elements: copper, manganese, molybdenum, and cobalt.

Samples were collected at 48 different places, usually from several layers down to 40 in., but in peat swamps several samples were obtained from as deep as 14 ft below water level, using a peat sampler. Despite repeated sampling with this special sampler the amounts of peat, and mineral matter obtained from beneath the peat, were usually insufficient for a complete range of analyses.

The samples represent the various soils in proportion to the area they cover, that is most of the samples represent the most common soils, especially the Class 4 soils, and peats. The Class 1 soils, which are rather rare, were sampled only at a few sites.

(i) *Soil Acidity and Soluble Salts.*—None of the samples were alkaline in reaction though one neutral sample (pH = 7) was collected in a part of the Tutong valley possibly subject to tidal influence.

Determinations of pH were made for several samples at the time of sampling, and after drying and storage. The two determinations, given in Table 2, generally showed some agreement despite the different methods involved, but materials

TABLE 2

THE pH OF SAMPLES, DETERMINED IN THE FIELD AND LABORATORY

Profile Number	Sample	Depth (in.)	Texture*	pH of Undried Sample in Brunei; Truog Indicator	pH of Dried Sample in Australia; Glass Electrode Method	Remarks
18	A433 (1)	0–4	*FSL*	4	4·9	Hillside soil
	(2)	12–15	*FSCL*	4·5		Class 4
	(3)	24–26	*SC*	5	4·8	
20	A435 (4)	130	*SL*	6	1·9	Under deep peat
23	A438 (1)	0–3	*SL*	5	4·6	Hillside soil Class 4
24	A439 (1)	0–3	*SL*	4·5	4·6	Hillside soil Class 5
26	A441 (1)	0–4	*S*	4	4·6	Hillside soil
	(2)	36–38	*S*	7	5·5	Class 5
31	A446 (3)	40–43	*S*	5	5·3	Valley soil Class 3
38	A453 (6)	170	*SyC*	6	2·2	Under deep peat
41	A456 (4)	27–30	*P*	4	c.4	
	(11)	156	*C*	6	5·1	Under deep peat

**S*, sand; *P*, peat; *C*, clay; *SL*, sandy loam; *FSL*, fine sandy loam; *FSCL*, fine sandy clay loam; *SC*, sandy clay; *SyC*, silty clay.

beneath peats showed great variation. Experience with coastal peat swamps in other countries has shown that sulphur as metallic sulphides is likely to be abundant in layers beneath the peat. When this material is exposed to the air transformation of sulphides to soluble acid sulphates and to sulphuric acid occurs, hence the high acidity in some of the Brunei peats after exposure and storage. Aluminium and iron were detected in the water soluble material from the layers beneath peats; the presence there of 1000–3000 p.p.m. of aluminium is regarded as very toxic for many crop plants. Failure of crop plants in strongly acid conditions may be due to aluminium toxicity which is likely to be serious at pH values of less than about 4·5. It is possible that the higher values of soluble salts in some of the samples with pH between 3 and 4 represent significant amounts of aluminium and iron.

Areas affected by tidal movement of sea-water should have significant amounts of sodium and chlorine. These, however, are insignificant except in the soil samples from profile 48 and the water sample from the same site.

(ii) *Particle Size Analysis.*—Determinations of the various proportions of clay, silt, and sand were made on many of the soil samples. The results showed that the high silt content of many samples was not detected in the field and that several samples described in the field as clay loam or clay should have been called silty clay loam or silty clay respectively. The mechanical compositions of surface and subsoil samples are given in Figures 14 and 15, which show that the local classes of soil are distinguished by varying amounts of sand.

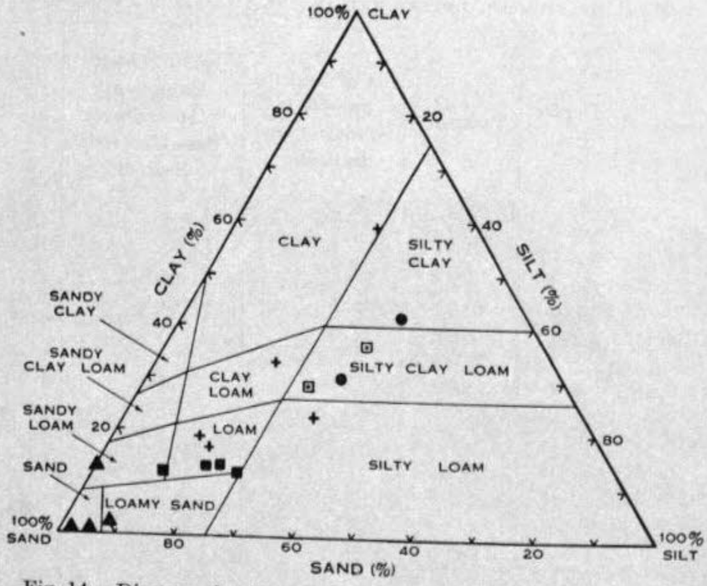

Fig. 14.—Diagram showing particle size composition and textures of surface soil samples. ●, Class 1; +, Class 2; ⊡, Class 3; ■, Class 4; ▲, Class 5.

These analyses were of particular use in examining the materials beneath the peat, which generally contained little sand and were equivalent in texture to clay loam, clay, or silty clay. Though the samples of peat were inadequate for many examinations, some sand determinations were made to provide information on their mineral fraction. These analyses indicate that some peat samples contain mineral matter deposited by flood waters and the small proportions of clay and silt may be a source of plant nutrients.

The large amounts of silt in the mineral soils are derived from the clays and fine sandstones forming the main rocks of the area. Much of the silt may be finely divided quartz but it is probable that reserves of plant nutrients are still available in the silt as well as the clay fractions. Determinations of clay minerals were made on other samples collected in Brunei by C. G. Stephens in 1956 and these indicate comparatively little weathering of minerals; there was little variation in the clay mineral composition of surface and subsoil samples and the minerals chlorite and mica were common in the samples. The minerals commonly identified in the clay fractions included kaolin, quartz, mica, chlorite, and iron oxide.

(iii) *Organic Matter*.—The organic matter present in samples is indicated by three determinations: loss on ignition, organic carbon, nitrogen. The highest amounts of organic matter were, of course, found in the peats; samples from the centre of a large swamp forest in the Tutong Valley contained approximately 98 per cent. organic matter. Many of the samples from peat swamps north of Brunei Town contained

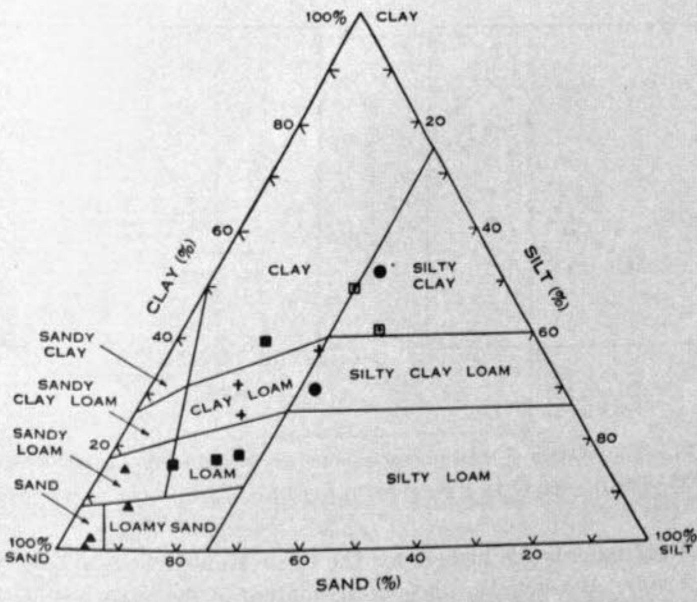

Fig. 15.—Diagram showing particle size composition and textures of subsoil samples. ●, Class 1; +, Class 2; ⊡, Class 3; ■, Class 4; ▲, Class 5.

lower proportions of organic matter and some with much less than 65 per cent. organic matter would correspond to mucks if drained.

In the mineral soils organic matter varied from 1 to 22 per cent. at the surface and from 0·2 to 5 per cent. in the subsoils. Most of the soils contained 2 to 5 per cent. organic matter at the surface and 0·5 to 1·5 per cent. in the subsoil. The highest proportions of organic matter were found in soils of the Classes 1 and 2 where surface soils contained up to 15 per cent. and subsoils up to 4·5 per cent. The most deficient soils were the light grey sands of Class 5, where organic matter is concentrated in the litter lying on the surface, or in the uppermost few inches of sand. The lower layers are generally most deficient except for the compact "coffee rock" which contained 1 per cent. or more of organic matter.

The organic matter contained an appreciable amount of phosphorus, calcium, potassium, and magnesium, as shown by the greater amounts of these substances in the surface layers.

(iv) *Phosphorus*.—The total phosphorus content, estimated from the concentrated acid extract, varied from 30 to 700 parts per million in the surface soils. With very few exceptions phosphorus is more abundant in the surface than in the subsoil. The variations of phosphorus with percentage clay and with organic matter are shown in the graphs (Figs. 16 and 17). These show a wide variation in clay content for given phosphorus values, but a general increase in phosphorus with organic matter. The highest phosphorus values were found for peats* which contain very little clay.

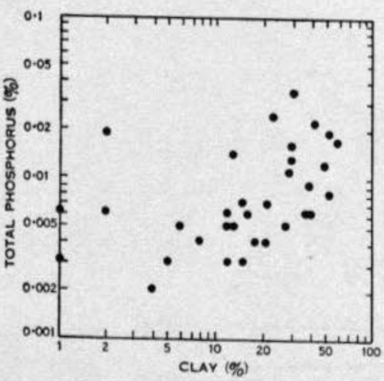

Fig. 16

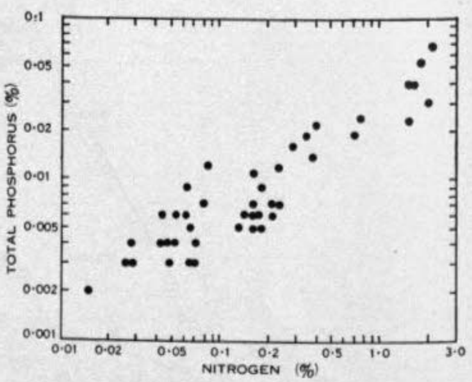

Fig. 17

Fig. 16.—The relation of total phosphorus to percentage of clay in soil samples.
Fig. 17.—The relation of total phosphorus to percentage nitrogen in soil samples.

The levels of phosphorus are highest for the Class 1 and 2 soils and lowest for the Class 4 and 5 soils. Although the phosphorus content of the peats is apparently high, this finding applies to the dry matter which is only a fraction of the wet pulpy mass sampled in the swamp.

The results show that the most widespread soils are deficient in phosphorus. The soils most abundant in phosphorus are rare and their phosphorus contents are not high by comparison with other countries. A reasonable content of phosphorus may be regarded as some amount exceeding 0·05–0·10 per cent.; these levels occur only in the dry peat material and the soil Classes 1 and 2. The determinations of phosphorus by Owen (1953) for Malayan soils are similar to those for Brunei soils. The sandier soils in Malaya and in Brunei are quite deficient in phosphorus and they contain amounts similar to those in the widespread sands of southern Australia, on which phosphorus fertilizer is essential for crops.

*It should be noted that all determinations refer to the percentage by weight of the given constituent *in the oven-dry sample*. In comparing peats with mineral soils it must be realized that bulk for bulk the mineral soils contain several times more oven-dry material than the peats. Hence if the phosphorus contents of a peat and two mineral soils are the same, then the two mineral soils might be regarded as more or less equally fertile but both would be vastly superior to the peat.

The total phosphorus is no more than a very rough guide to the phosphorus readily available to plants, which is apparently between 10 and 20 per cent. of the total. Another portion associated with organic matter is probably partly useful to plants but from 30 to 60 per cent. of this phosphorus may be unavailable. Investigations of the different fractions of soil phosphorus made for Australian soils by Williams (1950) and for Malayan soils by Owen (1953) are of value in assessing the Brunei soils. The conclusion is that there would be much more phosphorus available to plants in the soils of Classes 1 and 2 than in Classes 4 and 5 where phosphorus is restricted to the surface organic layer. Good responses of cultivated crops to phosphorus fertilizers are more likely to occur on the sandier soils of Classes 4 and 5 than

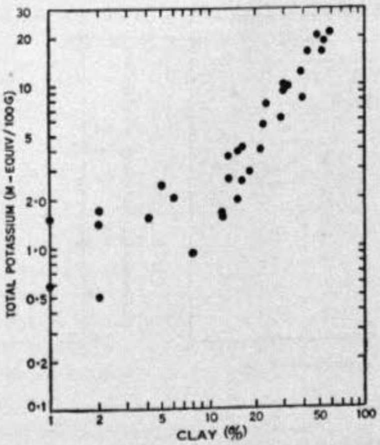

Fig. 18.—The relation of total potassium to percentage of clay in soil samples.

on the other soils. The cutting and burning of jungle, either primary or secondary growth, supplies some available phosphorus and is one reason why shifting cultivation can be used for growing occasional crops on infertile soils.

(v) *Potassium*.—The amounts of potassium soluble in concentrated acid are generally low and vary with clay content as shown in Figure 18. Potassium was low in peat samples, particularly those richest in organic matter; for example samples from profiles 16 and 45, having less than 10 per cent. mineral matter, contained 0·4 and 1·5 m-equiv/100g respectively.

As with phosphorus, only a fraction of the potassium is available to plants and an estimate of this amount is given by the quantity most easily detached from its association with the particles of clay and organic matter. The exchangeable potassium is much less than 1 m-equiv/100g in Brunei soils, that is, less than 0·04 per cent. potassium compared with the maximum of 0·8 per cent. extracted with concentrated acid. It generally increases with the total potassium (Fig. 19) and with the clay content but it is obvious from Figure 20 that exchangeable potassium is derived from organic matter in the case of very sandy soils. This is also indicated by the tendency for exchangeable potassium to be greater at the surface than in subsoil, despite the greater amounts of clay and total potassium in the subsoil.

The exchangeable potassium of different soils is shown in Table 3 which for a small number of samples suggests that the local classes of soil have been numbered in the same order as their total potassium status. With the probable exception of the Class 1 soils the amounts of exchangeable potassium are regarded as too low for satisfactory nutrition of cultivated plants.

