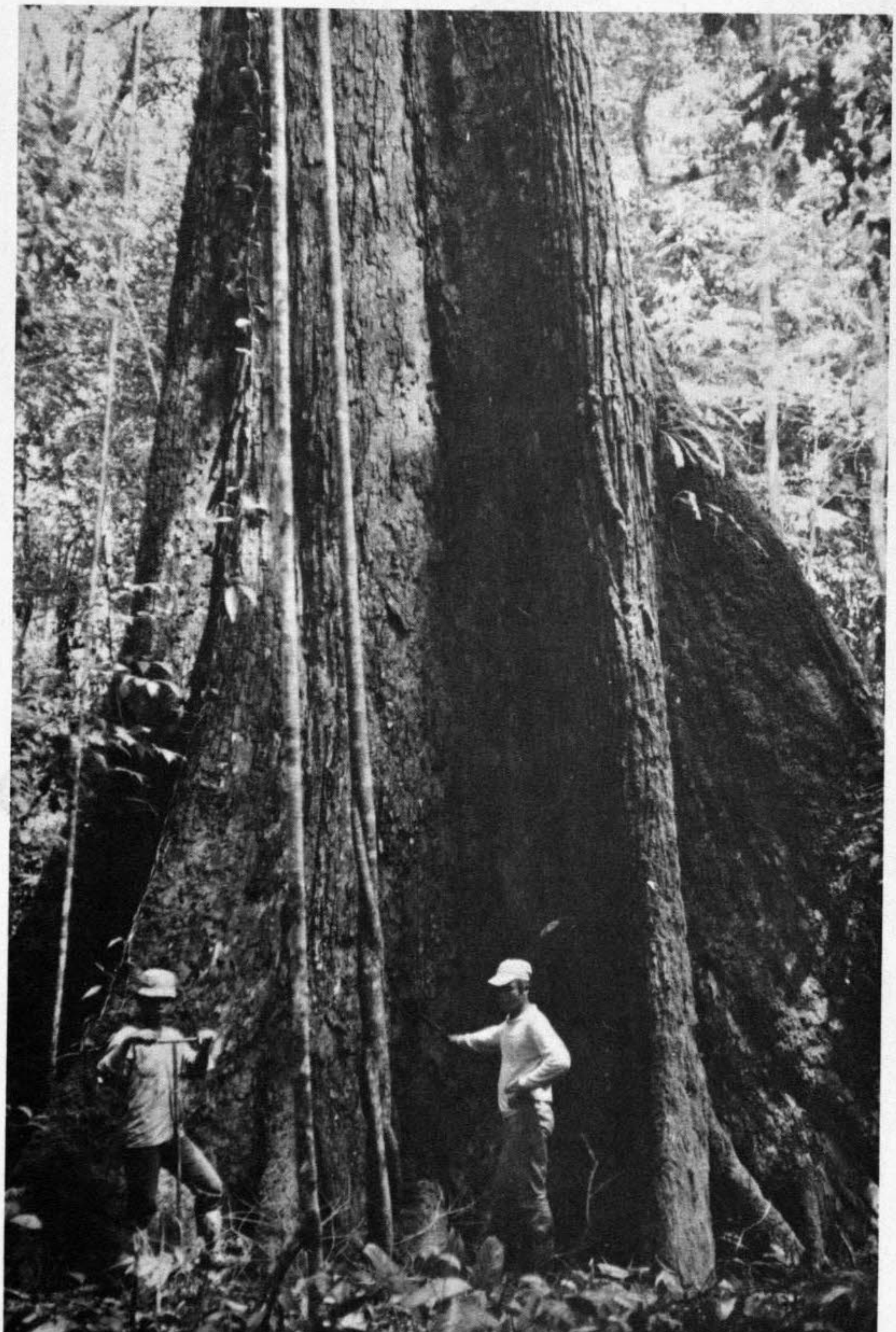
Land Resource Study

20 The Soils of Sabah Volume 3 Western parts of Tawau and Lahad Datu Districts

Land Resources Division, Ministry of Overseas Development,
Tolworth Tower, Surbiton, Surrey, England KT6 7DY

The soils of Sabah
Volume 3
Western parts of Tawau and Lahad Datu



The survey area is almost entirely under rainforest and contains some of the finest timber in Sabah

Land Resources Division

The soils of Sabah

Volume 3

Western parts of Tawau and Lahad Datu

P S Wright

Land Resource Study 20

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1975

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List of volumes

Volume 1	Classification and description (with an introduction to Volumes 1-5). B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright. Volume 1 is accompanied by maps of the soils of Sabah.
Volume 2	Sandakan and Kinabatangan Districts. B D Acres and C J Folland.
Volume 3	Western Parts of Tawau and Lahad Datu Districts. P S Wright.
Volume 4	South-Western Districts. R P Bower, P A Burrough, M S Kalsi and P Thomas.
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Introduction

ACKNOWLEDGEMENTS

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I would like to express my gratitude to the Director of Agriculture, the Assistant Director (Research) and the staff of the Department of Agriculture for their assistance during the course of this survey. My appreciation also goes to the Agricultural Officer, Tawau, and the Assistant Land Development Officer, Lahad Datu, and their staff for their assistance.

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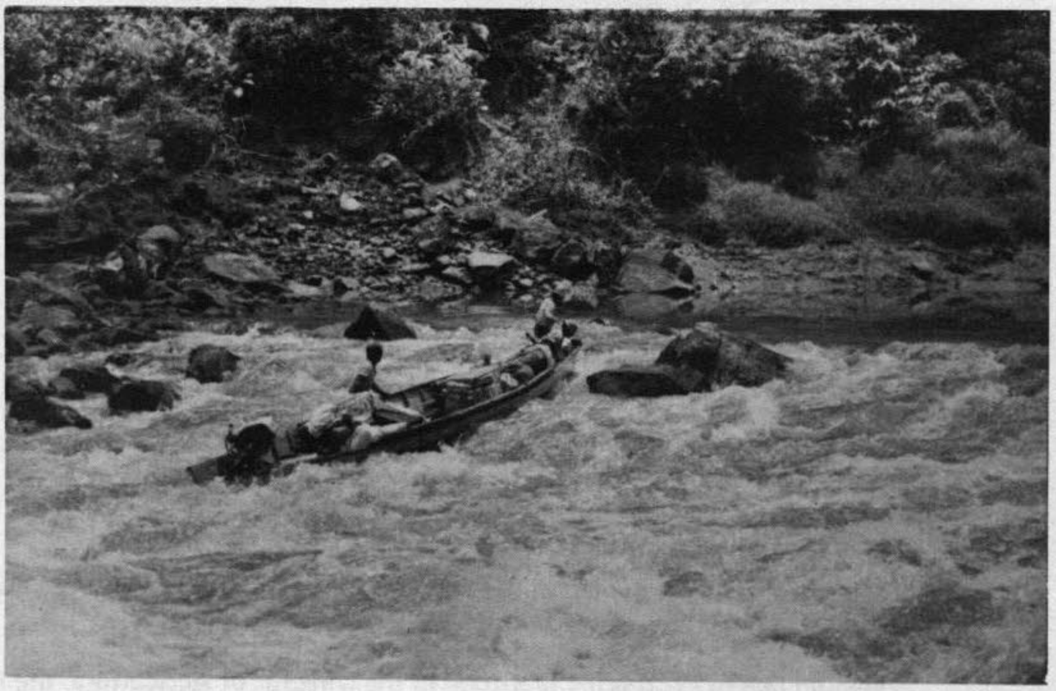
ABSTRACT

This volume describes the soils of the western parts of the Tawau and Lahad Datu Districts, an area of 5 700 km^2 (2 200 mi^2) of largely forested and mountainous land. Twenty-two soil associations are described on alluvium, sandstone, mudstone and igneous rocks. The soils in the associations are classified using the FAO classification and are further subdivided into soil families according to parent materials. The suitability of the soils is assessed for agricultural development: about 78% of the area is unsuitable, 14% is marginal and only 8% is considered to be suitable for agricultural development.

RÉSUMÉ

Ce volume traite des sols des sections occidentales des Districts de Tawau et Lahad Datu, où une aire de 5 700 km^2 (2 200 mi^2) se compose pour une grande part de terres montagneuses et boisées. On décrit vingt deux associations de sols qui se trouvent sur alluvion, grès, argilolithe et roches ignées. Les sols sont classés suivant le système FAO et subdivisés en familles suivant les roches-mères. On donne une classification des sols en fonction de leur productivité potentielle et on trouve que 8% de la superficie etudièe est utilisable pour l'agriculture, 14% pourrait être utilisé avec quelque difficulté, tandis que 78% est inutilisable.



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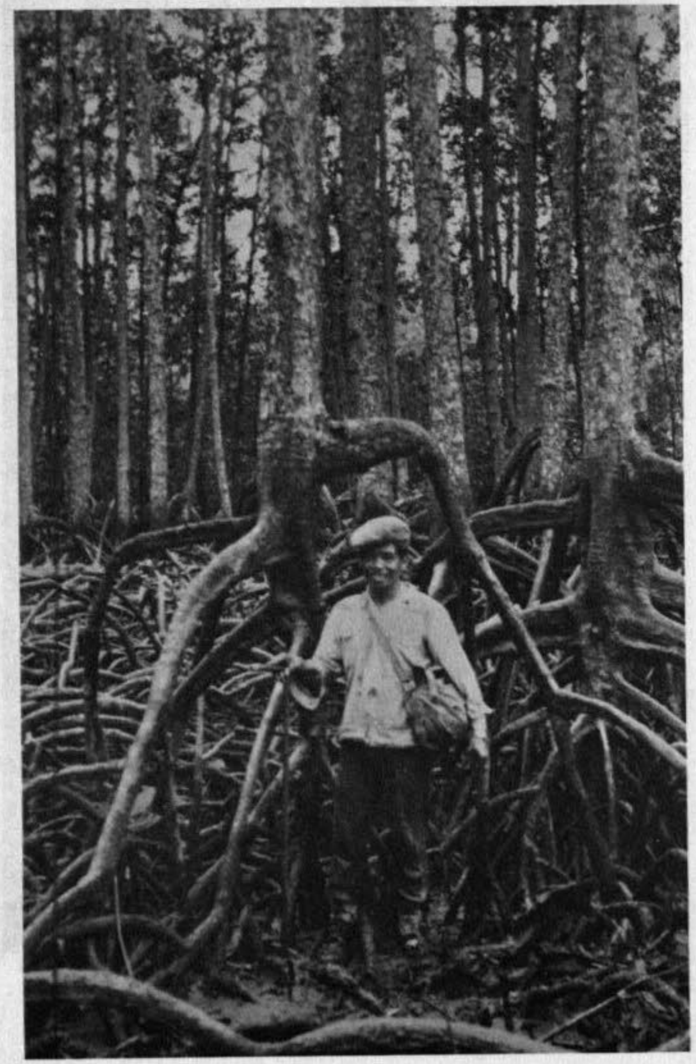