(vi) *Calcium.*—Both in soils and peats the amounts of calcium are remarkably low. The amounts of exchangeable calcium* do not exceed 0·5 m-equiv/100g and are even less than 0·1 in several samples. However, the amounts are not especially low

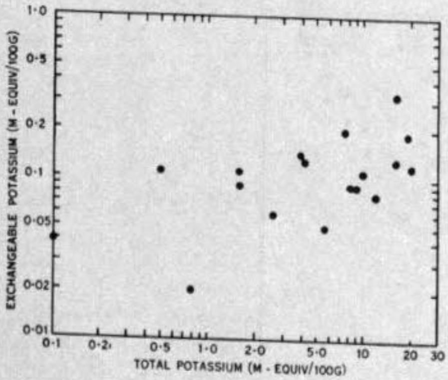

Fig. 19

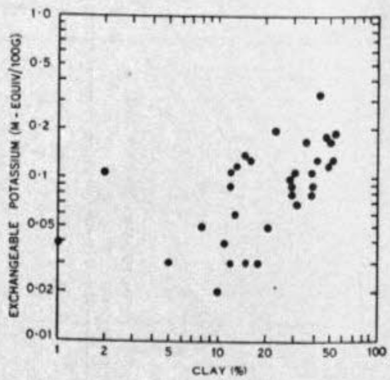

Fig. 20

Fig. 19.—The relation of total potassium to exchangeable potassium in surface and subsoil samples.
Fig. 20.—The relation of exchangeable potassium to percentage clay content in soil samples.

in comparison with other soils under similarly high rainfall and derived from similar rocks. In a variety of Malayan soils the total calcium* found by Willimott and Buckley (unpublished data) was mainly below 1 m-equiv/100g and down to 0·2 m-equiv/100g on the most deficient soils. For samples from swamps and levee banks in Southern Borneo, Van Wijk (1951) reported 1–4 m-equiv/100g total calcium for the surface layers of cultivated peaty swamp soils, and 0·25 m-equiv/100g for levee soils used for rubber, coconuts, or for shifting cultivation of rice. Determinations of calcium in a cultivated soil at the Kilanas Research Station south-west of Brunei Town showed 2·6 m-equiv/100g in the surface layer (Stephens, unpublished data) and this is quite comparable with the data of Van Wijk and with data for agricultural soils elsewhere in the world.

Though the amount of 0·1 m-equiv/100g, corresponding to 40 lb per acre for the top 6 in. of soil, is extremely small it may not represent an absolute deficiency, for calcium removed from the site by a rice crop probably does not exceed 10 lb of calcium per acre. However, continued cropping must rapidly reduce such an amount

*Total calcium and exchangeable calcium are approximately the same where calcium is present in very small amounts.

of calcium and it is concluded that cropping on such poor soils is very dependent on release of calcium and other elements from vegetation burnt in the preparation of land under shifting cultivation.

(vii) *Magnesium.*—As with calcium this element is also present in very small amounts in the soils, though rather more magnesium than calcium was found in most samples.

(viii) *Trace Elements.*—Twenty-two surface and subsoil samples from nine sites have been analysed for copper, molybdenum, manganese, and cobalt. Generally the sandy Class 4 and 5 soils are lower in these elements than the clay soils of Classes 1 and 2.

TABLE 3

CALCIUM, MAGNESIUM, SODIUM, AND POTASSIUM IN SURFACE SOILS

All values in m-equiv/100g

Soil Class	Profile Site	Vegetation	Exchangeable				Total K
			Ca	Mg	Na	K	
1	A457	Rubber plantation	0·2	0·4	0·10	0·33	16
2	A445	Rubber plantation	0·1	0·2	0·07	0·20	7·6
3	A430	Jungle	<0·1	0·2	0·09	0·17	*
	A447	Rubber, unproductive	<0·1	0·2	0·06	0·14	3·9
	A458	Secondary jungle	0·3	0·3	0·06	0·09	9·1
	A448	Swamp jungle	<0·1	0·2	0·06	0·11	10
4	A438	Jungle	0·2	<0·1	0·08	0·11	1·6
	A440	Secondary jungle	0·2	0·1	0·05	0·09	1·6
	A443	Grass (buffalo grazing)	0·2	0·7	0·05	0·06	2·6
	A444	Secondary jungle	0·1	0·2	0·06	0·13	4·1
5	A441	Overgrown fruit plantation	0·1	<0·1	0·04	0·04	0·1
	A449	Secondary jungle with bracken	<0·1	0·2	0·07	0·11	0·5
	A461	Regrowth jungle with unproductive rubber plantation	<0·1	<0·1	0·02	0·02	0·8

*Not determined.

The peats are variable; the highly organic peats contained less molybdenum, copper, and manganese than peats containing 25 to 45 per cent. mineral matter.

Compared with soils elsewhere in the world the samples are low in all four elements. Manganese is low in all samples, molybdenum is low in the most organic peats, and copper is low in the sandy soils and in one peat sample.

According to Mitchell (1955) a growing crop uses 0·01 p.p.m. molybdenum, 0·1 p.p.m. copper, and 1·0 p.p.m. manganese from the surface soil, so that none of the soils are deficient in absolute amounts of these elements. Cobalt taken up at 0·001 p.p.m. is not essential for plant growth. The total amounts shown in Table 4 are not identical with the amounts available to plants, e.g. manganese is more available in acid conditions and may become unavailable if lime is added, whereas molybdenum is more available under alkaline conditions.

Ehrencron (1949) and Allen and Coulter (1956) have carried out trials with trace elements on acid peats. In the experiments described in the earlier paper rice showed no response to copper. In the more recent experiments rice did not respond to any of the trace elements except copper which may have been harmful.

Fertilizer experiments with trace elements should include: molybdenum for most plants, particularly legumes, on most soils; copper for pineapples on peats and sandy soils; manganese for *padi* on peats and for pineapples on peats and sandy soils.

TABLE 4

COPPER, MOLYBDENUM, MANGANESE, AND COBALT IN BRUNEI SAMPLES

Determinations by spectrographic method. Values as parts per million
Values given in brackets refer to ash, all others refer to oven-dry sample

Sample	Cu	Mo	Mn	Co	Soil Description
431 (1)	12 (94)	0·13 (9·7)	8·3 (620)	0·05	Badas peat, 99% loss on ignition
460 (1)	3·9 (52)	0·74 (10)	27 (370)	<0·2	Tutong peat, 92% loss on ignition
456 (1)	34 (76)	9·5 (21)	42 (94)	<1	Berakas peat, 55% loss on ignition
(2)	28 (78)	5·2 (14)	30 (82)	<1	Berakas peat, 67% loss on ignition
(3)	26 (100)	6·0 (23)	25 (94)	<1	Berakas peat, 76% loss on ignition
452 (2)	27	4·7	90	<2	Swamp soil
(3)	25	5·2	81	<2	Swamp soil
461 (1)	3·4	2·2	15	<2	Class 5 soil
(2)	2·9	2·9	13	<2	Class 5 soil
(4)	3·8	2·9	14	<2	Class 5 soil
438 (1)	5·2	2·3	20	<2	Class 4 soil
(3)	4·1	2·4	22	<2	Class 4 soil
(6)	5·5	3·3	26	<2	Class 4 soil
458 (1)	13	5·7	64	<2	Class 3 soil
(3)	30	11	74	<2	Class 3 soil
(6)	36	5·6	70	<2	Class 3 soil
457 (1)	20	3·1	77	<2	Class 1, rubber plantation
(3)	41	3·6	67	<2	Class 1, rubber plantation
(5)	21	2·3	46	<2	Class 1, rubber plantation
448 (1)	18	2·8	51	<2	Class 1, forest
(2)	23	2·4	50	<2	Class 1, forest
(4)	13	3·8	51	<2	Class 1, forest

Although no figures are available, zinc is also likely to be deficient, particularly on sandy soils.

(ix) *Water Samples.*—Chemical analyses of 22 water samples, mainly from the area near Brunei Town, are given in Appendix III. The samples include flowing water in *sungeis* and drains, and stagnant water in swamps. Several of the swamp waters were obtained when peat samples were being collected.

With the single exception of water obtained at sample site 48, near S. Bekiau in the Tutong Valley the samples contained very low amounts of soluble material and none of the samples had pH below 4·5. Even the water from S. Bekiau, subject to tidal influence, is not very saline. There is no indication from the water samples that the surveyed areas are affected by salt from sea water, nor is there any suggestion that the waters are exceptionally acid.

(*h*) *Conclusions concerning Soil Fertility*

The local classification arranges the soils more or less in order of their productivity, which is also a measure of their fertility taking into account acidity, organic matter, phosphorus, potassium, and calcium. The Class 4 and 5 soils are most common in the surveyed area near Brunei Town and are also the most infertile soils. They are deficient in plant nutrients and drain so readily that growth of shallower rooting crops may suffer from lack of water during any dry period. Soils of Classes 1, 2, and 3 are not extensive; probably Class 3 soils are the most important as they cover bigger areas.

The peats are variable in quality and depth. Large extensive areas of peat occur commonly near the coast and are so deep, infertile, and acid that their use for crops cannot be recommended, and the local people make no attempt to use these swamps. Experiments by Ehrencron (1949) with acid peats from swamp forests in Borneo showed that cereal growth is virtually impossible unless calcium, nitrogen, phosphorus, and potassium are added. The deepest peat occurs furthest from hills or rivers. The very acid material under this peat usually contains large amounts of water-soluble salts injurious to crop plants. Efficient drainage of areas containing highly acid layers is necessary in any attempt to use such peat areas and applications of lime may be necessary.

The peat most suitable for crop use occurs at the edges of large swamps where flooding has brought in silt and clay, where the depth of peat is usually much less, and where the material beneath it is less acid. Some shallow peats in the surveyed areas have been used for shifting cultivation and there are some peaty areas used for wet *padi*, as at sample site 40, and to the north-east of *rentis* line L, north of the Muara Road. Rubber is grown on peat at several places and produces fair yields of latex in this highly acid, infertile environment.

Much of the better land is already used for rubber plantations and for small holdings, and shifting cultivation is practised on most of the remainder. This leaves only limited areas of Class 3, 4, and 5 soils and large areas of deep peat for the selection of small permanent holdings.

Local experience with rice shows that it grows best on soils of Classes 1 or 2, these being the best supplied with calcium, nitrogen, potassium, and phosphorus as well as being the least acid soils. Any clay soils with pH below 4·5 ought to be regarded as possibly too acid for rice production and likely to have injuriously high levels of soluble aluminium. It is significant that samples from a productive rice area at Kilanas Research Station showed pH values above 5. Since the determination of pH on some buried organic materials may change considerably after exposure, too much reliance should not be placed on those made immediately after sampling such layers, but with sandy, well-drained soils the determinations of pH made in the field at sampling with indicator solutions are probably quite reliable.

Fertilizers should increase production on the common soils in Brunei. At present some organic fertilizers are used on market gardens, but there may not be enough of these in Brunei to supply a large number of small holdings. The fertilizers most likely to be required are those which supply calcium, phosphorus, potassium, and nitrogen. Calcium, supplied in lime and in superphosphate, may give responses for rice grown on acid peats but is apparently not needed for rubber. Phosphorus and potassium are deficient in peats and in the Class 4 and 5 soils and should improve the growth of crops intended for these soils—rubber, rice, pineapples, and bananas. Nitrogen should benefit all crops on these infertile soils.

The Class 1 and 2 soils may not require fertilizer treatment in the first years of use after clearing but if the cropping practice removes large amounts of plant material there could ultimately be responses to certain types of fertilizers, especially phosphorus and nitrogen. Since these soils are not extensive in the area and any expansion of permanent agriculture can be made only on Class 3, 4, and 5 soils there is likely to be a general deficiency of nutrients. The most sandy soils are deficient in all the major nutrients and may also be deficient in trace elements. The more clayey soils, as in Class 3, contain larger supplies of potassium and phosphorus and their fertilizer requirements, except perhaps for lime, may be relatively unimportant in the first years of permanent agriculture. If fertilizers are readily available there is no doubt that some of the Class 4 and 5 soils would prove sufficiently productive for certain types of crops, especially pineapples, vegetables, and fruit, but they are possibly rather dry for rice. Improvement of nitrogen content on the infertile soils should be achieved by greater use of legume plants, for example *sesik bouya* (*Desmodium ovalifolium*) which may respond to phosphorus fertilizers and to molybdenum.

Experimental plots for fertilizer tests are needed on different soils, especially the more infertile ones. Attention should be given to the fertilizer requirements for rubber on hill soils of Classes 3 and 4, for rice on Class 3, for vegetables and pineapples on Classes 4 and 5, and for legume cover crops on all these soils. Where strongly acid conditions are known to occur on low-lying areas, either soils or peats, the value of lime in addition to other fertilizers should be tested—the fact that rubber trees grow well on these soils is no guarantee that food crops also will be productive.

Cultivation of hills is commonly practised in shifting cultivation but permanent agriculture on steep slopes must eventually suffer from erosion as the original protective litter and tree trunks disappear. Moreover, invasion by weeds such as *lalang* and ferns would become a serious trouble if fertility declined under continuous cropping without fertilizers. Continued cultivation on long steep slopes should not have to be considered in Brunei because the population is relatively small. The steep slopes are most suitable for production of timber, especially in a closely settled area where readily available timber is needed for building and for firewood. The moderate hill slopes are likely to require some conservation measures, such as terraces, if regular cultivation is undertaken. This should be practicable on moderate slopes of Class 3 soils, possibly on some Class 4 soils, but probably not on the very sandy Class 5 soils.

VI. Land Use Problems

The various uses made of the Brunei territory are shown in Table 5. Rubber is the major crop, its area greatly exceeding that used for food crops such as rice, coconuts, fruit, and vegetables. The large area of secondary forest shows the great importance of shifting cultivation. This practice, common in Brunei and many other tropical countries, is basically sound as it provides a restorative period of "jungle fallow" between crops (Fig. 21). Under normal conditions the better class, clay soils are used and these do not deteriorate readily after being cleared. The soil is only cultivated for 1 or 2 years and the "fallow" period is long enough to enable a build-up of organic matter and tree cover, thus mobilizing enough plant food for the next crop.

Table 5

LAND USE IN BRUNEI, 1953

Type of Land	Area	
	(sq. miles)	(%)
Permanent forest reserves	938	42
State land forests, intended for gradual alienation	740	33
Secondary forests, 1 to 50 years old, following shifting cultivation (Government land used under native customary law)	456	21
Rubber	47	2·5
Rice (wet and dry)	10	
Coconuts	2	
Residential areas, market gardens, fruit plantations	33	1·5
Total	2226	100

The comparison of the area in Brunei under secondary forest and that under rice indicates a fairly long period between crops. Where insufficient land is available, however, the system is dangerous: cultivation is forced onto the steeper sandy slopes, the cropping period is longer, and the interval between crops is shorter. The soil is exposed to an acute erosion hazard, leaching of the plant nutrients is intense and the organic matter disappears rapidly. Then eroded highly infertile soils become widespread and the secondary growth does not change into forest but remains a collection of ferns and coarse grass, especially *lalang*. Other parts of Borneo, parts of Sarawak for example, have apparently experienced this decline; the problem has not yet arisen in Brunei though there is evidence that some areas of most infertile soils have had to be used for shifting cultivation occasionally.

Permanent agriculture on sloping land requires, firstly, the control of erosion by some method of terracing or contour planting and, secondly, the maintenance or building up of soil fertility. Mention has been made of the probable fertilizer needs for land under permanent agriculture but it is equally important to maintain soil organic matter and a ground cover of plants or trash, thereby retaining the soil structure and checking erosion. Permanent agriculture on small holdings is a recent development in Brunei and there has been little need yet to protect frequently cultivated land from erosion or to supply it with fertilizers. Experience over a number of years will be required to show how to make a success of it.

Chemical analyses of Brunei soils have shown severe deficiencies of most plant nutrients, and several suggestions have been offered as to the probable fertilizer requirements for crops on different soils. Definite detailed recommendations can only be made after experiments are carried out in Brunei using different soils, crops, and fertilizers; many useful experiments might be made on existing small holdings. The lack of information on soils and fertilizer responses for different crops in the equatorial regions has encouraged a tendency to make comparisons with utterly different soils

Fig. 21.—A 40 per cent. slope of secondary jungle cleared for another crop of hill *padi* near S. Abang.

and crops in temperate regions. Even where the same crop is grown in both regions, for example rice, the recommendations for fertilizers are variable; ammonium sulphate has been used with good effect in some temperate and in some tropical regions but unless experiments are made in Brunei it will be impossible to say what use should be made there of this fertilizer. Soil acidity presents another example of the care needed in making recommendations for fertilizers. Many of the cultivated crops of tropical areas are more tolerant of acid conditions than those of temperate regions; rice, tea, and rubber, for example, grow well on acid soils and the correction of soil acidity is not necessary with many tropical crops. On the other hand acid soils in temperate regions often need liming to reduce acidity and improve the growth of cereals and pastures. Where lime is found to improve growth it is important not to add too much as liming reduces the availablility of most trace elements and may cause deficiency symptoms of manganese. Another trace element, molybdenum, is less available under acid than alkaline conditons, and a molybdenum deficiency might well warrant the use of lime to improve the availability of this element as it is the trace element most likely to be deficient. Trials with molybdenum have been suggested, particularly in reference to growth of legumes as cover crops.

Cover cropping is seldom practised in Brunei rubber plantations and there is much scope for trials with plants such as *Pueria* and *Centrosema*. A little use has been made of *Callopogonium mucinoides* but apparently no attempts have been made to use the legume *sesik bouya* (*Desmodium ovalifolium*) which grows well locally. The Rubber Research Institute at Kuala Lumpur recommends the use of cover crops to increase rubber yields but cost of seed usually is prohibitive to the small landholder and most of the Malayan work with cover crops has been carried out in estate plantations.

The extensive peat swamps in the surveyed areas are of no use for crops unless drainage is provided, but this is difficult and costly. The shallower peats and mucks are not really suitable for rice and an initial depth of more than 3½ or 4 ft of peat is regarded as not suitable for development as a *padi* area (Coulter, McWalter, and Arnott 1956). Overdrainage should be avoided, particularly on the coastal swamps where the oxidation of sulphide to sulphate and the production of sulphuric acid can produce sterile acid soils. The shrinkage characteristic of peats must also be taken into account. According to Van Wijk (1951) a shrinkage rate of 20 in. per annum is not unusual in the tropics. However, although the initial shrinkage after clearing and drainage may be 30 in. or so, the subsequent shrinkage is fairly slow. One of the difficulties in draining peats derived from swamp forest is the uneven surface caused by logs and their constant appearance on the surface as the peat shrinks. Different depths of peat with different shrinkage rates can also cause uneven surfaces and lead to secondary drainage problems. Experience in Malaya (Coulter 1957), Borneo, and elsewhere indicates that the deeper peats and mucks are best used for pineapples and coconuts and possibly for coffee and oil palm. *Padi* cannot be recommended for these areas; recent work in Malaya by Allen and Coulter (1956) has shown some promising results on deep peat from the use of fertilizer for *padi*, but on only one area. Deep peat is often used for rubber, but the conditions are not wholly satisfactory. As the peat shrinks the roots of the rubber tree are exposed and the trees tilt over as shown in Figure 22.

Most of the wet *padi* grown in Brunei depends on the natural rainfall received during the growing period, and proper drainage plus irrigation would remove most of the chance associated with this crop. These requirements are to be met in the proposed Mulaut irrigation scheme south-west of Brunei Town. Hill *padi* must depend entirely on rainfall and the yields vary accordingly—if heavy rains come too early they disrupt the burning of jungle and the sowing; lack of rainfall later in the season reduces crop yields. As far as can be seen hill *padi* must remain a crop of shifting cultivation. Livestock husbandry is not important in Brunei. Buffaloes are seen in swamp areas where grazing is available and where they play a part in *padi* production. Pigs are used in some Dusun villages in the Tutong valley and elsewhere. Cattle are not numerous, but work at Labu estate has shown that the grazing of cattle in conjunction with coconut production merits further attention. The poultry industry is being fostered by the Department of Agriculture but there is little evidence that much progress has been made in the *kampongs*. Any permanent agricultural settlement on small holdings should incorporate some form of livestock husbandry in association with cropping. Pigs, poultry, and possibly goats are the only animals worth considering under these conditions. Larger holdings are essential for cattle.

Fig. 22.—Drained peat soils near the Berakas air strip provide an insecure foothold for plantation rubber. A sampling site nearby showed the water level at 27 in. below the surface and the total depth of peat was 10 ft.

VII. Conclusions and Recommendations

The soil survey of the area near Brunei Town and inspections in the Tutong valley have shown that most of the land suitable for crop production is already being used. The chief exception is an area of about 2000 acres in the Lamunin district which should be suitable for permanent agriculture.

The division of the surveyed area into four types of land shows that most of it is steep hilly land, moderately hilly land, or swamps. The steep hilly land is not suitable for permanent cultivation, but the soil map shows that it includes patches of better soils, for example Class 3, and these could probably be used for rubber. The most useful swamp lands are those fringing the large swamp basins and extending along the small valleys. Some of this land is being used for rubber and for occasional rice crops and there are some permanent holdings on it. Most of the deep peat will be of little or no use for agriculture because of the difficulties associated with drainage and access. The moderately hilly land at present offers most scope for development of permanent agriculture on small holdings and the Simpang-Muara resettlement scheme has been established on this type of land. There are small areas of such land east and west of the Berakas Road but most of the best land along the Muara Road is already settled. Other areas suitable for small holdings occur near *kampongs* in the south-west part, and in the Gadong rubber estate. The soil map shows that Class 4 soils were common on the *rentis* lines through this moderately hilly land; patches of Classes 3 and 2 were found but were not extensive. Much of the land available for small holdings must therefore be regarded as similar or inferior to the Simpang-Muara resettlement area.

Except for the Lamunin area of the Tutong valley where further inspections are being made by the Brunei Administration there is very little suitable flat land. Other areas for settlement in Brunei could be found by a reconnaissance plant and soil survey of the whole State, making full use also of the knowledge of the local people who are well aware of the location and potential of the best agricultural land.

The social problem associated with moving part of the population and resettling them on the land has not been mentioned. It could easily prove one of the biggest drawbacks to rural development.

Permanent agriculture on small holdings in Brunei is possible on restricted areas near Brunei Town but the optimum areas of holdings, the most suitable crop, and the detailed fertilizer requirements are yet to be determined. It is inevitable that the practice of shifting cultivation will continue to be important for many years. This method of food production is most laborious and is harmful to natural resources where insufficient land is available, but it is the traditional way of growing food on land unsuitable for permanent agriculture and is the way of life for some well-knit, stable communities. In the Belgian Congo some attempts have been made to improve shifting cultivation (Jurion and Henry 1951) by reducing the period between crops, introducing plants capable of the same restorative work as the forest regrowth, and mechanization. This work may have some application in Brunei; other lines for improving shifting cultivation are being followed in Sarawak (Miller 1956).

The main points emerging from the survey are summarized below:

(1) Most of the surveyed area is not suitable for closer settlement as envisaged by the administration.

(2) The better-class land is already being used for plantation rubber, small holdings, or resettlement areas and the soil map shows small additional areas suitable for development.

(3) The Kedayan system of classification is a useful way of distinguishing local soils.

(4) The practice of shifting cultivation is sound under existing conditions.

(5) Terracing and contour cultivation are essential for a stable agriculture on sloping land.

(6) Soils data have provided a lead to fertilizer requirements but must be backed by field experiments using the particular plants intended for production.

(7) The reclamation of deep peat for wet *padi* is likely to be impracticable and uneconomic.

(8) Adequate water control is needed to grow wet *padi* efficiently.

(9) A broad ecological survey of the whole State would help to delineate areas suitable for agriculture.

(10) Accurate base plans and recent aerial photographs of scale, say, 1 in. to 20 chains are desirable for accurate mapping.

(11) Traversing along *rentis* lines is the only practical way of soil surveying.

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APPENDIX I

GLOSSARY OF VERNACULAR NAMES AND TERMS

aru—distinctive trees (*Casuarina* spp.) in coastal areas.

asam paya—"bitter fruit of swamps", found on the spiny palm (*Zalacca conferta*).

bakong[2]—broad-leafed low swamp plant (? *Crinum*).

batong[2]—tall coarse grass common in treeless areas.

belukar—secondary forest after shifting cultivation. Prominent plants may include *udok*[2], *talijuru*, *semperiding*, *simpoh*.

bi-bidok—small tree common in secondary forests.

bingkulat—a buttressed forest tree with smooth bark.

bukit—hill.

cassava—tapioca.

dual—tree with pneumatophores, smooth pale bark, and ovate leaves; present in *perepat* swamps.

jalan—track or road.

jelutong—tall tree (*Dyera* sp.) providing a latex which is the principal ingredient of chewing gum.

kampong—village.

kapur paya—valuable hardwood tree (*Dryobalanops rappa*).

keramunting—shrub (*Rhodomyrtus* sp.) with edible fruit.

kerangas—lowland heath forest.

kuala—mouth of a river.

lalang—coarse grass (*Imperata cylindrica*) which is an important weed in cultivated areas.

langitu—bracken fern (*Pteridium aquilinum*).
liat—clay.
luba—prominent palm on sandy hill tops.
nibong—tall coastal palm (*Oncosperma filamentosa*).
nipah—palm (*Nipa fruticans*) common along tidal reaches of rivers.
obah—tree (*Eugenia*).
padi—the rice crop.
pasir—sand.
perepat—swamp tree (*Sonneratia caseolaris*) with aerial roots; one of the mangrove group.
perupok—forest tree.
powas—large tree with smooth mottled bark, small leaves, dense foliage; slightly buttressed.
pulai paya—swamp tree with buoyant white wood, used for corks and in boat building.
pulau—island.
pulau buah—"fruit island"; distinctive area of tall fruit trees.
rassau—palm-like plant (*Pandanus*) also known as screw-pine, common in coastal swamps.
rotan beni—small rotan (*Flagellaria*).
rengas—a group of trees with sap causing sores on the skin.
rentis—a cut line through jungle.
rimba—primary forest.
rimba paya—swamp forest.
rumput—grass.
sedaman—tree (*Macaranga*).
salingkawan—creeping fern (*Gleichenia*) known in Malaya as *resam*.
semperiding—tall coarse swamp sedge with sharp-edged three-angled stem (possibly *Cyperus* or *Scleria*).
sesik bouya—prostrate legume (*Desmodium ovalifolium*).
simpoh—distinctive yellow-flowered tree common in secondary regrowth (*Dillenia* or *Wormia*).
sungei—river or stream.
talijuru—tall coarse swamp sedge with blunt-edged three-angled stem (possibly *Cyperus* or *Scleria*).
tanah—soil, earth, or land.
tanah bakar—burning soil, first-class quality.
tanah kuning—yellow soil.
tanah karit—stingy soil of poorest quality.
tanah liat—clay soil.
tanjong—bend (of a river).
tapok-tapokan—*Selaginella*.
terantang—tall tree (*Campnosperma*) of swamp forest.
trusop—small tree.
udok[2]—shrub or small tree (*Melastoma*) prominent in regrowth; known in Malaya as "Straits rhododendron".
utan—the jungle or rain-forest (equivalent to *rimba*).