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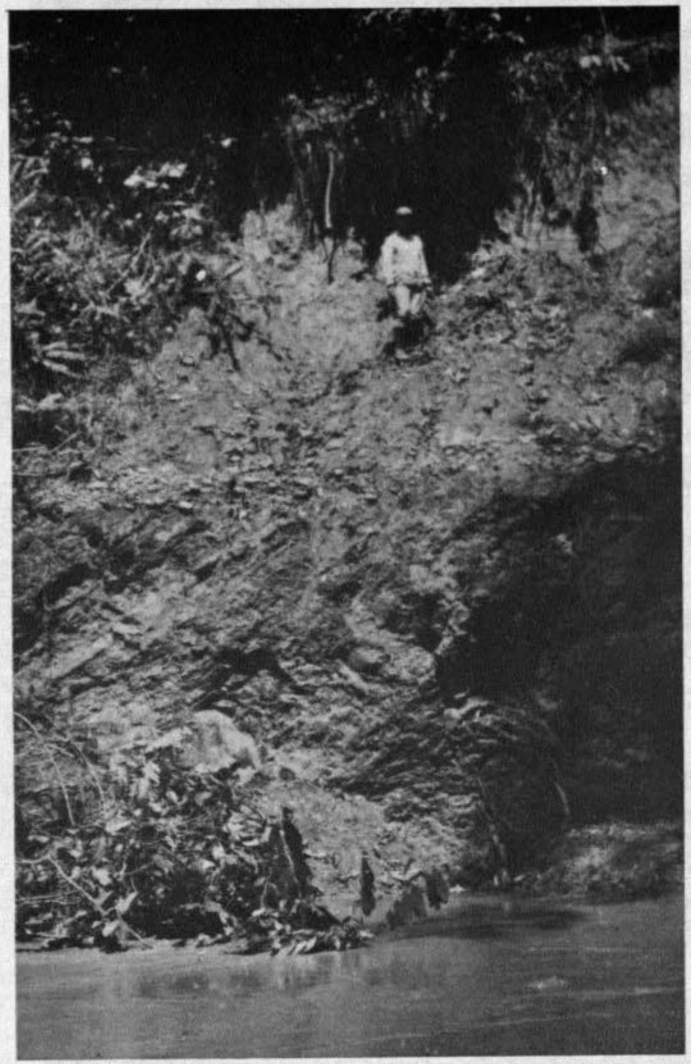
PLATE 3-4 *Nypa fruticans* in a tidal swamp of the Weston Association



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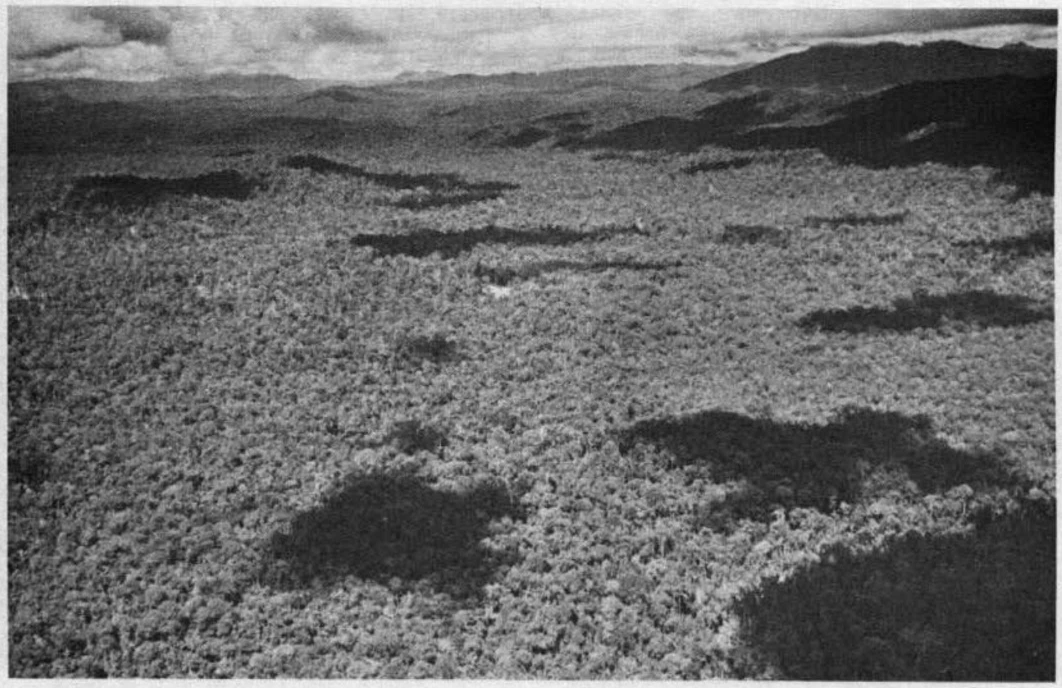

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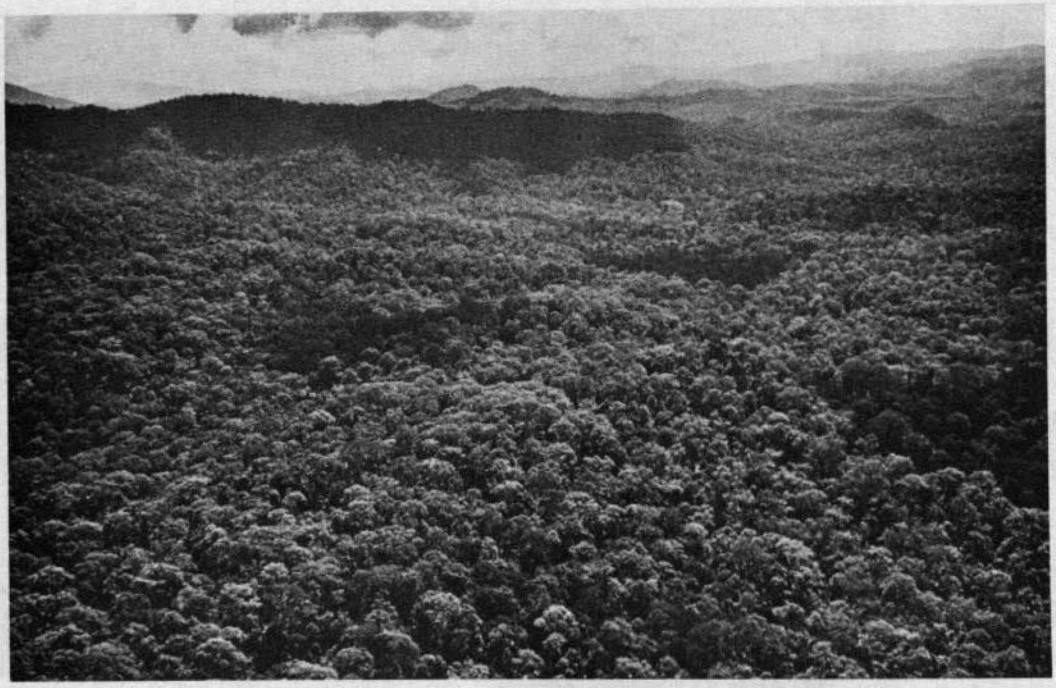

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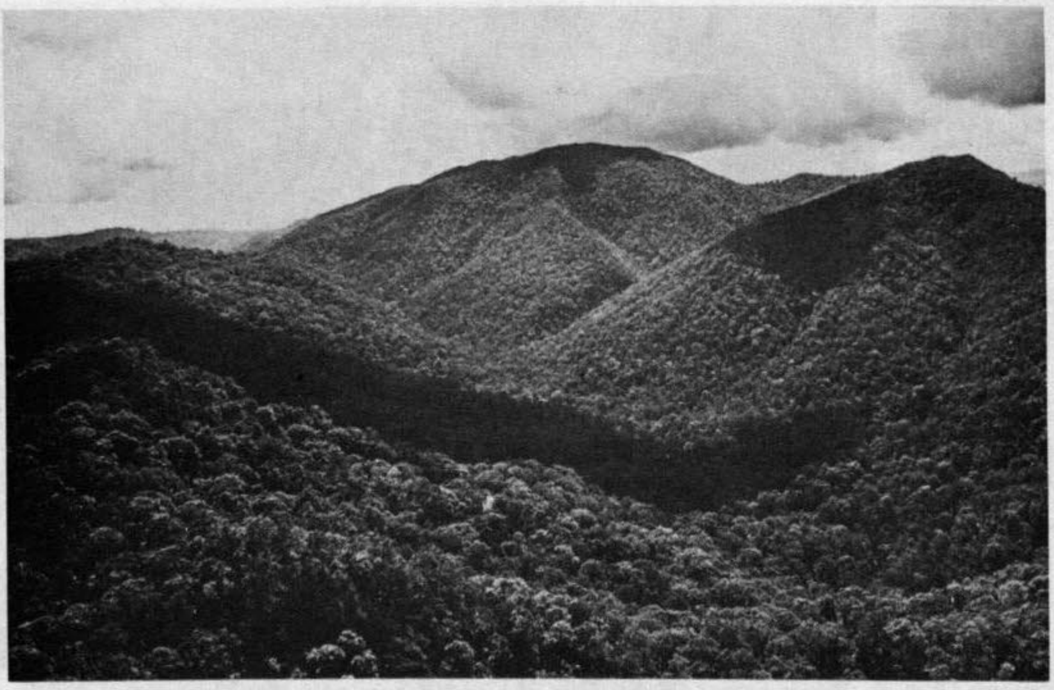