APPENDIX II

RAINFALL AT KILANAS AGRICULTURAL STATION, BRUNEI

TABLE 6

MONTHLY RAINFALL (IN.), 1936–1956

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1936	—	—	—	—	9·11	3·91	9·44	5·02	4·62	13·61	7·70	7·43	—
1937	14·80	3·48	7·35	11·54	11·09	8·58	5·70	3·86	10·85	11·44	12·30	13·34	114·33
1938	7·97	1·50	12·80	11·87	13·87	6·82	8·20	14·87	6·79	9·22	7·45	9·65	111·01
1939	4·71	4·50	1·11	8·05	7·39	11·12	6·13	10·51	7·25	10·23	10·80	27·14	108·94
1940	8·67	11·33	3·73	4·80	9·21	5·48	2·70	8·26	8·62	9·70	10·61	6·65	89·76
1941	1·53	0·10	4·92	6·52	4·28	7·33	6·26	1·97	11·09	8·15	9·09	12·18	73·42
1942	13·27	1·56	6·21	9·48	5·10	17·72	6·82	8·02	5·90	9·09	15·22	13·16	111·55
1943	10·19	9·38	14·56	6·10	1·83	2·08	3·02	12·20	4·78	14·67	6·38	16·88	102·07
1944	14·61	5·39	5·89	6·15	14·00	8·46	4·59	4·87	8·78	9·73	9·54	9·29	101·30
1945	16·47	14·47	6·91	3·46	3·67	6·20	5·85	13·93	11·38	21·69	12·72	14·95	131·70
1946	13·03	7·43	4·64	3·79	6·57	6·36	2·55	4·76	7·82	12·58	12·37	19·38	101·28
1947	1·83	6·26	12·37	11·93	8·83	8·79	4·66	14·61	11·61	9·53	9·95	19·01	119·38
1948	5·79	6·59	10·38	5·76	7·13	2·26	11·98	3·44	7·69	16·72	21·01	9·90	108·65
1949	5·63	6·47	5·57	13·07	9·44	13·93	12·23	8·35	14·82	17·15	10·51	8·80	125·97
1950	5·66	18·79	3·11	11·11	8·30	3·03	6·39	9·12	9·18	9·29	10·02	10·57	104·57
1951	6·95	10·94	2·89	7·38	9·06	8·12	7·96	6·30	11·20	6·18	11·89	18·43	107·30
1952	3·45	8·75	9·93	4·15	10·12	8·77	7·69	5·82	12·03	10·88	14·18	17·39	113·16
1953	6·99	4·40	2·69	7·24	9·60	5·30	13·21	2·90	13·12	10·74	14·33	7·11	97·63
1954	7·84	3·06	5·85	10·00	4·32	16·93	9·23	10·11	12·87	13·82	9·07	8·06	111·16
1955	14·84	5·21	1·78	4·91	5·69	13·52	8·65	11·82	14·30	15·16	17·60	13·24	126·72
1956	18·22	3·96	6·66	8·22	5·09	14·97	—	—	—	—	—	—	—

TABLE 7

RAINY DAYS

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936	—	—	—	—	12	14	14	12	14	18	16	19
1937	17	8	10	18	19	14	12	11	17	22	21	19
1938	15	5	22	18	18	10	15	18	16	15	17	17
1939	11	15	9	14	17	13	9	13	19	10	12	5
1940	17	17	10	13	16	10	6	17	14	17	26	14
1941	9	1	14	13	18	12	12	14	18	14	23	24
1942	22	7	5	19	15	16	13	19	14	19	25	20
1943	24	16	20	15	12	10	11	18	12	26	22	18
1944	28	11	9	15	25	13	10	10	10	19	16	17
1945	26	19	14	14	9	6	10	13	13	18	19	26
1946	21	19	20	13	15	12	8	12	17	20	20	19
1947	5	15	19	23	17	16	13	18	17	17	20	25
1948	13	18	13	15	17	14	15	14	17	20	23	13
1949	13	11	7	17	23	12	14	16	16	17	16	17
1950	13	16	11	20	15	10	13	21	16	20	21	17
1951	19	22	10	16	14	12	16	14	13	15	17	21
1952	6	14	16	11	15	12	16	13	15	18	18	19
1953	10	11	5	10	10	14	19	6	11	22	20	13
1954	19	9	12	15	11	18	13	15	17	24	17	21
1955	22	14	9	13	12	22	11	21	18	18	18	21
1956	20	17	12	12	12	17	—	—	—	—	—	—

TABLE 8

HIGHEST DAILY RAINFALL 1936–1956

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3·45	3·70	4·94	3·62	2·89	8·88	6·28	5·58	6·27	4·50	5·00	5·26

Appendix III

DETAILS OF SOILS AND WATER SAMPLES

The colour notation in the descriptions that follow is that given in the Munsell soil colour charts but the colour names are those used currently in Australian soil surveys and they do not conform to any published notation.

The methods of analyses were essentially those described by Piper (1942) but with some modifications. Boiling concentrated hydrochloric acid was used to extract acid-soluble phosphorus, potassium, calcium, and magnesium; and a normal solution ammonium chloride for the extraction of the exchangeable cations. The phosphorus was determined by a colorimetric method using butyl alcohol to dissolve the phospho-molybdate complex, calcium and magnesium were determined by titration with the sodium salt of ethylenediaminetetra-acetic acid, and an EEL Flame Photometer was used for the determination of sodium and potassium. A 1 : 5 soil : water suspension was used for the determination of pH, total soluble salts (by conductivity), chloride, soluble aluminium, and soluble iron.

Chlorides are reported as sodium chloride and phosphorus as the element. The term "very low salts" signifies that the total salts are less than 0·05 per cent., with chlorides less than 0·01 per cent.; while "low salts" signifies total salts less than 0·1 per cent., and chlorides less than 0·05 per cent.

The laboratory analyses were carried out in the Soil Chemistry Section, Division of Soils, C.S.I.R.O., by J. T. Hutton, R. D. Bond, and Filicia J. A. Wark.

TABLE 9

SOIL SAMPLES

Site 1. Brunei area, *rentis* B, peg 17

Profile A374

Depth (in.)	
0–1	Dark brown forest litter and roots with sandy soil.
1–3	Dull brown (5YR 5/2) crumbly sandy loam with many lateral roots.
3–6	Dull brown (5YR 3/2) crumbly mellow sandy loam with fewer roots.
6–10	Yellowish brown (10YR 5/6 and 4/2) sandy loam diffusely mottled, slightly compact.
10–22	Yellow-brown (10YR 6/8) sandy loam, slightly compact.
26–40	Bright yellow-brown (10YR 7/8) sandy clay loam, friable.
72–85	Yellow-brown (10YR 6/8) with light red (2–5YR 6/6) mottled sandy clay loam with thin pieces of ironstone.

Class 4 soil on hilltop 50–100 ft above sea-level.

Vegetation: thin jungle probably 15–20 years old.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)				
								Total	Ca	Mg	K	Na
0–1	4·4	0·024	0·005	15	2·2	0·01	1·0	23	0·1	0·3	0·27	0·08
1–3	4·4	0·012	0·002	5·9	1·2	0·006	0·9	11	0·1	0·1	0·10	0·02
3–6	4·6	0·009	0·001	4·3	1·1	0·004	1·1	9·4	<0·1	<0·1	0·05	0·01
6–10	4·9	0·008	0·001	3·3	1·1							
10–22	5·1	0·004	<0·001	2·5	1·0	0·003	1·4	6·8	<0·1	<0·1	0·01	0·01
26–40	5·1	0·004	<0·001	2·5	1·1							
72–85	5·3	0·003	<0·001	2·2	0·9							

TABLE 9 (*Continued*)

Site 2. Brunei area, *rentis* A, peg 32

Profile A375

Depth (in.)

0–½	Dull brown (10YR 5/2) coarse granular mellow clay loam.
1–5	Yellow-brown (10YR 5/4) coarse granular porous clay loam with roots, diffuse change.
7–10	Dull yellow-brown (10YR 5/6) clay loam; uniform in appearance, slightly compact, giving soft clods on digging. Fewer roots.
13–22	Dull yellow (10YR 6/6) clay, soft cloddy when dug out. Occasional pieces sandy ironstone.
31–42	Dull yellow and light red mottled clay, friable to stiff. Few pieces ironstone.
62–67	Light yellow (10YR 6/6), grey, and yellow-brown mottled friable clay with occasional pieces of soft rock (mudstone).

Class 3 soil on low hilltop 60–70 ft above sea-level.

Vegetation: Secondary jungle with *luba* palm, *simpoh*, sedges, and grass.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)				
								Total	Ca	Mg	K	Na
0–½	4·6	0·024	0·006	12	2·8	0·01	4·0	22	0·5	1·6	0·32	0·10
1–5	4·8	0·011	0·003	6·6	2·1	0·01	6·3	18	0·2	0·9	0·14	0·05
7–10	4·8	0·008	0·001	5·0	1·9							
13–22	4·9	0·006	0·001	4·6	2·1	0·009	11	17	0·2	0·2	0·10	0·05
31–42	5·1	0·006	0·001	4·8	2·3							
62–67	5·4	0·005	0·001	4·7	2·2							

TABLE 9 (*Continued*)

Site 3. Brunei area, *rentis* D, peg 87

Profile A376

Depth (in.)

0–3 Light yellowish grey and light yellowish brown granular clay loam, gradual change.

7–10 Light yellow-brown friable clay, uniform down to

27–30 Reddish brown and yellow-brown clay with soft ironstone.

Class 3 soil on midslope of hill 50–100 ft above sea.

Vegetation: Secondary jungle after cultivation for hill *padi*.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)				
								Total	Ca	Mg	K	Na
0–3	4·8	0·010	0·003	7·8	2·2	0·01	5·5	27	0·8	0·1	0·17	0·06
7–10	4·8	0·005	<0·001	4·7	2·4	0·01	7·2	20	<0·1	<0·1	0·10	0·02
27–30	5·1	0·003	<0·001	6·6	2·4							

Site 4. Brunei area, *rentis* D, between pegs 94 and 95.

Profile A377

Depth (in.)

0–3 Grey-brown fine sandy clay loam, mellow and crumbly. pH 4·6, very low salts. Loss on ignition, 8·1%; P, 0·02%; exchange capacity, 16 m-equiv/100g (Ca 1·0, Mg 0·3, K 0·3 m-equiv/100g).

6 Yellow and light yellow-grey clay.

Class 2 soil at foot of hill-slope in narrow valley. A garden growing cucurbits on trellises. The sample represents a composite of four samples from the cultivated garden. Ashes had been added to the soil.

TABLE 9 (*Continued*)

Site 5. Brunei area, *rentis* D, peg 102

Profile A378

Depth (in.)	
0–3	Dark grey mellow crumbly sandy loam. The first inch represents forest litter.
3–30	Light yellow-brown sandy loam, friable.
30–40	Bright yellow-brown with faint red mottling, friable fine clay loam.

Class 4 soil at crest of steep hill 150–200 ft above sea.

Vegetation: Jungle with matted fern undergrowth of *salingkawan* (?*Gleichenia*). No evidence of cultivation in last 20–30 years.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)				
								Total	Ca	Mg	K	Na
0–3	4·1	0·011	0·002	5·9	1·4	0·005	0·9	15	0·1	<0·1	0·07	0·03
10–12	4·9	0·004	<0·001	2·6	1·0	0·004	0·9	7·8	<0·1	<0·1	0·01	0·01
30–40	5·2	0·002	<0·001	2·7	1·1							

TABLE 9 (*Continued*)

Site 6. Brunei area, *rentis* D, between pegs 61 and 62

Profile A379

Depth (in.)	
0–1	Plant litter.
1–3	Grey granular crumbly fine sandy loam.
3–8	Grey and dull yellow-brown fine sandy loam.
10–28	Bright yellow-brown and light grey fine sandy loam, sodden and structureless, distinct change to
28–40	Light grey clay, sticky and stiff.

Class 4 soil on swampy valley floor.

Vegetation: Palms and jungle.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)				
								Total	Ca	Mg	K	Na
0–3	4·6	0·014	0·004	8·3	1·5	0·01	1·6	13	0·2	0·2	0·08	0·02
10–15	4·9	0·006	0·001	1·7	0·7	0·004	2·0	8·7	<0·1	<0·1	0·02	0·01
30–33	4·9	0·005	<0·001	2·0	0·8							

TABLE 9 (*Continued*)

Site 7. Brunei area, *rentis* D, peg 78

Profile A380

Fluid peat or muck at 6 to 12 in. below water level. pH 4·9; salts, 0·2%; Cl^- as NaCl, 0·07%; loss on ignition, 72%.

Peat or muck in extensive swamp, near flowing water course.

Vegetation: Coarse grass (*batong*[2]).

Site 8. Brunei area, *rentis* D, near peg 11

Profile A381

Depth (in.)	
0–6	Partly decomposed sedge or grass.
6–12	Dark grey and yellow mottled wet sandy clay loam with some charcoal.
12–30	Light grey wet fine sandy clay loam.
30–33	Light grey clay, representing the desirable clay for a *padi*-growing soil. pH 5·2; very low salts; loss on ignition, 5·2%.

Class 4 soil in swamp, 2 chains from edge.

Vegetation: Coarse grass (*batong*[2]).

Site 9. Brunei area, *rentis* D, near peg 17

Profile A427

Depth (in.)	
0–7	Dark grey-brown (7·5YR 4/2) mellow crumbly sandy loam.
7–34	Dull yellow (2·5Y 7/4) sandy clay loam.
34–40	Bright yellow-brown (10YR 8/8 dry) and light grey (2·5Y 8/6 dry) clay.

Class 4 soil on hill slope.

Vegetation: Jungle with *nibong* palm (*Oncosperma*) and *powas*.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv/100g)
0–3	4·6	0·016	0·003	5·9	1·2	0·16	0·006	2·5
18–21	5·1	0·004	0·002	1·7	0·9	0·043		
35–38	5·0	0·004	0·002	2·2	1·0	0·045	0·004	6·4

TABLE 9 (*Continued*)

Site 10. Brunei area, *rentis* D, near peg 29

Profile A428

Depth (in.)	
0–1	Litter including bracken roots.
1–3	Greyish brown (10YR 5/3) mellow crumbly sandy loam. Loss on ignition, 4·8%.
12–15	Light brownish yellow and brown finely mottled sandy loam. Loss on ignition, 2·3%.
24–30	Brownish yellow (10YR 7/6) dry compact sandy clay. Loss on ignition, 2·1%.
30–40	Bright yellowish brown (10YR 6/6), red (2·5YR 6/8), and light grey (5Y 8/2) mottled clay with sand. Loss on ignition, 3·6%.
40	Yellow-brown and light yellowish grey mottled clay with sand and weathered rock.

Class 4 soil on crest of ridge.

Vegetation: Secondary jungle with *simpoh* trees, sedge (*semperiding*) and dense fern—bracken and *salingkawan* (?*Gleichenia*).