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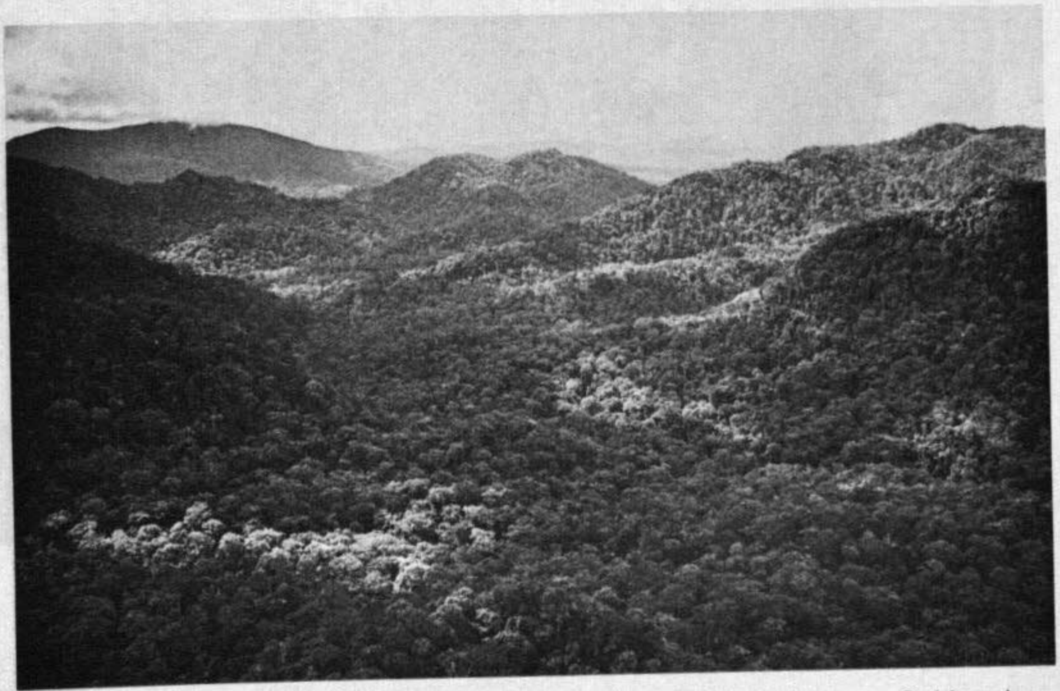

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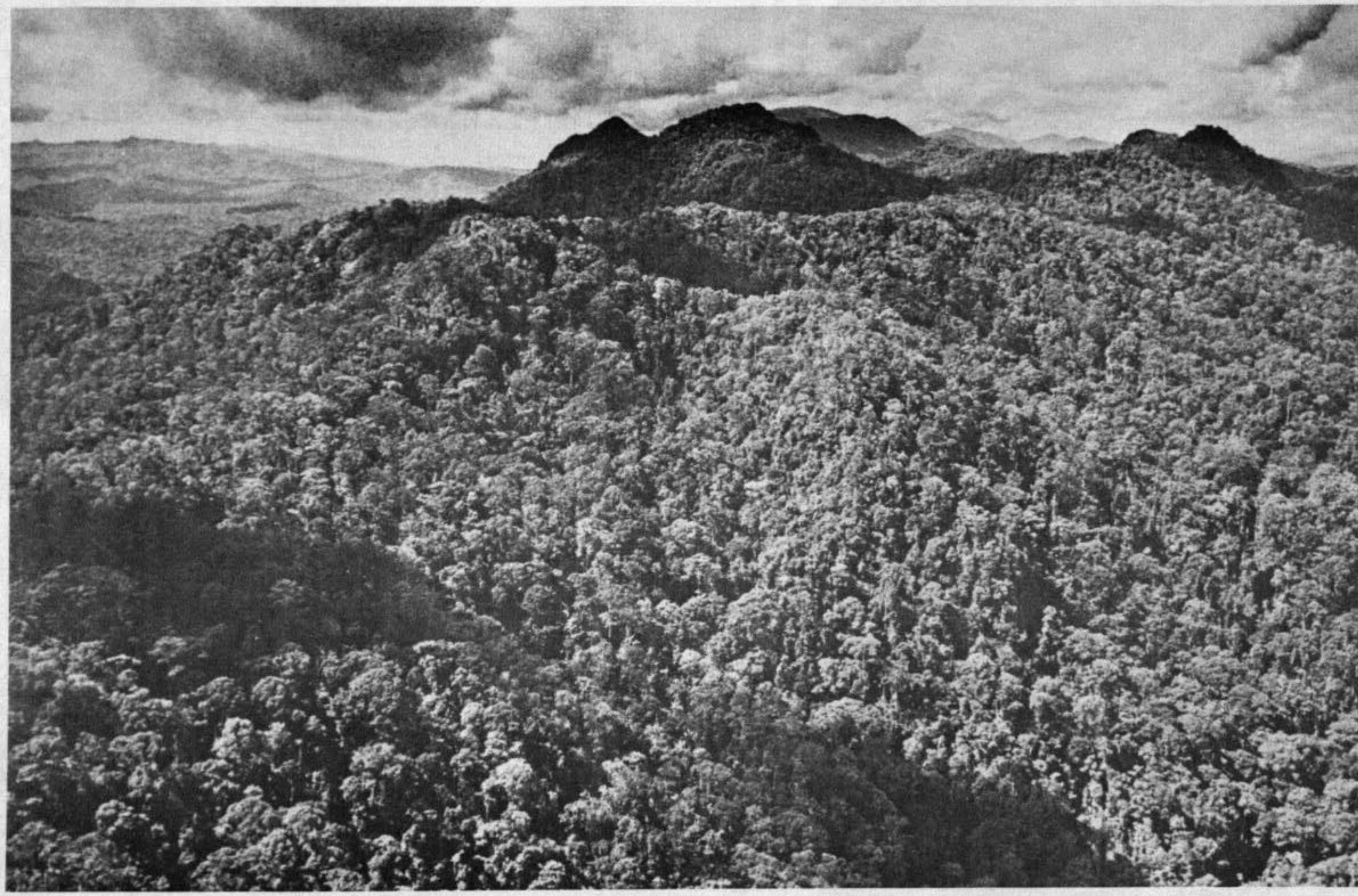

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STEREOGRAM 3-2 The Brantian Association (12) on a coastal terrace between the Umas Umas and Brantian rivers. Mangrove swamps of the Weston Association (1) and sandstone and mudstone hills of the Lokan Association (39) are clearly distinguished (Scale 1 : 40 000)

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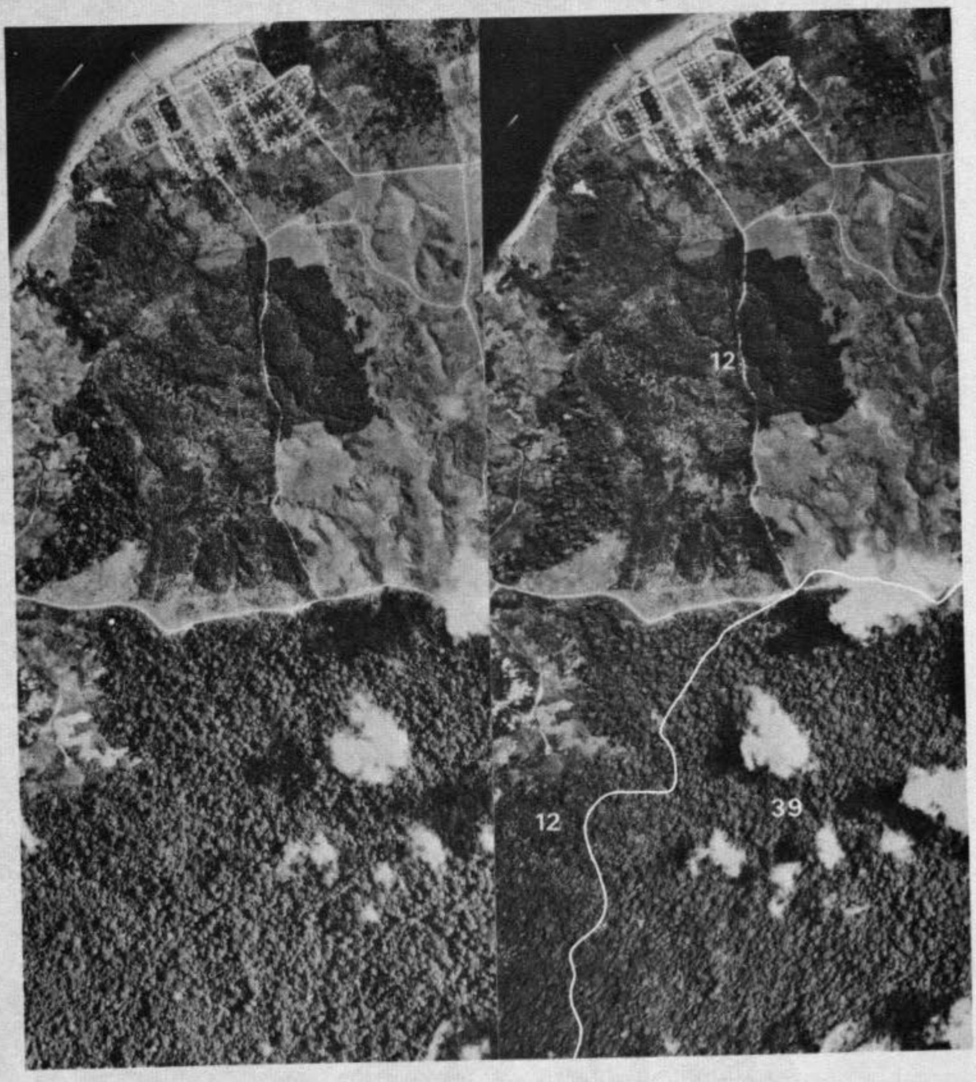

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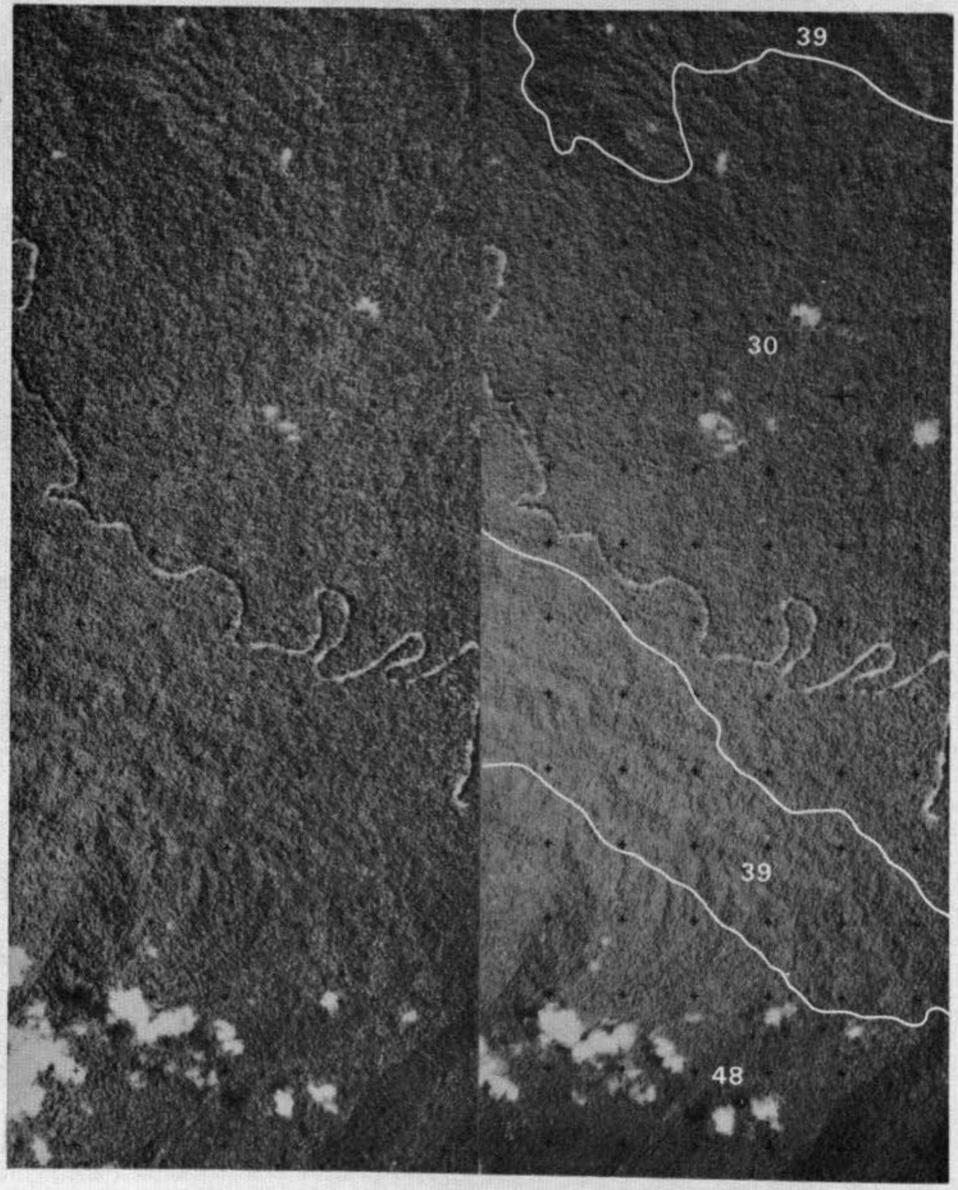

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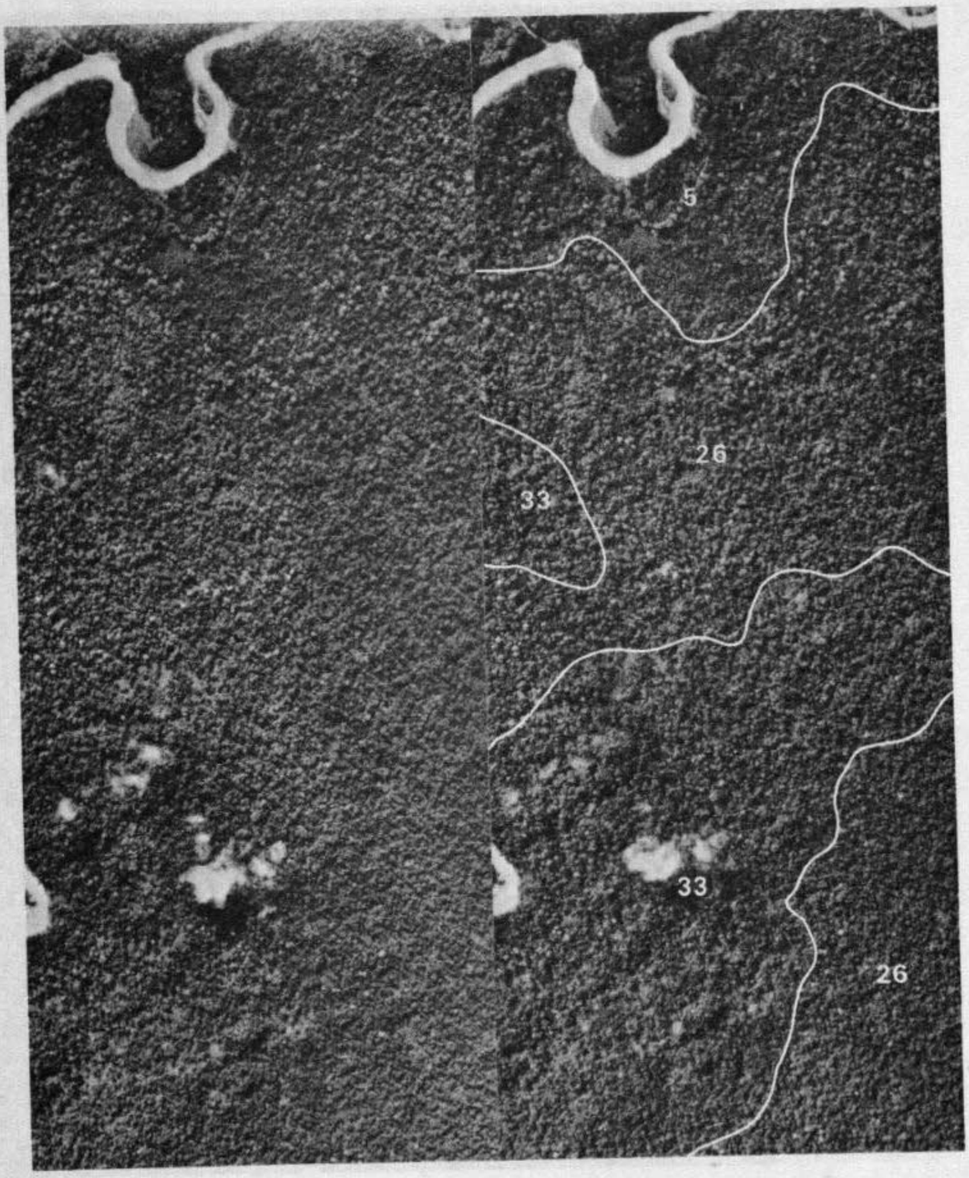

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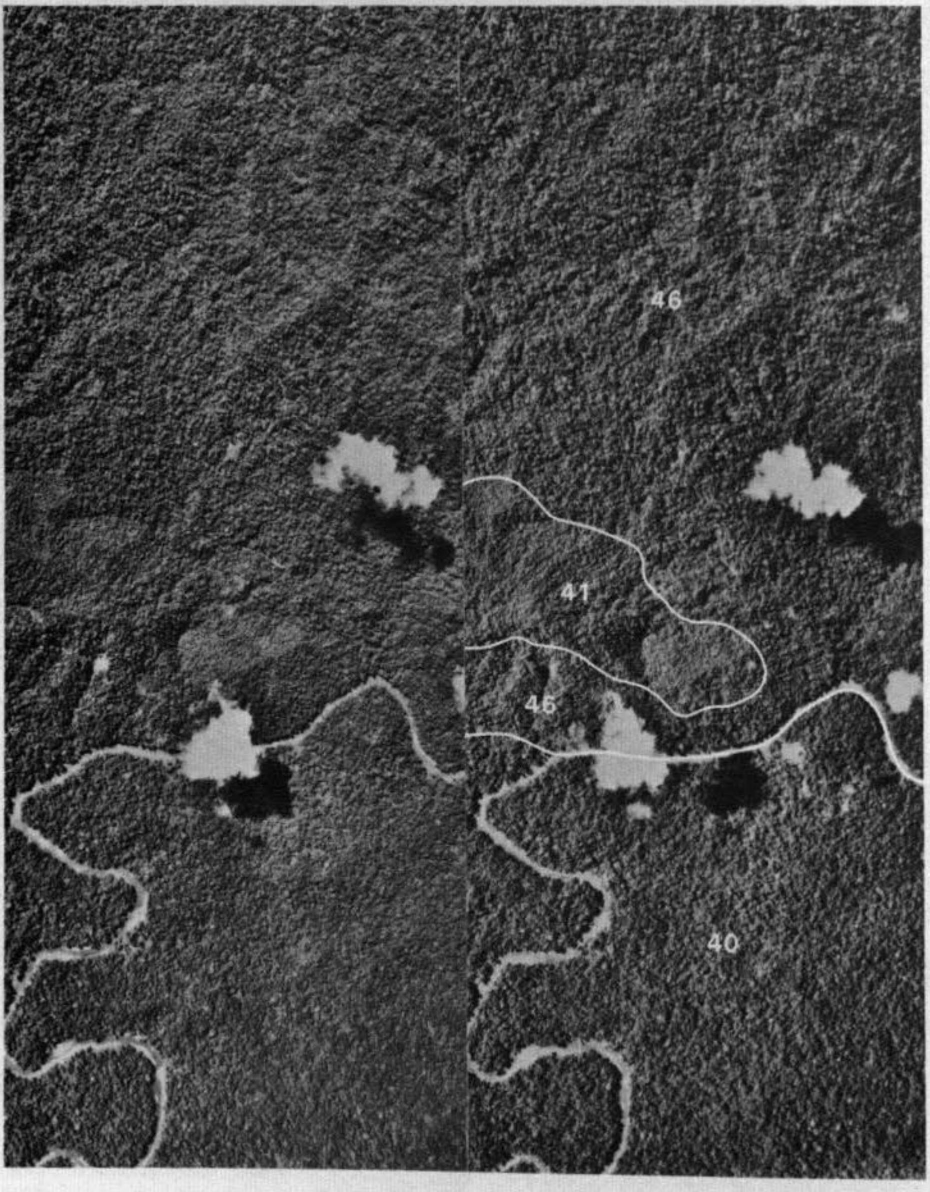