Site 11. Brunei area, *rentis* L, peg 14

Profile A382

Fluid peat or muck to at least 6 ft below water level.
Sample from 36 in. below water level. pH 4·2; very low salts; loss on ignition, 92%.

Peat or muck on extensive swamp.

Vegetation: Swamp forest of *perepat* (?*Sonneratia*).

Water Sample No. 4 (surface water) was also collected at this site.

TABLE 9 (*Continued*)

Site 12 (and 36). Brunei area, *rentis* L, peg 43

Profile A383, *above water level*

Profile AA451, *below water level*

Depth (in.)	
0–3	Dark brown peat or peaty loam, above water level.
3–12	Dark brown peat, above water level.
36	Brown slimy peat, below water level.
60	Brown (10YR 4/4 to 3/2) sodden peat.
84	Very dark brown (10YR 2/2) peat.
108	Dark brown (10YR 3/3 to 2/2) peat.
132	Dark brown (10YR 4/4 to 3/2) peat and clay.
144	Brown (10YR 4/4 to 3/2) muck or silt.
156	Brown (10YR 4/4 to 3/2) peaty silt.
168	Brown (10YR 4/4 to 3/2) peaty silt.

Peat in valley swamp.

Vegetation: Young rubber plantation; originally probably swamp forest of *perepat* (?*Sonneratia*) and *rassau* (?*Pandanus*).

Shallow drains have reduced the water level to about 15 in. below surface of peat.

Water Sample No. 7 of mixed-up ground-water at sample site.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)
0–3	3·6	0·10	0·006	60	27	
3–12	3·6	0·12	0·022	46	46	
36				55	8·0	32
60				60	10·3	36
84				84	12·7	52
108				71	9·7	53
132				45	6·9	26
144	3·7	0·18	0·003	32	7·4	18
156				40	10·5	23
168				45	9·4	27

TABLE 9 (*Continued*)

Site 13. Brunei area, *rentis* F, peg 75

Profile A429

Depth (in.)

0–10 Grey (10YR 4/2) mellow crumbly sand. Loss on ignition, 3·8%.
10–27 Light yellow-brown (10YR 4/3) sand, mellow. Loss on ignition, 2·2%.
27–36 Light yellow-grey (5Y 8/3) sand. Loss on ignition, 1·6%.

Class 5 soil on crest of flat-topped hill.

Vegetation: Secondary jungle, with dense fern (?*Gleichenia*) undergrowth. Possibly 40 years since cultivation.

Site 14. Brunei area, *rentis* F, peg 95

Profile A430

Depth (in.)

0–3 Brown (7·5YR 4/4) friable small cloddy clay loam with fern litter and roots.
4–15 Yellow-brown (7·5YR 5/6) friable clay.
15–33 Light reddish brown (2·5YR 5/8) with diffuse yellow mottle, friable clay.
33–40 Red (2·5YR 6/8), yellow-brown (10YR 7/6), and dark red (10R 4/6) clay and weathered rock.

Class 3 soil, near crest of high steep hill.

Vegetation: Secondary jungle, possibly 50 years old, with dense undergrowth of ferns—bracken and *Gleichenia*(?).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
							Ca	Mg	K	Na	H				
0–3	3·9	0·024	0·004	9·5	3·1	0·27	<0·1	0·2	0·17	0·09		4	24	36	35
10–12	4·7	0·007	0·002	6·3	2·5		<0·1	0·1	0·13	0·06	22·0	3	22	33	41
27–30	4·9	0·004	0·001	6·7	3·0							2	14	27	57
37–40	5·1	0·003	0·001	6·2	2·6	0·10	0·1	0·1	0·17	0·06	18·8	6	14	29	50

TABLE 9 (*Continued*)

Site 15. Badas swamp near Seria. Sampled about 3 miles from coast near railway line

Profile A384

Depth (in.)	
0–6	Dark brown peat, sodden, overlying peat probably 50 ft deep. pH 3·8; low salts; loss on ignition, 92%.

Peat from extensive swamp forest, approx. 10 ft above sea-level.

Vegetation: Swamp forest with trees 100–150 ft high.

Water Sample No. 1 collected at this site.

Site 16. Badas swamp near Seria. Sampled about 3¾ miles from coast, near railway line

Profile A431

Dark brown (5YR 2/2) at 6–12 in. below water level. Peat probably 50 ft deep. Loss on ignition, 99%; organic C, 61%. Boiling conc. HCl yielded P, 0·02%; K, 0·4 m-equiv/100g; Ca, 4·0 m-equiv/100g; Mg, 6·0 m-equiv/100g.

Peat from extensive swamp forest approx. 10 ft above sea-level.

Vegetation: Swamp forest with trees 100–150 ft high.

Water Sample No. 2 was collected at this site about 12 in. below surface.

Site 17. Brunei area, *rentis* O, near peg 115

Profile A432

Depth (in.)	
0	Water level.
0–5	Dark brown muck; rotting vegetation and fine sand.
12–36	Below water. Light grey (10YR 8/3, turning 10YR 5/2 on exposure) clay (fine sand, 9%; silt, 25%; clay, 59%). pH 4·8; very low salts; loss on ignition, 11·9%; P, 0·02%; K, 12·1 m-equiv/100g.

Class 2 soil from small inland swamp occasionally used for rice.

Vegetation: Raft-like vegetation of sedge and grass.

TABLE 9 (*Continued*)

Site 18. Brunei area, *rentis* O, peg 124

Profile A433

Depth (in.)	
0–12	Brown (10YR 4/3) fine sandy loam, mellow crumbly.
12–18	Dull light brown (10YR 5/3) and yellowish brown (10YR 7/8) fine sandy loam with black flecks.
18–24	Bright yellowish brown fine sandy loam.
24–30	Yellowish brown (7·5YR 6/8) and light yellow (10YR 8/6) mottled loam.

Class 4 soil on upper slope of steep high hill.

Vegetation: Jungle without significant undergrowth.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
0–4	4·9	0·014	0·003	6·3	3·3	0·17	0·006	2·5	11	55	18	16
12–15				3·9	1·2				9	55	18	17
24–26	4·8	0·004	0·001	2·2	1·2	0·043	0·004	3·9	9	54	15	21

TABLE 9 (*Continued*)

Site 19. Brunei area. *rentis* O, near peg 147

Profile A434

Depth
(in.)

0–3 Brown (10YR 4/4) fine sandy loam (fine sand, 64%; silt, 19%; clay, 13%). pH 5·1; very low salts; N, 0·37%; loss on ignition, 10·4%; P, 0·01%; K, 3·6 m-equiv/100g.

Class 4 soil on floor of small valley with meandering *sungei*.

Vegetation: Jungle.

Site 20. Brunei area, *rentis* B, near peg 37

Profile A435

Depth
(in.)

0 Water level
0–72 Slimy dark brown (10YR 2/2) peat or muck.
72–110 Light grey (10YR 7/2) clay, turning dull brown (10YR 5/2) on exposure.
110–145 Dark grey (5Y 3/1) sandy loam.
145–160 Light grey (5Y 6/1) loam.

Peat in extensive swamp, 10–15 ft above sea-level.

Vegetation: *Rassau* (? *Pandanus*), occasional *asam paya* (*Zalacca conferta*), *terantang* (? *Campnosperma*), *simpoh* (? *Dillenia*), *udok*[2] (?*Melastoma*), *rotan beni*, *talijuru*, *ribu*[2].

Water Sample No. 14 taken below surface.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)	N (%)	Soluble Fe (m-equiv /100g)	Soluble Al (m-equiv /100g)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
24				78	9·5	46					
60				53	7·3	31				0	41
96				15·4	3·4	6·9				0	14
130	1·9	3·5	<0·001	19·5	4·7	8·5	0·11	113	24	6	53
154				8·4	2·5	3·2				3	65

TABLE 9 (*Continued*)

Site 21. Brunei area, *rentis* C, peg 40

Profile A436

Depth (in.)	
0	Water level.
0–100	Grey-brown (10YR 5/2) muck or peat, turning dark brown on exposure.
100–115	Grey-brown (10YR 4/2) sticky clay.
115–130	Light grey-brown sticky clay, turning brown (10YR 5/2) on exposure.
130–150	Grey clay.
150–160	Dark grey-brown sandy muck.

Peat in extensive swamp, 10–15 ft above sea-level.

Vegetation: Swamp forest, 30–40 ft high. *Terantang* (*Campnosperma*), scattered *asam paya* (*Zalacca conferta*), *pulai paya* (?*Alstonia spathulata*), *bakong*[2] (?*Crinum*), *salingkawan* (*Gleichenia*).

Water Sample No. 15 was collected at this site.

Depth (in.)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
84	55	7·2	31		
108	25	5·1	11·6	0	36
120	13·0	2·8	5·4	0	16
138	11·9	3·3	3·7	0	2
162	39	8·8	16·0	10	22

TABLE 9 (*Continued*)

Site 22. Brunei area, *rentis* R, near peg 61

Profile A437

Depth (in.)	
0–6	Dark grey-brown (10YR 2/2) crumbly mellow loam.
6–18	Dull yellow-brown (2·5Y 5/4) crumbly mellow loam.
18–24	Yellowish brown clay loam.
24–30	Bright yellowish brown (10YR 8/8) with reddish brown (5YR 6/8) inclusions, stiff clay loam.
30–40	Light yellow-brown (10YR 7/8) and light grey (2·5Y 8/8) clay loam.

Class 4 soil on flat area near bottom of broad valley.

Vegetation: Secondary jungle.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)	N (%)	P (%)	K (m-equiv /100g)
0–4	5·1	0·013	0·003	10·1	3·1	5·1	0·23	0·007	2·1
8–12	5·1	0·004	0·002	4·4	1·8				
24–27	5·0	0·004	0·001	2·3	1·2			0·003	4·6
37–39	5·1	0·002	0·001	1·7	1·0		0·031		

TABLE 9 (*Continued*)

Site 23. Brunei area, *rentis* R, near peg 44

Profile A438

Depth (in.)

0–3 Greyish brown (10YR 3/2) mellow crumbly fine sandy loam, with roots and charcoal.
3–8 Grey-brown to yellow-brown mellow crumbly fine sandy loam, with roots.
8–16 Yellowish brown (10YR 5/6) mellow fine sandy loam.
16–24 Brownish yellow (10YR 6/6) with flecks of reddish brown (2·5YR 6/8) fine sandy loam.
34–36 Bright yellowish brown (7·5YR 7/8) with reddish brown (2·5YR 6/8) mottled fine sandy loam.
36–45 Bright yellow-brown (7·5YR 6/6), reddish brown (5YR 6/8), and light yellow (10YR 7/8) sandy clay.

Class 4 soil on high steep hill.

Vegetation: Old secondary jungle with thick ground cover of *salingkawan* (?*Gleichenia*), occasional *udok*[2] (?*Melastoma*). Area at 1–2 chains east was cultivated last year.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
									Ca	Mg	K	Na	H				
0–3	4·6	0·012	0·002	8·9	1·7	0·18	0·005	1·6	0·2	<0·1	0·11	0·08	23·2	23	49	12	12
3–8	4·8	0·008	0·002	4·1	1·4									21	53	14	12
8–16	5·1	0·004	0·001	2·5	1·0	0·056	0·003	1·5	<0·1	<0·1	0·03	0·05	8·5	20	53	14	12
16–24	5·1	0·003	0·001	2·3	1·0									20	52	11	16
34–36	5·2	0·003	0·001	1·9	0·9	0·028	0·003	1·9	<0·1	<0·1	0·03	0·03	5·3	20	52	12	15
36–45	5·3	0·002	0·001	2·1	1·0									20	49	2	29

TABLE 9 (*Continued*)

Site 24. Brunei area, *rentis* R, near peg 24

Profile A439

Depth
(in.)
0–3 Greyish brown mellow sandy loam with yellowish brown flecks.
6–18 Dull yellow-brown (7·5YR 6/6) sandy loam.
24–30 Bright yellowish brown sandy clay loam.

Class 4 soil on lower hill slope.

Vegetation: Open forest (*rimba pasir*). *Aru* (*Casuarina*), *bingkolat*, *salingkawan* (?*Gleichenia*), *tapok-tapokan* (*Selaginella*). No evidence of cultivation.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv/100g)
0–3	4·6	0·013	0·003	5·2	1·3	0·13	0·005	2·6
6–9	4·9	0·006	0·002	2·8	1·1	0·067	0·003	2·9
24	4·9	0·004	0·001	2·5	1·1	0·051	0·004	5·0

TABLE 9 (*Continued*)

Site 25. Brunei area, Gadong *rentis* V, peg 26

Profile A440

Depth (in.)

0–3 Grey-brown (10YR 4/2) fine sandy loam, mellow and crumbly.
3–6 Greyish brown (2·5Y 6/2) fine sandy loam, mellow and crumbly.
6–15 Yellowish brown fine sandy loam.
15–24 Yellow-brown (10YR 7/8) and light grey (10YR 8/1) fine sandy clay loam, stiff.
24–40 Bright yellowish brown (2·5Y 7/6), light grey (5Y 8/1), and reddish brown (5YR 5/8) clay loam.

Class 4 soil on slopes of low hill approx. 50 ft above sea-level.

Vegetation: Thin secondary jungle of *simpoh* (?*Dillenia*), *bi-bidok*, *soma*[2], ferns including *salingkawan* (?*Gleichenia*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
									Ca	Mg	K	Na	H				
0–3	4·4	0·018	0·004	5·2	1·5	0·14	0·006	1·6	0·2	0·1	0·09	0·05	16·7	5	58	24	12
3–6	4·6	0·010	0·002	3·0	1·1				0·1	<0·1	0·04	0·04	10·9	5	59	24	11
16–18	4·3	0·003	<0·001	1·8	0·9	0·028	0·004	2·9	<0·1	<0·1	0·03	0·01	6·5	4	57	21	18
40–45	4·6	0·007	0·001	2·7	1·3				<0·1	<0·1	0·08	0·03	9·3	3	47	21	29

TABLE 9 (*Continued*)

Site 26. Brunei area, Gadong *rentis* V, peg 29

Profile A441

Depth (in.)

0–3 Light grey-brown (10YR 4/1) minutely speckled sand.
3–15 Light grey-brown loose sand.
15–40 Offwhite, very light grey (10YR 8/1) loose sand.