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D.O.S. 3183 Z

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STEREOGRAM 3-7 Mount Ambun. An upthrust block of ultrabasic igneous rocks in the Bidu Bidu Association (41) is clearly distinguishable from the surrounding hills of basic and intermediate igneous rocks within the Mentapok Association (42) (Scale 1 : 40 000)

D.O.S. 3183 Aa

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STEREOGRAM 3-8 The Mentapok Association in the headwaters of the Segama with Mount Tribulation in the south-east. These steep, rugged mountains are composed of basic and intermediate igneous rocks of the Crystalline Basement Formation and the soils are mainly Orthic and Chromic Luvisols, with Cambisols on very steep slopes and ridge tops (Scale 1 : 45 000)

D.O.S. 3183Ab

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STEREOGRAM 3-9 The Orchid Plateau. A dissected remnant of a former erosion surface on rocks of the Crystalline Basement Formation; the soils of the plateau (Orchid Plateau Association,24) are mainly strongly weathered Orthic Acrisols; the steep plateau sides occur within the Mentapok Association (42) (Scale 1 : 40 000)

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Part 2

Geographical background

LOCATION

The area surveyed covers the western parts of the Tawau and Lahad Datu Districts within the Tawau Residency on the east coast of Sabah, Malaysia. These districts lie between longitudes 117° and 118° E and latitudes 4° 10′ and 5° 15′ N and cover an area of approximately 5 700 km^2 (2 200 mi^2). The area consists largely of forested mountainous land. From Cowie Harbour and a narrow zone of lowlands in the south, the land rises sharply to a series of mountain ranges over 600 m (2 000 ft) high. A number of large rivers rise in these mountains, flowing either southwards into Cowie Harbour or eastwards to the Sulu Sea and Darvel Bay.

SETTLEMENT AND POPULATION

There are no towns in the survey area. The administrative and economic centres are Tawau and Lahad Datu which are 19 km and 32 km (12 mi and 20 mi) respectively to the east of the survey boundary. Settlements in the area consist of timber camps, settlement schemes and villages. These are all in the Tawau District, apart from the Bena timber camp which is in the upper Tingkayu Valley in the Lahad Datu District (Text Map 3-1).

The native population at one time was much larger than at present. An expedition that walked from Tenom to Serudong in 1906 to investigate a possible railway route, encountered settlements on the Sesui River (Weedon, 1906). During the present survey, areas of secondary forest were found in the Luasong and Tiagau Valleys and these are probably the sites of former villages. The decline in the native population was hastened during the Confrontation with Indonesia in 1963-1966, when people living in border settlements were moved to settlement schemes near Tawau, on Pulau Sebatik and at Kalabakan. The only villages remaining in the survey area are in the Serudong Valley and on Pulau Sebatik; in the Serudong Valley there is one Murut village of approximately 200 people and on Sebatik, to the east of Bergosong, there are a few small Tidong settlements. On the Sungai Segama there is no settled population, but people from the lower reaches of the river occasionally hunt in the area, and during the Japanese occupation they briefly settled there.

There are 3 settlement schemes in the survey area which are administered by the Sabah Land Development Board. On Pulau Sebatik there are schemes at Bergosong and Tamang, in which Tidongs are settled and at Kuala Merotai on the mainland there is another scheme for Tidongs. At Kalabakan there is a cooperative scheme for both Muruts and Tidongs.

There are 4 timber camps in the western part of the Tawau District and 1 in the western part of the Lahad Datu District. The Wallace Bay Company has its headquarters at Wallace Bay on Pulau Sebatik and owns Kalabakan, Luasong and Brumas Camps and formerly owned Brantian Camp which has now been sold to a contractor who is operating in the Syarikat Pintasan concession in the upper Umas Umas Valley. The population of these camps is diverse and includes Chinese, Indonesians, Philipinos, Ibans and Indians. The total population of the timber camps is about 4 600, including about 150 people at the Bena Camp (Blake, 1972).

COMMUNICATIONS

Roads in the survey area have all been built by timber companies. New roads for timber extraction can be built at the rate of about 1½ km (1 mi) a month, but roads which are no longer used, quickly fall into disrepair and become overgrown. Text Map 3-1 is therefore an illustration of the state of main communications as they were in the middle of 1972. An extensive road system stretches from Umas Umas to Kalabakan and northwards to Luasong and the Brassey Range, leading to the Sungai Kuamut in the Kinabatangan District. Another road system goes north from Umas Umas to Brumas and a branch will eventually reach the watershed of the Segama.

In the western parts of the Lahad Datu District there are few roads. One system crosses the Upper Bole, and another follows the valley of the Upper Tingkayu. They both join the main Tawau to Lahad Datu road.

Where there are no roads, rivers are sometimes an alternative means of travel. The Serudong is navigable for approximately 58 km (36 mi) above Serudong by dug-out canoes; outboard engines are impracticable because of the frequency of rapids. The Kalabakan is navigable to the mouth of the Tiagau, using flat-bottomed boats with outboard engines (Plate 3-1) and to the mouth of the Anjeranjermut by dug-out canoe (Collenette, 1965b). The Tiagau is navigable to the mouth of the Luasong by dug-out canoe. On the Segama, the Ladder Hill Falls, several kilometres below Dismal Gorge, are the limit of navigation. The routes traversed during the course of the survey are shown in Text Map 3-2.

ECONOMY

Before the second world war, there was little economic activity in the survey area. A coal mine was worked in the Silimpopon Valley between 1904 and 1932 and a number of gold prospecting expeditions were made in the Segama and Bole rivers. However, no alluvial deposits worthy of exploitation were found. In 1898 a dredge was towed to the mouth of the Bole but it was unsuitable for the river and the project was soon abandoned (Fitch, 1955). The only agricultural enterprise, apart from shifting cultivation, was an abaca plantation near the present site of Brantian camp.

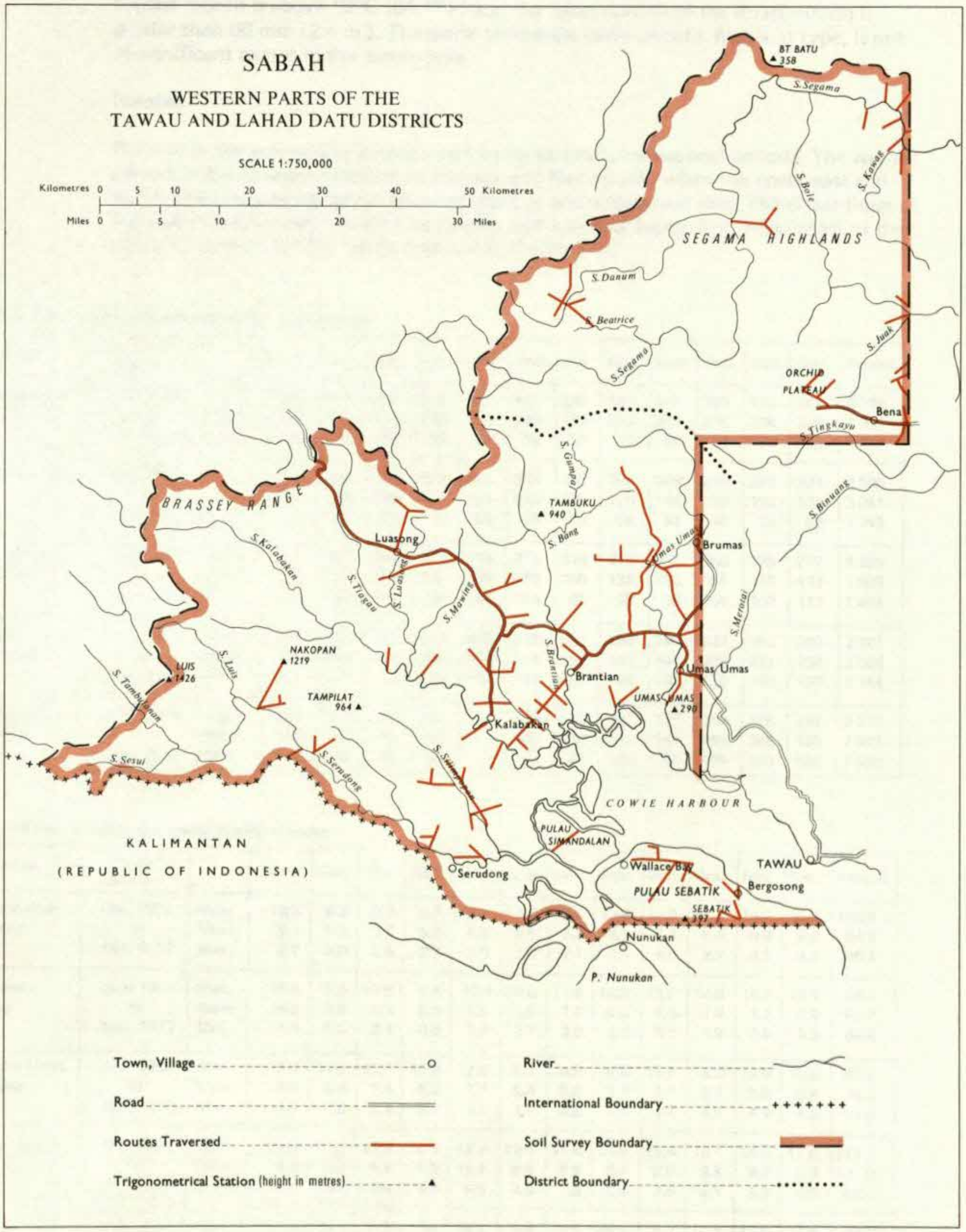
Timber is now the basis of the economy of the survey area, and most of the land has already been divided into timber concessions. The largest concession is owned by the Wallace Bay Company extracting an average of 1 500 cu ft of timber per acre, (Blake, 1972); most of this is exported in log form (Plate 3-2). A mill has recently been opened on Pulau Sebatik to produce chips of mangrove wood for export.