Class 5 soil on lower hill slope.

Vegetation: Secondary growth, mainly shrubs and ferns, almost covering an abandoned, unhealthy plantation of pineapples and scattered small fruit trees. *Simpoh* (?*Dillenia*), *keramunting* (?*Rhodomyrtus*), bracken, *rumput usar* (a fine tufted grass).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
									Ca	Mg	K	Na	H				
0–4	4·6	0·007	0·002	1·8	0·3	0·048	0·003	0·1	0·1	<0·1	0·04	0·04	4·8	44	50	5	1
36–38	5·5	0·001	<0·001	0·1	0·1		0·001	0·1						39	55	5	0

TABLE 9 (*Continued*)

Site 27. Brunei area, Gadong *rentis* VI, peg 20

Profile A442

Depth (in.)	
0–3	Yellowish grey-brown mellow crumbly fine sandy loam.
3–12	Yellowish grey fine sandy loam.
12–18	Dull yellow fine sandy clay loam.
18–30	Yellow-brown (10YR 6/6) clay loam.
30–40	Yellow-brown (10YR 6/6), light grey (2·5Y 8/4), and reddish brown clay loam, friable.

Class 4 soil, mid slope of low ridge.

Vegetation: Secondary jungle of *simpoh* (?*Dillenia*); *udok*[2] (?*Melastoma*); ferns including *salingkawan* (?*Gleichenia*) and bracken.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv/100g)
0–3	4·6	0·018	0·002	6·8	1·7	0·18	0·009	5·1
18–20	4·9	0·005	0·001	3·4	1·5			
36–40	5·2	0·003	0·001	4·3	1·9	0·080	0·007	8·8

TABLE 9 (*Continued*)

Site 28. Brunei area, Gadong *rentis* VI, between pegs 2 and 3

Profile A443

Depth (in.)	
0–4	Grey (5Y 4/1) with brown (7·5YR 5/8) along root lines, cloddy loam.
6–24	Grey (10YR 6/1) and brown (10YR 5/4) mottled, stiff cloddy clay loam.
24–33	Dull yellow (2·5Y 5/4) and light grey (2·5Y 7/0) sticky clay loam.
33–40	Light grey (5Y 7/1) clay, turns yellow-brown (10YR 6/8) on exposure.

Class 3 soil on swampy valley bottom.

Vegetation: Grasses and sedges on area used for buffalo grazing.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
										Ca	Mg	K	Na	H				
0–4	4·6	0·016	0·002	4·8	1·1	2·1	0·16	0·005	2·6	0·2	0·7	0·06	0·05	11·8	2	64	20	13
12–15	4·8	0·010	0·001	4·0	1·3										1	53	18	25
27	5·0	0·005	0·001	3·3	1·6		0·065	0·005	6·1	0·1	0·5	0·10	0·07	9·4	1	52	15	28
36–40	4·7	0·011	0·002	4·7	2·4					0·1	0·8	0·18	0·07	13·1	1	22	26	47

TABLE 9 (*Continued*)

Site 29. Brunei area, Gadong *rentis* I, peg 9

Profile A444

Depth (in.)

0–4 Grey-brown (10YR 4/1 and 4/3) with yellow-brown specks (10YR 6/6), fine sandy loam, mellow and crumbly, with surface litter.
4–12 Brown (5YR 5/8) fine sandy clay loam, friable small clods; small fragments ironstone.
12–27 Brown (5Y 5/8) stiff cloddy clay with pieces reddish ironstone, especially from 15 in.
30–36 Light brown (5YR 6/8) and yellowish brown clay with small pieces gravel and rock (ironstone).

Class 4 soil on crest of high steep hill; with ferruginous rock exposed nearby.

Vegetation: Young secondary jungle of *simpoh* (?*Dillenia*); *keramunting* (?*Rhodomyrtus*); *tapok-tapokan* (*Selaginella*); and *salingkawan* (?*Gleichenia*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	Gravel of Field Sample (%)
									Ca	Mg	K	Na	H					
0–4	4·6	0·010	0·002	6·3	1·9	0·14	0·006	4·1	0·1	0·2	0·13	0·06	20·0	10	50	21	16	
6–12	4·8	0·005	0·002	3·5	1·5													6
18–20	5·1	0·003	0·001	5·6	2·4	0·063	0·009	8·2	0·1	0·1	0·09	0·02	15·6	15	27	15	39	
30–34	5·2	0·002	0·001	4·7	2·1													3

TABLE 9 (*Continued*)

Site 30. Brunei area, at south boundary Gadong Estate

Profile A445

Depth (in.)	
0–6	Very dark grey (10YR 3/1) and dark brown (10YR 3/2) granular organic clay loam with many roots.
6–18	Light grey (10YR 6/2) and light brown (10YR 7/3) sticky clay.
18–40	Dark brown (10YR 3/3) organic loam, sodden from 24 in.
40	Very light grey clay.

Class 2 soil on narrow valley bottom in rubber plantation with artificial surface drains. Rubber trees possibly 30 years old form complete canopy. Trees 18–24 in. diameter at tapping panel and currently in use for tapping.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
									Ca	Mg	K	Na	H				
0–4	3·8	0·069	0·004	28	8·0	0·75	0·02	7·6	0·1	0·2	0·20	0·07	102	18	16	32	23
12–15	4·4	0·017	0·002	12·8	4·2	0·23	0·01	16									
34–36	3·8	0·098	0·004	45	7·1									31	11	25	19

TABLE 9 (*Continued*)

Site 31. Brunei area, close to bridle-path from Kpg. Kairong to Kpg. Beribi

Profile A446

Depth (in.)	
0–4	Dark brown (10YR 4/2) with small flecks yellowish brown (7·5YR 6/8) granular mellow clay loam.
4–15	Yellowish brown (10YR 5/4) clay, soft small clods.
15–24	Brownish yellow sandy clay loam.
24–45	Dull yellow and light grey sand.

Class 3–4 soil in narrow valley.

Vegetation: Secondary jungle.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	P (%)	K (m-equiv /100g)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
0–4	4·9	0·015	0·003	9·3	2·4	0·03	9·8	5	38	22	31
8–12	4·8	0·006	0·001	5·6	2·4			3	31	25	37
40–43	5·3	0·003	0·001	0·9	0·4	0·005	2·0	20	69	5	6

TABLE 9 (*Continued*)

Site 32. Brunei area, in Gadong Estate on eastern projection of *rentis* II

Profile A447

Depth (in.)

0–4 Brown (10YR 4/4) loam, crumbly mellow.

4–8 Yellow brown (10YR 6/6) clay loam, friable.

8–36 Bright yellowish brown (10YR 6/8) to brown (7·5YR 6/8) stiff clay.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
									Ca	Mg	K	Na	H				
0–3	4·7	0·015	0·002	5·5	1·5	0·16	0·007	3·9	0·1	0·2	0·14	0·06	18·4	13	52	18	15
4–8	4·7	0·007	0·001	4·1	1·8				<0·1	<0·1	0·07	0·04	18·4	10	41	15	31
30–36	5·1	0·003	0·001	4·1	1·8	0·061	0·006	12	<0·1	<0·1	0·08	0·06	13·0	9	36	14	38

TABLE 9 (*Continued*)

Site 33. Brunei area, *rentis* R, near peg 99

Profile A448

Depth (in.)	
0–10	Water and muck.
10–16	Dark grey (2·5Y 4/2) sticky silty clay loam.
16–24	Dark grey (10YR 5/1) sticky silty clay loam, turns brown (10YR 4/2) on exposure.
24–30	Brown (5YR 6/8), light grey (5Y 7/1) sticky clay.
30–40	Light yellow-grey and light grey mottled sticky clay, turns yellow-brown (10YR 7/8) on exposure.

Class 2 soil on swampy narrow valley bottom.

Vegetation: Swamp forest 30–40 ft high. *Obah paya, simpoh* (?*Dillenia*); occasional *asam paya* (*Zalacca conferta*). No trees larger than 9 in. diameter. Probably cultivated 30–40 years ago for rice.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
									Ca	Mg	K	Na	H				
10–16	4·6	0·013	0·002	10·9	5·7	0·28	0·02	10	0·1	0·2	0·11	0·06	35·5	3	30	33	30
16–21	4·8	0·008	0·002	10·7	3·3		0·01	7·6						3	34	28	30
27–30	4·7	0·009	0·002	3·8	1·5	0·072			0·1	0·2	0·11	0·07	11·4	1	34	24	38
34–37	4·7	0·009	0·002	2·6	1·2	0·053	0·006	8·1						1	34	22	39

TABLE 9 (*Continued*)

Site 34. Brunei area, *rentis* T, peg 25

Profile A449

Depth (in.)	
0–2	Organic litter with sand.
2–9	Dark grey-brown speckled (10YR 3/1 and 10YR 6/2) crumbly sand.
9–22	Very light grey-brown (10YR 7/2) loose sand.
22–23	Dark brown (10YR 4/3) compact sand with yellow-brown inclusions.
23–25	Yellow-brown (10YR 8/8), brown (10YR 6/4), and dark brown (10YR 4/3) indurated sand ("coffee rock").
25–34	Brown (10YR 6/4) loose sand.

Class 5 soil on terrace 20–30 ft above valley bottom.

Vegetation: Secondary growth of shrubs and small trees to 15 ft. *Keramunting* (?*Rhodomyrtus*); *udok*[2] (?*Melastoma*); *simpoh* (?*Dillenia*); bracken. Poor growth of pineapples on this soil a few yards away.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Ca (m-equiv /100g)	Mg (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
												Ca	Mg	K	Na	H				
+2–0	4·2	0·11	0·014	31	4·7	19·6	0·69	0·02	1·7	1·3	2·0						47	50	1	2
0–5	4·3	0·015	0·002	6·0	0·9		0·17	0·006	0·5			<0·1	0·2	0·11	0·07	18·9	22	69	5	2
9–14	4·9	0·004	0·001	0·2	0·5		0·008													
20–21	4·9	0·007	0·001	2·6	1·3		0·071	0·004	0·9								19	65	8	8
21–23	5·3	0·003	0·001	4·4	1·9	2·0	0·050										28	64	5	4
23–32	5·3	0·002	0·001	1·7	0·8		0·026	0·003	2·4								15	75	4	5

Site 35. Brunei area, *rentis* T, peg 42

Profile A450

Dark brown peat from water level to 72 in. or more. Probed to 120 in. nearby without finding clay. Loss on ignition, 86%; organic C, 53%; N, 2·0%; P, 0·03%; K, 2·5 m-equiv/100g; Ca, 1·6 m-equiv/100g; Mg, 5·0 m-equiv/100g.

Peat on valley bottom.

Vegetation: Swamp forest 40–50 ft high. *Terantang* (?*Campnosperma*); *perepat* (?*Sonneratia*); *asam paya* (?*Zalacca conferta*); *dual*; *rassau* (?*Pandanus*)

TABLE 9 (*Continued*)

Site 36.

Profile A451—See Site 12.

Site 37. Brunei area, *rentis* H, between pegs 8 and 9

Profile A452

Depth (in.)	
0–40	Water and rotting vegetation.
40–50	Grey-brown (10YR 5/2) silty clay loam.
50–58	Dark yellow-grey silty clay.
58–66	Yellow-grey (5Y 6/1) silty clay, turns brown (10YR 5/6) on exposure.
66–75	Yellow-grey clay turns brown on exposure.
75–150	Light grey (10YR 7/2 or 7/1) clay.

Swamp soil near low hills.

Vegetation: Open sedge and grass swamp used for buffalo grazing and occasional rice cropping. Occasional small *perepat* trees indicate original swamp forest. Site referred to as "*paya gamboran*" (soft or peaty soil) or "*paya mengalun*" (weaving or springy swamp). Ferns—*tapok-tapokan* (*Selaginella*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Ca (m-equiv /100g)	Mg (m-equiv /100g)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
36				87	13·7	50	1·5	0·02	3·2	2·7	2·9		
42–45				8·9	4·0	3·3						2	21
60	4·6	0·015	0·005	7·0	3·4	1·9						0	15
72	4·1	0·046	0·003	4·9	2·3	1·3						0	20
84				6·9	3·4	1·7						0	13
120				6·1	3·1	1·1							

TABLE 9 (*Continued*)

Site 38. Brunei area, *rentis* H, between pegs 31 and 32

Profile A453

Depth (in.)	
0–40	Watery peat.
40–120	Dark brown (10YR 2/2) peat.
120–140	Dark grey-brown peaty loam.
140–180	Dark grey-brown organic silty clay.

Peat from extensive swamp 10–15 ft above sea-level.

Vegetation: Swamp forest 30–40 ft high. *Terantang* (?*Campnosperma*), *dual*, *simpoh*, *bakong*[2] (?*Crinum*), *semperiding*, occasional *asam paya* (?*Zalacca conferta*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)	Soluble Fe (m-equiv /100g)	Soluble Al (m-equiv /100g)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
48–60				83	13·8	53				
78				85	15·0	54				
102				62	13·0	39				
126	2·3	2·3	<0·001	35	10·3	19·3	38	36	5	25
150				30	9·3	14·6			4	30
174	2·2	2·9	<0·001	27	9·3	12·9	60	30	22	30

TABLE 9 (*Continued*)

Site 39. Brunei area, *rentis* J, between pegs 7 and 8

Profile A454

Depth (in.)

0	Water level.
0–150	Dark brown (10YR 3/3) peat which turns darker on exposure.
150–180	Grey-brown (2·5Y 6/2) slimy muck, turns dark brown on exposure.

Peat in extensive swamp forest.

Vegetation: Swamp forest 50–70 ft high. Trees up to 24 in. diameter at base. *Perepat* (?*Sonneratia*); *terantang* (?*Campnosperma*); occasional *rassau* (?*Pandanus*); *obah paya*; occasional *asam paya* (?*Zalacca conferta*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
42				95	13·8	57		
66				97	19·5	68		
102				98	8·7		0	7
138				66	16·9	46		
174	3·1	0·58	0·003	15·1	6·0	8·1	2	30

TABLE 9 (*Continued*)

Site 40. Brunei area, *rentis* B, between pegs 84 and 85

Profile A455

Depth (in.)	
0	Water level.
0–45	Dark brown peat or muck.
45–72	Grey-brown (10YR 5/2) silty clay.
108–132	Brown peat or muck.
132–175	Light brown (10YR 7/2) silty clay, turns darker on exposure.