There has been considerable agricultural development in the last 10 years mainly in the form of settlement schemes. On Pulau Sebatik there are 2 settlement schemes which grow rubber. On the mainland there is a scheme at Kalabakan growing coconuts, and another scheme at Kuala Merotai growing oil palm. There is 1 private plantation on Pulau Sebatik which grows cocoa.

Since the establishment of settlement schemes, shifting cultivation has decreased but it is still practiced along the Serudong and Kalabakan rivers and on Pulau Sebatik to the east of Bergosong. Damar and rattan are the main items of jungle produce which are collected. Inshore fishing is the traditional livelihood for the Tidong fishermen of Cowie Harbour.

AREAS TRAVERSED

TEXT MAP 3-2



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CLIMATE

According to Koppen's classification (Trewartha, 1954) the western parts of the Tawau and Lahad Datu Districts have a tropical rainy climate; the mean temperature of the coolest month is above 18°C (64.4°F) and the mean rainfall of the driest month is greater than 60 mm (2.4 in.). The warm temperate rainy climate, highland type, is not of significant extent in the survey area.

Rainfall

Rainfall in the survey area is controlled by twice-yearly monsoonal periods. The wettest periods occur between October to January and May to July when the north-east and south-west trade winds bring unsettled weather and widespread rain. The driest times of the year occur between January and April, and July and September, when most of the rainfall is convectional. (Tables 3-1a and b; Figure 3-1).

TABLE 3-1a Monthly and annual rainfall in millimetres

Station	Years of record		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Kalabakan Camp	Jan. 1961	Max.	490	175	231	234	427	447	239	345	379	320	412	401	2 790
	to	Mean	231	139	150	142	209	243	183	206	210	215	228	229	2 395
	Oct. 1972	Min.	145	76	66	58	76	99	53	79	99	69	103	103	2 041
Wallace Bay	June 1952	Max.	422	155	328	239	315	381	246	368	345	379	307	333	2 305
	to	Mean	124	97	135	136	191	218	179	210	176	203	196	176	2 051
	Nov. 1972	Min.	41	15	53	0	86	69	76	56	53	48	23	83	1 743
Umas Umas Camp	Apr. 1963	Max.	249	295	282	272	254	211	224	218	292	356	328	277	2 380
	to	Mean	149	151	188	148	195	162	150	133	130	185	218	173	1 989
	Sept. 1972	Min.	38	48	117	69	104	104	66	28	36	104	107	117	1 464
Luasong Camp	Feb. 1966	Max.	305	262	300	373	475	315	295	300	340	333	356	295	2 997
	to	Mean	240	166	176	208	264	215	224	163	202	219	231	228	2 564
	Oct.1972	Min.	137	71	61	114	140	114	198	64	150	130	160	150	2 144
Brantian Camp	Oct. 1967	Max.	305	257	132	239	269	239	201	267	221	259	356	241	2 372
	to	Mean	146	128	96	136	146	182	154	149	147	196	249	189	1 873
	July 1972	Min.	76	76	33	64	23	102	84	86	69	109	175	150	1 590

TABLE 3-1b Monthly and annual rainfall in inches

Station	Years of record		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Kalabakan Camp	Jan. 1961	Max.	19.3	6.9	9.5	9.2	16.8	17.6	9.4	13.6	14.9	13.4	16.2	15.8	109.8
	to	Mean	9.1	5.5	5.9	5.6	8.2	9.6	7.2	8.1	8.3	8.3	9.0	9.0	94.4
	Oct. 1972	Min.	5.7	3.0	2.6	2.3	3.0	3.9	2.1	3.1	4.0	2.7	4.1	4.1	80.3
Wallace Bay	June 1952	Max.	16.6	5.9	12.9	9.4	12.4	15.0	11.9	18.8	13.6	14.9	16.2	13.1	94.9
	to	Mean	4.8	3.8	5.3	5.3	7.5	8.5	7.0	8.2	6.9	7.9	7.7	6.9	80.7
	Nov. 1972	Min.	1.6	0.6	2.1	0.0	3.4	2.7	3.0	2.3	2.1	1.9	0.9	3.3	68.6
Umas Umas Camp	Apr. 1963	Max.	9.8	11.6	11.1	10.9	12.5	8.3	8.8	8.6	11.5	14.0	12.9	10.9	93.7
	to	Mean	5.9	5.9	7.4	5.8	7.7	6.4	5.9	5.2	5.1	7.3	8.6	6.8	78.3
	Sept. 1972	Min.	1.5	1.9	5.4	2.7	4.1	4.1	2.6	1.1	1.4	4.1	4.2	4.6	57.6
Luasong Camp	Feb. 1966	Max.	12.0	10.3	11.8	14.7	18.7	12.4	11.6	11.8	13.4	13.1	14.0	11.6	118.0
	to	Mean	9.4	6.5	6.9	8.2	10.4	8.5	8.8	6.4	8.0	8.6	9.1	9.0	101.0
	Oct. 1972	Min.	5.4	2.8	2.4	4.5	5.5	4.5	7.8	2.5	3.5	5.1	6.3	5.9	84.4
Brantian Camp	Oct. 1967	Max.	12.0	10.1	5.2	9.4	10.6	9.4	7.9	10.5	8.7	10.2	14.0	9.5	93.3
	to	Mean	5.7	5.0	3.7	5.3	5.7	7.1	6.0	5.8	5.7	7.7	9.8	7.4	73.7
	July 1972	Min.	3.0	3.0	1.3	2.5	0.9	4.0	3.3	3.4	2.7	4.3	6.9	5.9	62.6

The driest parts of the survey area are the coastal lowlands. Brantian is the driest station with a mean annual rainfall of 1 873 mm (73.7 in.), but Umas Umas has the lowest

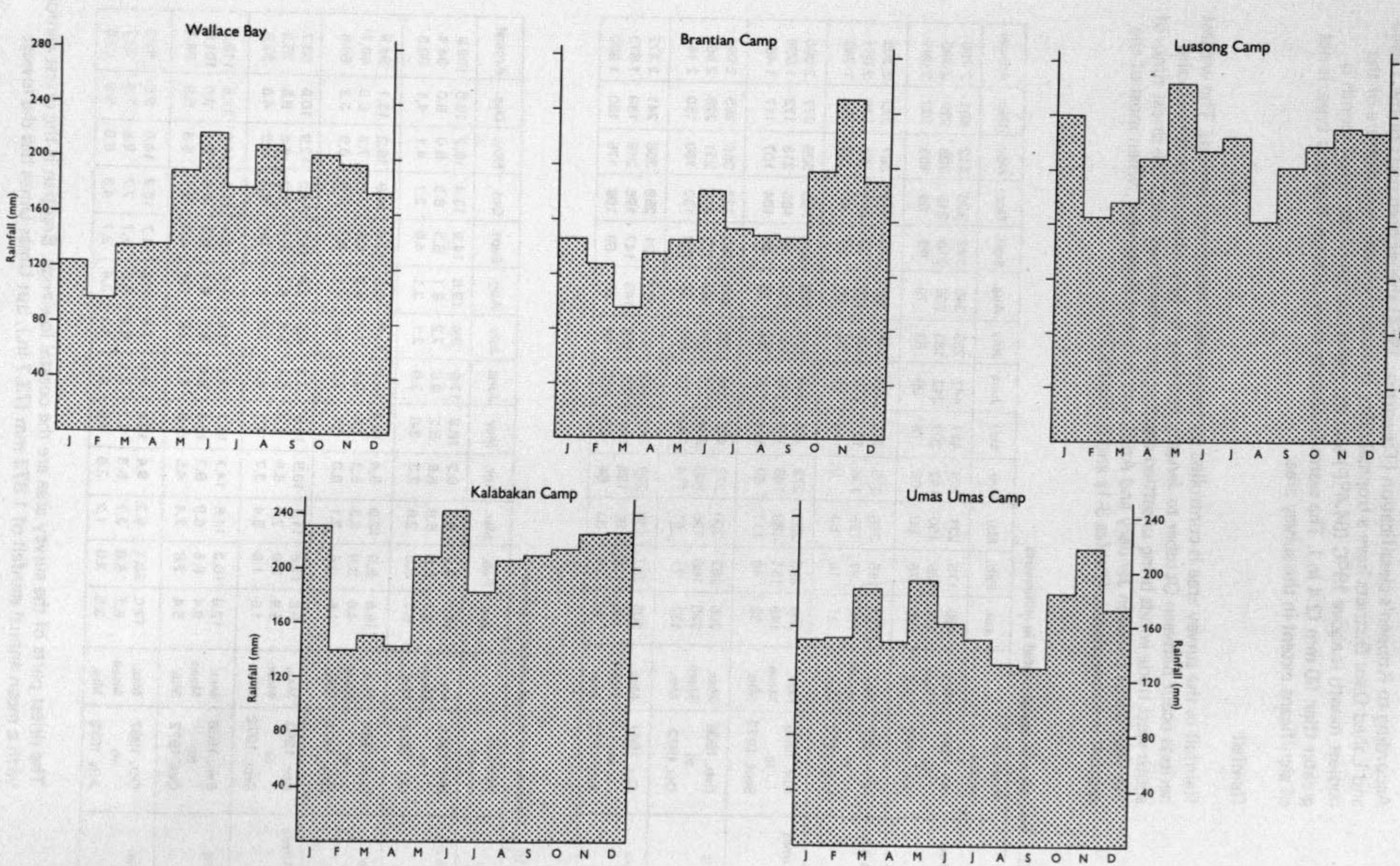

FIGURE 3-1 Mean monthly rainfall (mm)

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minimum annual total of only 1 464 mm (57.6 in.). The reason for the relative dryness of the coastal lowlands is due in part to the rainshadow effect of the surrounding mountains and in part to the low relief which causes less convectional rain than the mountains. Rainfall increases inland and Kalabakan has an annual average of 2 395 mm (94.4 in.) whilst Luasong, which is still higher and further inland, is the wettest station with an annual average of 2 564 mm (101 in.). The rainfall of much of the survey area is likely to be comparable to or greater than that of Luasong.

Temperature

There are no temperature records for the survey area, but figures which are probably representative of the coastal lowlands are available for Tawau (Table 3-2). April and May are the warmest months and December to February are the coolest months, but the temperature difference between these periods is only 1.1°C (2°F). The diurnal variations in temperature are less than 7.8°C (14°F).

TABLE 3-2 Mean monthly temperatures at Tawau in °C and °F

	Jan. °C	Jan. °F	Feb. °C	Feb. °F	Mar. °C	Mar. °F	Apr. °C	Apr. °F	May °C	May °F	June °C	June °F	July °C	July °F	Aug. °C	Aug. °F	Sept. °C	Sept. °F	Oct. °C	Oct. °F	Nov. °C	Nov. °F	Dec. °C	Dec. °F	Mean °C	Mean °F
Mean maximum	29	85	30	86	31	87	32	89	32	89	32	89	32	89	32	89	32	89	31	88	31	87	30	86	31	88
Mean minimum	23	74	23	74	24	75	25	77	25	77	24	75	24	75	24	75	24	75	24	75	24	75	23	74	24	75
Mean monthly	27	80	27	80	27	81	28	83	28	83	28	82	28	82	28	82	28	82	28	82	28	81	27	80	28	82

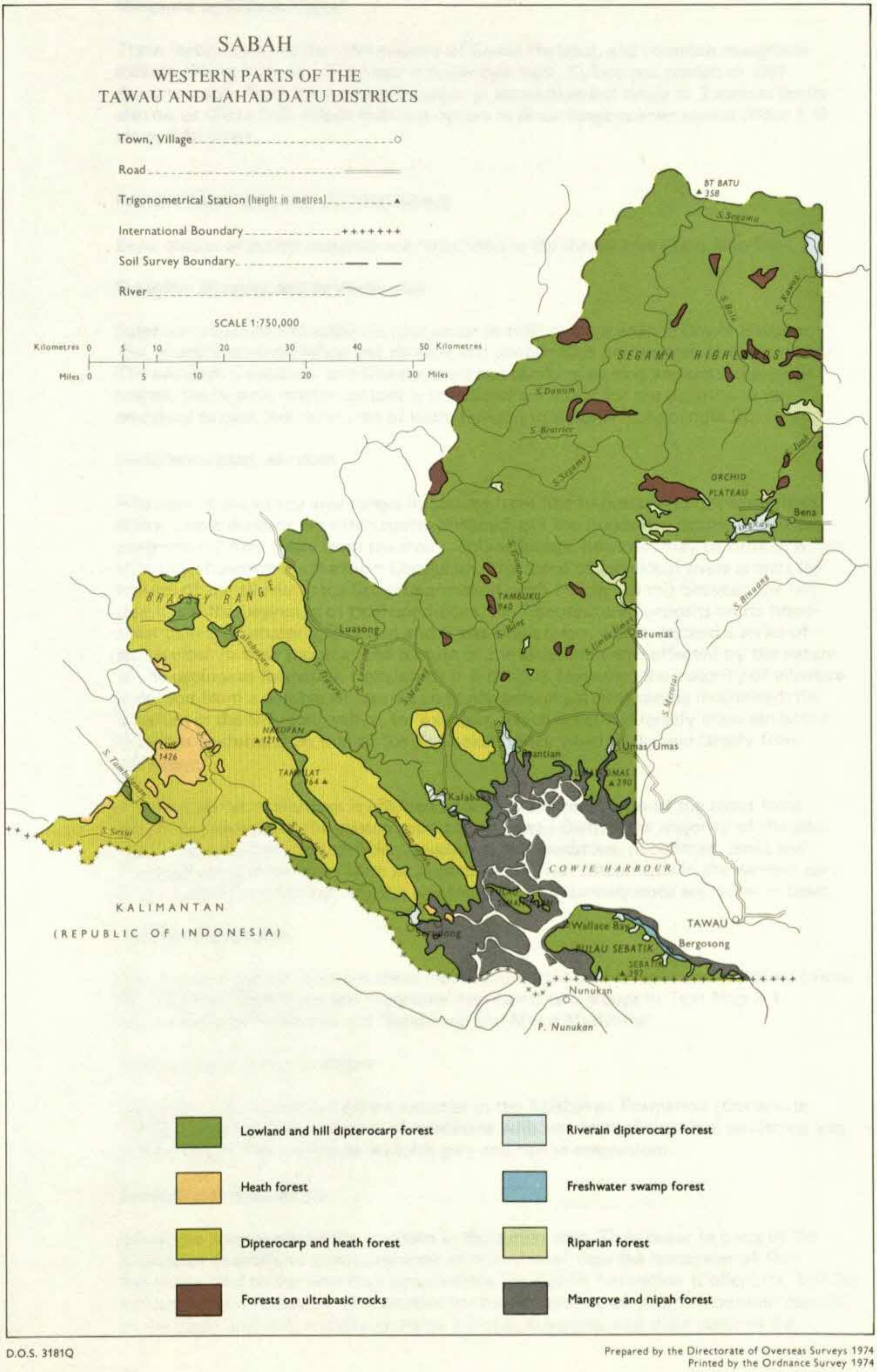
VEGETATION

Most of the survey area is still covered by its natural vegetation of tropical rain forest although extensive areas in the south and east have been logged in the past 20 years. Eight forest types are recognised (Text Map 3-3). The description of these forest types is based in part on tree plots examined by the Forest Department in the course of the soil survey. For further information, the reader is referred to Fox (1972) and Wood and Meijer (1964).

Lowland and Hill Dipterocarp Forest

This is by far the most extensive forest type in the survey area. It varies considerably according to such factors as soil conditions, landform and the colonisation pattern of individual tree species, and consequently only limited statements can be made concerning its composition. Dipterocarp forest has a number of storeys. The upper discontinuous storey stands at 30-45 m (100-150 ft) above the ground, although there are occasional larger trees up to 50 m (200 ft) high. The main storey stands at about 20-30 m (70-100 ft) from the ground and consists of young trees of the upper storey and some species which do not generally grow higher. The lower storey consists of saplings of the upper two storeys and small trees and shrubs which are tolerant of shade. The lowest storey is generally sparse and consists mainly of young seedlings, lianas, and ferns.

The forest is composed largely of the family Dipterocarpaceae of which 10 genera, comprising about 150 species, are known to occur in Sabah. Of these genera *Shorea, Parashorea, Hopea, Dipterocarpus* and *Dryobalanops* are common in the survey area. Judging by the data from tree plots and the logs exported by the Wallace Bay Company (Blake, 1972), the commonest dipterocarps on sandstone and mudstone hills belong to the genus *Shorea,* subgenus *Rubroshorea*, known locally as red seraya. Species identified include *Shorea parvifolia, S. leptoclados, S. leprosula, S. pauciflora, S. beccariana* (all red seraya), *S. multiflora* and *S.faguetiana* (yellow seraya), *Parashorea tomentella* and *P. malaanonan* (white seraya) and *Dipterocarpus* spp. (*keruing*). Non-dipterocarps are an important component of the dipterocarp forest and they include the following genera: *Koompassia, Barringtonia, Castanopsis, Calophyllum, Diospyros, Eugenia,* and *Dysoxlyum.*



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Mangrove and Nipah Forest

These forests occur in the tidal swamps of Cowie Harbour, and common mangroves include *Rhizophora* spp, *Bruguiera* spp, *Ceriops tagal, Xylocarpus granatum* and *Avicennia* spp. These trees generally occur in association but single or 2-species stands also occur (Plate 3-3). *Nipah fruticans* occurs in dense single-species stands (Plate 3-4) along tidal rivers.

PARENT MATERIALS OF THE SOILS

Eight classes of parent materials are recognised in the survey area (Text Map 3-4).

Sulphidic alluvium and sulphidic peat

Sulphidic alluvium and sulphidic peat occur in tidal swamps around Cowie Harbour. The deposits are both saline and alkaline and contain high percentages of total sulphur. The alluvium is medium- and fine-textured and contains varying amounts of organic matter; the organic matter content is sometimes sufficient for the deposits to be described as peat (see definition of histic horizon in Volume 5, Appendix 2).

Undifferentiated alluvium

Alluvium in the survey area ranges in texture from fine to coarse and it is sometimes stony. Levee deposits are often coarse-textured, but the floodplain deposits become progressively finer away from the rivers. This sequence, however, may be broken where tributary streams cross the main floodplain. The speed of individual rivers affects the texture of the alluvium; the Sungai Kalabakan, with 16 km (10 mi) between the last rapids and the beginning of tidal conditions, has finer-textured deposits on its floodplain than the Serudong, Brantian and Umas Umas rivers, which descend a series of rapids close to their mouths. The texture of the alluvium is also affected by the nature of the geological formation from which it is derived. However, the majority of alluvium is derived from a number of sources and only general patterns can be recognised; the alluvium in the Serudong valley, for example, which is derived largely from sandstone, is coarser-textured than that of the Kalabakan valley which is derived largely from mudstone.

The base status of alluvium is affected largely by the base status of the rocks from which it is derived. In the western part of the Tawau District the majority of the alluvium is derived from base-deficient sandstone and mudstone; in contrast, basic and intermediate igneous rocks form large parts of the river catchments in the western part of the Lahad Datu District and the alluvial deposits in consequence are richer in bases.

Mudstone/sandstone

This group of parent rocks has three main subdivisions in this report, as indicated below. One of these, 'Sandstone and mudstone' represents two groups in Text Map 3-4: 'Sandstone and Mudstone' and 'Sandstone and Minor Mudstone'.

Mudstone and minor sandstone

Mudstone is the dominant parent material in the Kalabakan Formation (Collenette, 1965b). This formation consists of mudstone with rare beds of siltstone, sandstone and conglomerate. The mudstone is bluish grey and rich in magnesium.

Sandstone and mudstone

Sandstone and mudstone are common in the survey area. They occur in parts of the Kalabakan Formation, producing areas of higher relief than the remainder of that formation, and to the west they occur within the Kapilit Formation (Collenette, 1965b), forming areas of subdued relief relative to the surrounding sandstone mountain cuestas. In the south and east, notably on Pulau Sebatik, sandstone and shale occur in the

Kalumpang Formation; they also occur in the Umas Umas Formations near Umas Umas Camp (Kirk, 1962). In the Kapilit, Kalabakan and Umas Umas Formations the sandstone is mainly siliceous and low in bases. Some of the sandstone of the Kalumpang Formation on Pulau Sebatik is described as feldspathic (Kirk, 1962). The mudstones are generally grey or black, and in the Kalumpang and Umas Umas Formations, are carbonaceous (Kirk, 1962).