Peat in extensive lowland swamp within 5 chains of low hills. Used last year for wet *padi* and being prepared for another *padi* crop. At present covered with sedges—*talijuru*, occasional *simpoh* (?*Dillenia*) trees, and *udok*[2] (*Melastoma*). Many tree stumps and logs, also scattered *terantang* (?*Campnosperma*); *pulai paya* (?*Alstonia*); and *asam paya* (?*Zalacca conferta*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Organic C (%)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
30				67	19·4	46		
66				40	10·6	27	3	28
90				68	17·1	47	0	27
120	3·8	0·085	0·003	20	6·9	12·9	0	33
138				17·3	6·7	10·0	2	19
174	3·8	0·069	0·003	16·1	5·7	9·2	0	14

TABLE 9 (*Continued*)

Site 41. Brunei area, *rentis* T, near peg 3

Profile A456

Depth (in.)	
0–1	Dark brown (10YR 2/2) rotting vegetation.
1–6	Dark brown to black (10YR 2/2 to 2/1) granular mellow peat; dried or partly burnt.
6–12	Dark brown and black peat.
27	Water level.
27–105	Dark brown soft woody peat, containing wood (particularly from 27–50 in.).
105–140	Grey to very light grey silty clay, turning darker on exposure.
140–160	Very light grey and light yellow clay.

Peat in small swamp basins near low hills. Drained by many shallow drains and used for rubber plantation about 9 years old. Many trees lean over and several are uprooted. Rubber trees are in use for latex extraction.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Ca (m-equiv /100g)	Mg (m-equiv /100g)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
0–½	3·7	0·32	0·007	55	20	38	1·8	0·05	4·7	1·9	5·0		
½–6	3·7	0·17	0·005	67	36	53	1·6	0·04	3·9	0·7	3·5		
6–12	3·8	0·092	0·003	76	22	50	1·5	0·04	2·6	0·6	2·3		
27–30													
48–54				95	18·7	65							
72–78				87	8·9			0·007	2·9				
96–100				77	18·2	53						0	23
120				17·9	6·6	10·2		0·006	12			5	27
132	3·9	0·080	0·002	2·9	1·2	0·50						4	37
144				4·8	2·4	0·29		0·01	15			3	21
156	5·1	0·013	0·004	6·2	2·3	0·60						4	19

TABLE 9 (*Continued*)

Site 42. Brunei area, *rentis* AA, between pegs 22 and 23

Profile A457

Depth (in.)	
0–4	Dark grey-brown (10YR 4/2) crumbly mellow clay. Many roots of rubber trees. Worms noticeable.
4–14	Very light grey (10YR 7/1) with yellow-brown (10YR 6/8) veins sticky clay with few roots.
14–29	Dark grey (10YR 3/1) and brown (10YR 4/2) mottled silty clay, sticky.
29	Water level.
29–36	Brown silty clay (10YR 4/2).
36–45	Brown (10YR 5/3) peaty loam, turns dark brown on exposure.

Class 1 soil on flat area near hill slopes.

Vegetation: Rubber plantation, in use for latex extraction.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
										Ca	Mg	K	Na	H				
0–4	4·3	0·037	0·004	12·1	3·2	4·6	0·39	0·02	16	0·2	0·4	0·33	0·10	42·4	2	11	37	42
6–10	4·7	0·007	0·002	6·0	3·1		0·13								1	3	34	58
16–20	4·4	0·032	0·003	15·4	4·0		0·34	0·02	16	0·1	0·4	0·13	0·07	57·0	3	7	28	52
30–33	4·7	0·009	0·002	7·9	2·0		0·16								1	34	29	31
40–45	4·6	0·024	0·002	12·6	2·1	6·8	0·21	0·007	5·6	0·2	1·1	0·05	0·07	31·7	6	49	20	21

TABLE 9 (*Continued*)

Site 43. Brunei area, *rentis* X, peg 15

Profile A458

Depth (in.)	
0–3	Brown (10YR 4/3) granular mellow clay loam with few pieces charcoal.
3–6	Yellowish brown clay loam.
6–12	Brown (5YR 6/8) and light reddish brown (2·5 YR 5/8) clay. Brown along vertical cracks and worm channels.
12–18	Light reddish brown (5YR 6/6) stiff clay with grey and red inclusions. Some small pieces platey ironstone.
18–30	Yellow-brown (10YR 7/8), light grey (10YR 8/1), and red-brown (2·5YR 6/8) sticky clay.
30–38	Light grey (10YR 8/1), yellow-brown (10YR 7/8), and occasional red, sticky clay.
38–45	Light grey and yellow sticky clay.

Class 3 soil on crest of flat-topped hill 20–30 ft above sea-level.

Vegetation: Secondary jungle, about 5 years old. *Simpoh* (?*Dillenia*), *udok*[2] (*Melastoma*), *keramunting* (*Rhodomyrtus*), grass—*roman pawau*.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
										Ca	Mg	K	Na	H				
0–3	4·8	0·008	0·001	6·7	2·4	2·7	0·16	0·01	9·1	0·3	0·3	0·09	0·06	22·6	20	23	28	29
7–10	4·9	0·005	0·001	5·0	2·2										13	17	26	44
15–18	5·0	0·004	0·001	6·7	2·7		0·093	0·01	20	0·1	0·2	0·12	0·05	19·8	15	13	25	49
20–25				5·1	2·7										6	10	32	52
33–36	4·9	0·006	0·001	6·1	2·6			0·008	19	<0·1	0·2	0·19	0·06	20·6	5	5	33	53
42–44	4·7	0·009	0·002	6·1	2·4		0·12								6	6	34	53

TABLE 9 (*Continued*)

Site 44. Brunei area, *rentis* X, between pegs 18 and 19

Profile A459

Depth (in.)

0–24 Dark grey-brown fine sandy loam, sodden with water to surface.

24–36 Grey-brown (10YR 4/2) peaty sandy loam, turning almost black on exposure. pH 3·3; salts, 0·9%; Cl^- as NaCl, 0·004%; loss on ignition, 27%, organic C, 13·7%; N, 0·31%; coarse sand, 45%; fine sand, 43%; silt, 7%; clay 5%.

Swamp soil in valley flooded by tidal movement.

Vegetation: Swamp forest—*pulai* (?*Alstonia*); *perepat* (?*Sonneratia*); *rassau* (?*Pandanus*); *simpoh* (?*Dillenia*); and *bingkulat*.

Site 45. Tutong area, on log track from S. Tutong to Kpg. Pat Nunok, approx. 1 mile east of S. Perupok

Profile A460

Depth (in.)

0–156 Dark brown (10YR 2/2) peat. Surface of peat also represents water level.

156–180 Grey (5Y 5/2) silty clay, turns dark grey and yellow-brown on exposure.

Peat in extensive swamp forest not more than 10–15 ft above sea-level. The site is not subject to flooding.

Vegetation: Forest at least 100 ft high, including *terantang* (?*Campnosperma*); *kayu kapur* (?*Dryobalanops*); *perepat* (?*Sonneratia*); *jelutong* (?*Dyera lowii*); *pulai* (?*Alstonia*).

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Ca (m-equiv /100g)	Mg (m-equiv /100g)	Soluble Fe (m-equiv /100g)	Soluble Al (m-equiv /100g)	Coarse Sand Ignited (%)	Fine Sand Ignited (%)
0–6	4·1	0·074	0·008	92	9·5	58	2·1	0·07	1·5	4·5	2·5				
18				98	10·3			0·01	0·1						
42				97	11·3			0·005	0·1						
66				97	12·0	61								0	3
84				97	11·3			0·002	0·1						
120				86	12·8	53								0	14
144				67	11·2										
174	2·6	1·5	0·028	12·9	3·5	3·9						23	12	2	36

TABLE 9 (*Continued*)

Site 46. Tutong area, vicinity of Kpg. Pat Nunok, on track from 7¼ mile post on Kuala Abang Road.

Profile A461

Depth (in.)	
0–3	Dark greyish brown (7·5YR 3/2) sand with thin organic litter on surface.
3–6	Brown to light brown sand.
6–12	Very light brown to very light grey (10YR 8/1) loose sand.
13–15	Light grey (10YR 7/2) and brown (7·5YR 5/2) very compact sand ("hardpan").
15–24	Yellowish brown very compact sand with few pieces of waterworn gravel—sandstone.
24–45	Brown sand, not compact or indurated.
45–54	Dark brown (7·5YR 3/2) compact sand.
54–60	Very dark brown (10YR 2/1) to black hard compact sand ("coffee rock").
60–63	Dark grey-brown (10YR 4/1) sodden sand.

Class 5 soil on flat-topped hill 50–100 ft above sea-level.

Vegetation: Neglected rubber plantation which includes specimens of original jungle: *perepat bukit, nibong* (?*Oncosperma*); *kayu impas* (?*Koompassia*); *silat* (palm); sedges and ferns as ground cover.

Depth (in.)	pH	Salts (%)	Cl⁻ as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	P (%)	K (m-equiv /100g)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
										Ca	Mg	K	Na	H				
0–2	3·8	0·037	0·001	5·4	0·8	3·5	0·21	0·006	1·4						25	63	8	2
6–12				0·3	0·1		0·008	0·001	0·8	<0·1	<0·1	0·02	0·02	1·5	29	65	6	0
13–15	4·6	0·008	0·001	0·6	0·1		0·015	0·002	1·5						23	55	15	4
50–54				4·7	2·0	2·5	0·043	0·006	1·5						8	86	5	1
54–60	4·6	0·011	0·001	7·7	2·4	4·0	0·073								10	81	1	4
60–63				0·4	0·1		0·008	0·002	0·6						2	94	4	1

TABLE 9 (*Continued*)

Site 47. Tutong area, on track from S. Bekiau to Kpg. Bekiau

Profile A462

Depth (in.)	
0–3	Grey-brown (10YR 5/1) sand. Loss on ignition, 2·9%.
3–6	Light brown sand.
6–18	Very light brown (10YR 7/2) sand. Loss on ignition, 0·3%.
18–24	Brown and very light brown mottled compact sand.
24–30	Dark brown (10YR 4/3) compact sand with hard pellets, darker material, and pockets of loose brown sand. Loss on ignition, 5·6%.
30–40	Layered grey-brown sand and silty clay loam. Loss on ignition, 4·0%.
40–46	Light brown sand.
46–50	Yellow, light grey, and light reddish brown fine sandy loam.
50–60	Layers of silty, sandy, and clay material, mainly dark grey and yellowish brown in colour.

Class 5 soil on flat-topped hill 50–100 ft above sea-level.

Vegetation: Secondary jungle with *udok*[2] (?*Melastoma*); *simpoh* (?*Dillenia*); *keramunting* (?*Rhodomyrtus*); *powas*, *rengas*, and seedling rubber (*Hevea*).

TABLE 9 (*Continued*)

Site 48. On plain close to S. Bekiau at track to Kpg. Bekiau

Profile A463

Depth (in.)	
0–2	Dark brown (10YR 2/2) organic loam with many fine grass roots.
2–6	Dark grey-brown (10YR 3/1) sandy loam.
7–20	Grey-brown (10YR 5/2) sand.
21–33	Dark brown (10YR 3/3) sodden sand. Water level at 24 in.
36–48	Dark grey sandy clay loam.
48–70	Greenish grey sand, turns yellowish brown on exposure.

Class 4 soil on open grassy flat area, not more than 10 ft above sea-level.

Vegetation: Grass and sedge cover at sample site. Nearby shrubs and trees include *simpoh*, palms, *terantang*.

Depth (in.)	pH	Salts (%)	Cl^- as NaCl (%)	Loss on Ignition (%)	Air-dry Moisture (%)	Org. C (%)	N (%)	Exchangeable Cations (m-equiv/100g)					Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
								Ca	Mg	K	Na	H				
0–2				32	18·0	19	1·1	0·6	1·7	0·47	1·1	68	27	44	0	13
2–6	4·7	0·050	0·029	9·8	6·5								6	79	2	6
7–20	5·8	0·034	0·018	2·2	1·6		0·038	0·3	1·4	0·03	0·35	5·3	4	88	2	5
21–33	7·0	0·080	0·043	4·4	1·3	2·4	0·057	1·6	5·2	0·05	0·86	7·3	4	82	4	8
54–60	3·5	0·49	0·063	2·3	0·8		0·035	1·1	1·2	0·02	0·15	4·3	3	81	5	10

TABLE 10

WATER SAMPLES

Results of analyses expressed as milli-equivalents per litre*

Sample No.	Location and Description	Na	Ca+Mg	K	Cl	SO_4^{--}	HCO_3^-
1	*Rentis* D, peg 35. Surface water of stagnant peat swamp	0·05	0·06	0·005	0·04	†	0·06
2	*Rentis* D, peg 35. 12–15 in. below sample No. 1	0·20	0·08	0·068	0·07	0·13	0·09
3	*Rentis* L, pegs 10–11. From sedge swamp	0·07	0·06	0·015	0·06	†	†
4	*Rentis* L, peg 14. Surface water in forest peat swamp at collection of soil samples, site 11	0·18	0·09	0·010	0·16	†	0·09
5	*Rentis* L, pegs 15–16. Water at 36 in. below surface of forest peat swamp	0·10	0·06	0·004	0·02	†	0·06
6	East of *rentis* L, peg 22, in flowing drain from 10-year old wet *padi* settlement	0·17	0·08	0·012	0·10	0·08	0·06
7	*Rentis* L, near peg 43. Ground water in drained peat area, now growing rubber	0·07	0·7	0·052	0·07	†	†
8	*Rentis* F, peg 85. Flowing water in hilly area	0·04	0·13	0·008	0·03	0·07	0·02
9	Badas swamp forest near Seria. Ground water sample at soil sample site 15	0·07	0·15	0·018	0·10	†	†
10	Badas swamp forest near Seria. Ground water sample at soil sample site 16	0·06	0·18	0·092	0·14	†	†
11	*Rentis* H, pegs 31–32. Stagnant water in *asam paya* peat swamp	0·07	0·18	0·011	0·06	0·14	†
12	*Rentis* H, peg 36. Water in peat swamp forest	0·20	0·06	0·021	0·28	†	†
13	*Rentis* H, near peg 45. Flowing water from *sungei* in swamp forest	0·05	0·06	0·006	0·03	0·05	0·05
14	*Rentis* B, peg 37. Stagnant water from peat swamp at soil sample site 20	0·07	0·5	0·03	0·03	0·4	†
15	*Rentis* C, peg 40. Stagnant water from forest peat swamp at soil sample site 21	0·06	0·2	0·03	0·06	0·2	†
16	Gadong rubber estate. Flowing water from *sungei* in hilly area	0·03	0·08	0·004	0·01	0·04	0·08
17	*Rentis* T, pegs 34–35. Flowing water in *asam paya* peat swamp	0·07	0·05	0·013	0·05	0·06	0·02

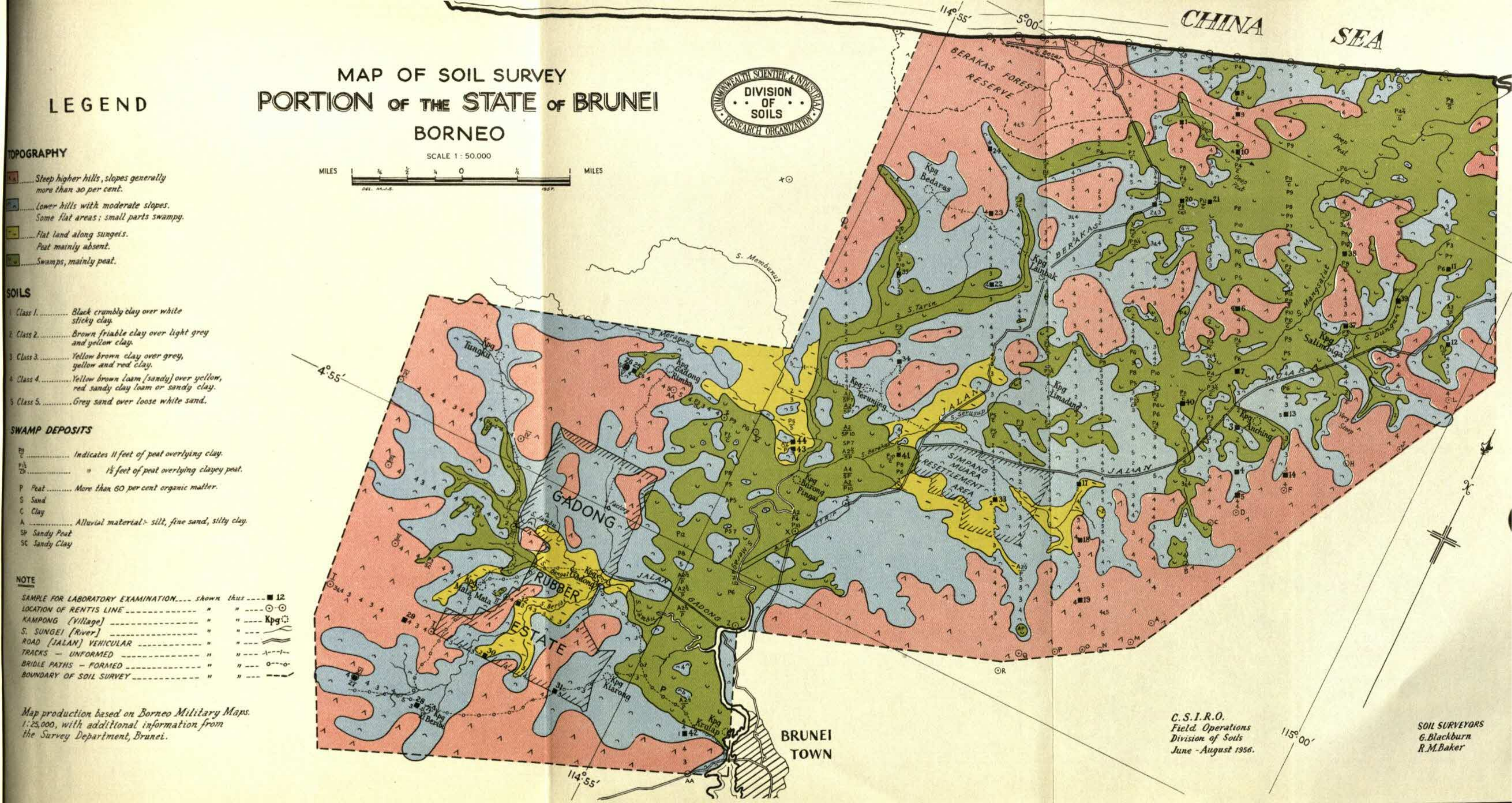
*In many cases the amount of clear water obtainable from the samples was very small (20 ml) and satisfactory analysis was not possible. No samples had pH below 4·5.

†Not determined.

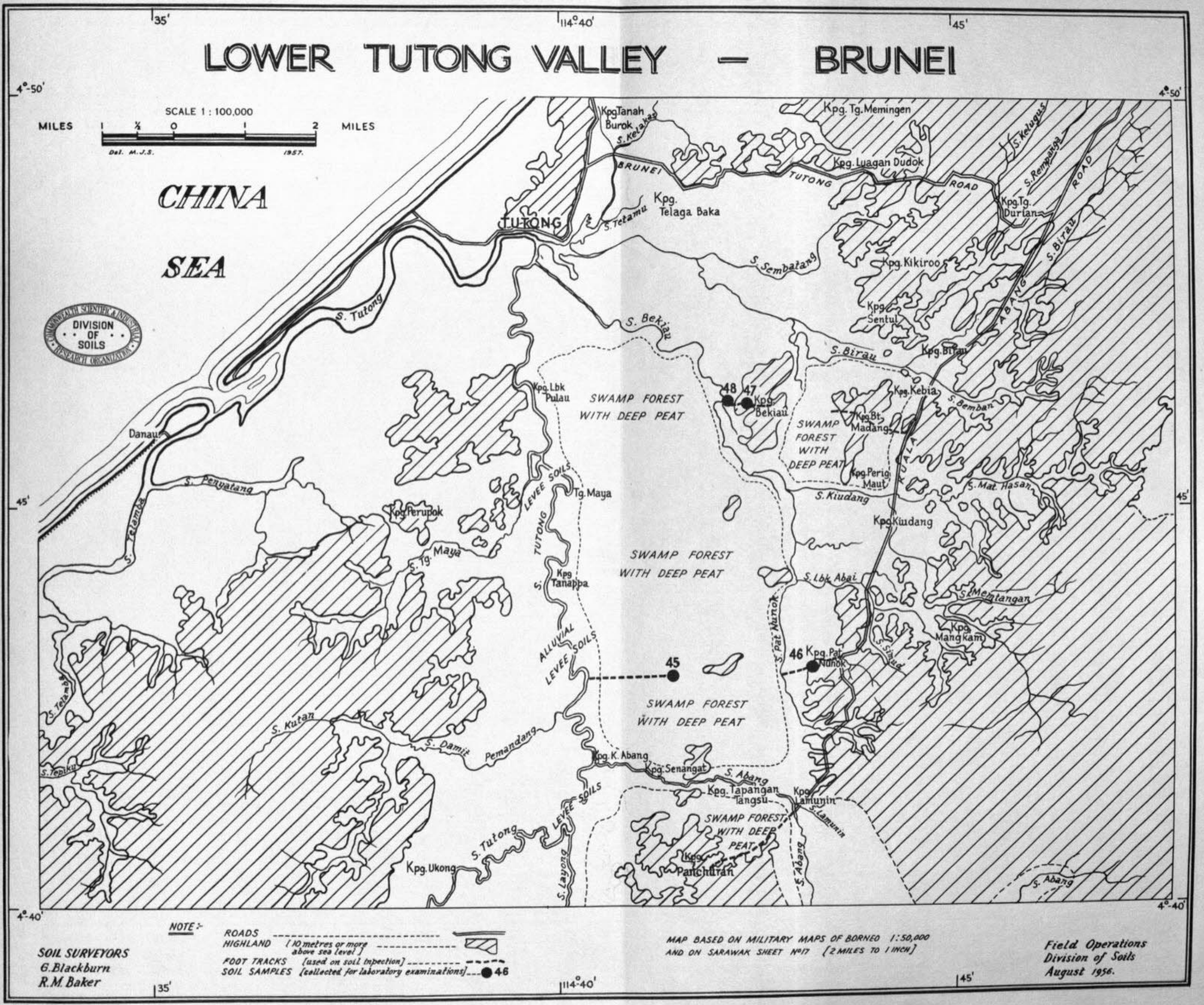
TABLE 10 (*Continued*)

Sample No.	Location and Description	Na	Ca+Mg	K	Cl	SO_4^{--}	HCO_3^-
18	*Rentis* T, pegs 52–53. Flowing water in peat swamp	0·05	0·07	0·004	0·05	0·05	0·03
19	Tutong valley. Flowing water in S. Perupok from swamp forest near site 45	0·18	0·14	0·004	0·21	†	0·01
20	Tutong valley. Track from Abang road to Kpg. Bekiau. Stagnant surface water from swamp forest	0·10	0·20	0·075	0·14	†	0·25
21	Water from S. Bekiau in *nipah* palm zone	1·0	0·6	0·038	1·0	†	0·6
22	Ground water on grazing flats near S. Bekiau. Collected at 39 in. below soil surface at sample site 48	40	16	0·6	41	†	†

†Not determined.



MAP OF SOIL SURVEY
PORTION OF THE STATE OF BRUNEI
BORNEO
SCALE 1 : 50,000
MILES
MILES
COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANIZATION
DIVISION OF SOILS
LEGEND
TOPOGRAPHY
Steep higher hills, slopes generally more than 30 per cent.
Lower hills with moderate slopes. Some flat areas; small parts swampy.
Flat land along sungeis. Peat mainly absent.
Swamps, mainly peat.
SOILS
Class 1. Black crumbly clay over white sticky clay.
Class 2. Brown friable clay over light grey and yellow clay.
Class 3. Yellow brown clay over grey, yellow and red clay.
Class 4. Yellow brown loam [sandy] over yellow, red sandy clay loam or sandy clay.
Class 5. Grey sand over loose white sand.
SWAMP DEPOSITS
Indicates 11 feet of peat overlying clay.
" 1½ feet of peat overlying clayey peat.
P Peat More than 60 per cent organic matter.
S Sand
C Clay
A Alluvial material:- silt, fine sand, silty clay.
SP Sandy Peat
SC Sandy Clay
NOTE
SAMPLE FOR LABORATORY EXAMINATION shown thus ■ 12
LOCATION OF RENTIS LINE " "
KAMPONG [Village] " " Kpg
S. SUNGEI [River] " "
ROAD [JALAN] VEHICULAR " "
TRACKS — UNFORMED " "
BRIDLE PATHS — FORMED " "
BOUNDARY OF SOIL SURVEY " "
Map production based on Borneo Military Maps 1:25,000, with additional information from the Survey Department, Brunei.
CHINA SEA
BERAKAS FOREST RESERVE
GADONG
RUBBER ESTATE
SIMPANG MUARA RESETTLEMENT AREA
BRUNEI TOWN
JALAN GADONG
JALAN
Kpg Bedaras
Kpg Lumbak
Kpg Tungku
Kpg Gadong Rimba
Kpg Terunjing
Kpg Binrong Pingai
Kpg Limadang
Kpg Salimboiga
Kpg Anching
Kpg Mata Mata
Kpg Kiarong
Kpg Krulap
S. Memburut
S. Tarin
S. Mangsalut
C.S.I.R.O.
Field Operations
Division of Soils
June - August 1956.
SOIL SURVEYORS
G. Blackburn
R.M. Baker


LOWER TUTONG VALLEY — BRUNEI
SCALE 1 : 100,000
MILES 1 ½ 0 1 2 MILES
Del. M.J.S. 1957.
CHINA SEA
DIVISION OF SOILS
COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANIZATION
35'
114°40'
45'
4°50'
4°45'
4°40'
Kpg. Tanah Burok
S. Kelakas
Kpg. Tg. Memingen
S. Kelugus
S. Rempanga
BRUNEI
TUTONG
ROAD
Kpg. Luagan Dudok
Kpg. Telaga Baka
S. Telamu
TUTONG
Kpg. Tg. Durian
S. Birau
S. Sembalang
Kpg. Kikiroo
ABANG
Kpg. Sentul
S. Tutong
S. Bekiau
S. Birau
Kpg. Birau
Kpg. Kebia
S. Bemban
Kpg. Lbk Pulau
SWAMP FOREST WITH DEEP PEAT
48
47
Kpg. Bekiau
SWAMP FOREST WITH DEEP PEAT
Kpg. Bt. Madang
KUALA
Danau
Kpg. Perig Maut
S. Penyatang
LEVEE SOILS
Tg. Maya
S. Kiudang
S. Mat. Hasan
S. Telamba
Kpg. Perupok
Kpg. Kiudang
S. Tg. Maya
TUTONG
SWAMP FOREST WITH DEEP PEAT
S.
Kpg. Tanappa
S. Lbk Abai
S. Pat Nunok
S. Memtangan
Kpg. Mangkam
ALLUVIAL LEVEE SOILS
45
46
Kpg. Pat Nunok
S. Sinaut
S. Telamba
SWAMP FOREST WITH DEEP PEAT
S. Kutan
S. Damit
Pemandang
S. Tepiku
Kpg. K. Abang
Kpg. Senangat
S. Abang
Kpg. Tapangan Tangsu
Kpg. Lamunin
S. Lamunin
LEVEE SOILS
SWAMP FOREST WITH DEEP PEAT
S. Tutong
Kpg. Ukong
S. Layong
Kpg. Panchuran
S. Abang
S. Abang
NOTE :-
ROADS
HIGHLAND [10 metres or more above sea level]
FOOT TRACKS [used on soil inspection]
SOIL SAMPLES [collected for laboratory examinations] 46
SOIL SURVEYORS
G. Blackburn
R.M. Baker
MAP BASED ON MILITARY MAPS OF BORNEO 1:50,000
AND ON SARAWAK SHEET No17 [2 MILES TO 1 INCH]
Field Operations
Division of Soils
August 1956.

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