Sandstone, with minor amounts of mudstone, is the dominant parent material in the Kapilit Formation (Collenette, 1965b). The sandstone is siliceous, hard and grey and forms thick beds of mudstone.

Mudstone, sandstone and miscellaneous rocks

Mudstone, sandstone and miscellaneous rocks occur within the Chert-Spilite and Kuamut Formations (Leong, 1972) and have also been recognised during this soil survey in the vicinity of Kalabakan within the Kalabakan Formation and to the south of the lower reaches of the Serudong within the Simengaris Formation (Collenette, 1965b). These rocks often occur as slump deposits (Leong, 1972) composed of boulders of assorted rocks in a mudstone matrix. Sandstone is the rock most commonly encountered in the mudstone matrix, but tuffaceous rocks, chert, ultrabasic and basic intrusive igneous rocks, basalt, spilite and volcanic agglomerate also occur in varying proportions. The mixture of rocks is so complex that a number of rock types are commonly encountered in a single exposure. Individual rock types are locally dominant. A current theory is that the slumping which gave rise to these deposits occurred in a subduction zone between the Australian and Asian land masses (Hamilton, 1972).

Parts of the Kuamut and Chert-Spilite Formations appear to be bedded, particularly in areas of high relief. In such areas, sandstone and mudstone are the most common rocks, but the same range of rocks recognised in the slump deposits also occur.

In the slump deposits, mudstone is commonly grey or black, but red and green varieties also occur. Soils derived from these mudstones frequently have high levels of exchangeable magnesium. Sandstone is commonly siliceous and low in bases but in some areas, notably on the watershed between the Segama and Kinabatangan, it has a greenish tint and is probably tuffaceous (Fitch, 1955). In the field it is sometimes difficult to distinguish a tuff from sandstone or mudstone. Soils derived from parent material identified as tuff in the Danum Valley had very high magnesium levels, but intermediate and acid tuffs almost certainly occur as well. Basalt and spilite both occur; they have similar chemical compositions (Table 3-3). Chert is commonly red or purple but is sometimes brown, grey or white; it generally occurs as very large boulders.

Because the slump deposits are unconsolidated and contain high clay contents they are subject to shearing and slipping. This may well present problems when roads are built.

Ultrabasic igneous rocks

Ultrabasic igneous rocks identified during the survey were serpentinite and peridotite, but other rocks known to occur are dunite, pyroxenite, troctolite and hornblendite (Fitch, 1955, Kirk, 1962 and Leong, 1972). Ultrabasic rocks contain large amounts of iron and magnesium oxides (Table 3-3).

Basic and intermediate igneous rocks

The majority of the basic and intermediate igneous rocks occur in the Crystalline Basement Formation (Leong, 1972). Gabbro, dolerite, diorite and metamorphosed forms of these rocks were identified during the course of the survey. Acid igneous rocks are also known to occur in this formation (Leong, 1972), but were not encountered. These rocks have higher amounts of silica, aluminium, calcium, potassium and sodium than ultrabasic rocks, reflecting the greater proportion of feldspars in their composition (Table 3-3).

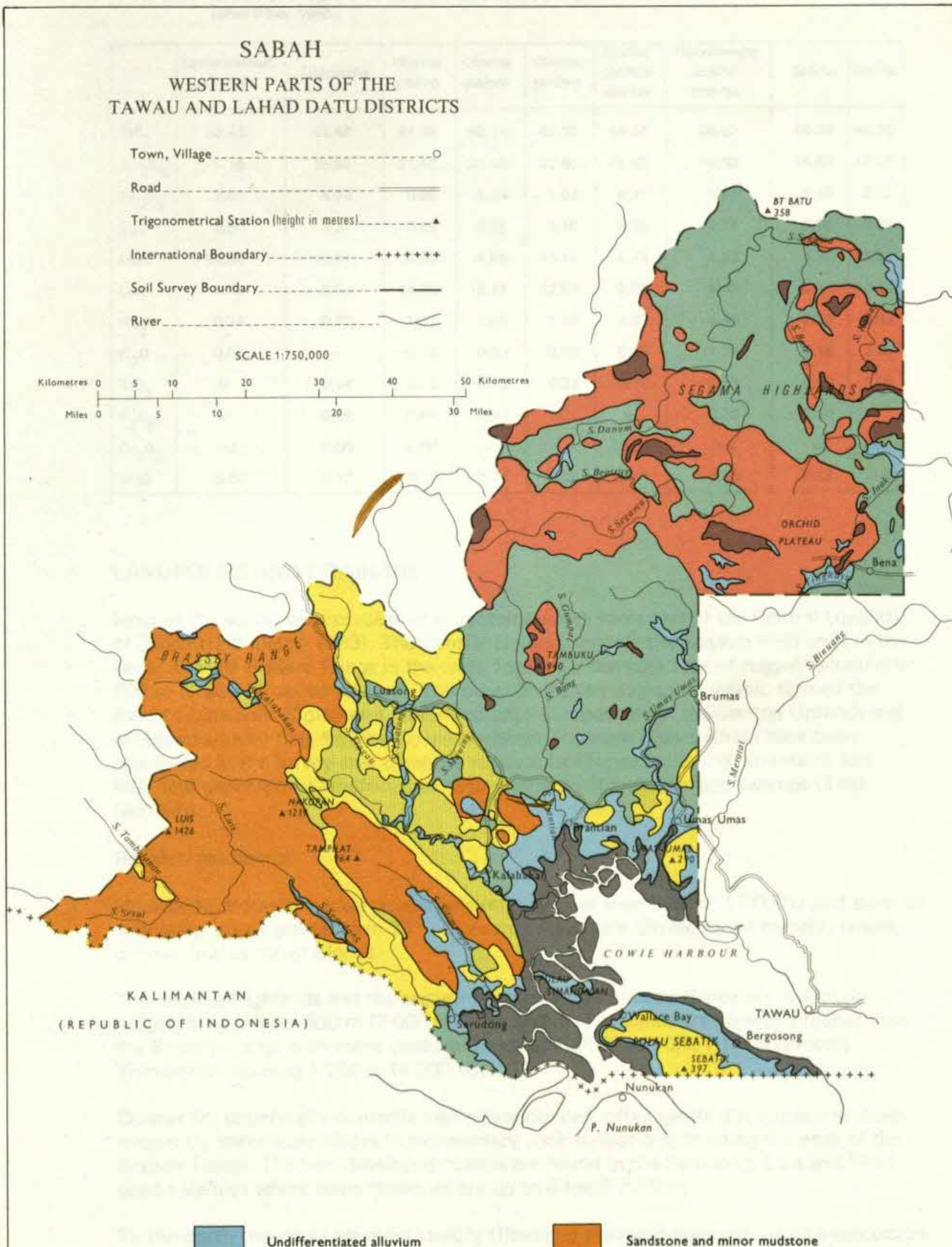

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TABLE 3-3 **Percentage composition of igneous rocks from the Segama Valley and the Darvel Bay area (after Fitch, 1955).**

	Serpentinised dunite	Troctolite	Olivine gabbro	Olivine gabbro	Olivine gabbro	Uralite gabbro-diorite	Hornblende-quartz diorite	Spilite	Spilite
SiO_2	36.43	41.46	47.08	46.17	46.33	45.31	66.03	44.89	49.30
$A1_2O_3$	6.18	16.29	21.46	37.16	22.60	16.53	16.63	15.80	12.89
Fe_2O_3	2.89	4.74	0.86	1.64	1.03	8.33	1.51	1.40	3.72
FeO	5.80	3.37	3.69	0.88	3.18	6.26	1.77	9.10	3.79
MgO	32.86	16.97	9.00	4.55	10.16	5.44	1.63	4.76	3.97
CaO	4.40	9.37	14.02	15.24	12.84	8.96	4.48	5.44	10.49
Na_2O	0.34	0.12	1.81	1.92	1.40	2.97	4.40	5.53	5.59
K_2O	0.05	—	0.22	0.03	0.52	0.48	1.27	0.18	2.05
TiO_2	tr	0.14	0.22	0.13	0.32	3.16	0.53	4.06	1.04
P_2O_5	tr	0.05	0.01	0.23	tr	tr	0.19	1.10	—
Cr_2O_3	nd	0.06	0.08	—	—	nd	nd	nd	nd
MnO	0.04	0.12	0.12	0.01	0.06	0.11	0.10	0.08	nd

LANDFORMS AND DRAINAGE

Most of the survey area consists of mountains which form part of the Central Uplands of Sabah (Collenette, 1963). The Central Uplands include the Segama Highlands in the north and the Brassey Range in the west, forming a complex area of rugged terrain over 300 m (1 000 ft) above sea-level. The other broad physiographic region, termed the Eastern Lowlands (Collenette, 1963) includes the foothills of the Central Uplands and extensive alluvial flats fringing Cowie Harbour. The main classes which have been recognised in the survey area comprise residual landforms including mountains and hills, and depositional landforms including terraces, floodplains and swamps (Text Map 3-5).

Residual landforms

Mountains. Mountains have an absolute relief greater than 300 m (1 000 ft) and steep or very steep slopes greater than 25°. Three main types are distinguished namely, ranges, cuestas, and upthrust blocks.

The Segama Highlands and the eastern portion of the Brassey Range are mountain ranges rising to over 600 m (2 000 ft). The Segama Highlands are generally higher than the Brassey Range with many peaks of more than 900 m (3 000 ft) and Gunong Tribulation reaching 1 260 m (4 200 ft).

Cuestas are structurally controlled with pronounced, often gentle dip slopes and steep, frequently sheer scarp slopes in sedimentary rock formations, forming the west of the Brassey Range. The best developed cuestas are found in the Serudong, Luis and Silim-popon Valleys where some dipslopes are up to 8 km(5 m) long.

To the north the strata are more steeply tilted and the mountains consist of a succession of short, steep, dip and scarp slopes. These mountain cuestas are higher than the rest of the Brassey Range, the highest peak being Gunong Luis at 1 426 m (4 706 ft). A number of other peaks, including Nakopan and Tampilat are over 900 m (3 000 ft).

Upthrust blocks are intrusions of ultrabasic igneous rocks which protrude through and stand above surrounding mountains. Three such upthrust blocks are Gunong Ambun (Plate 3-14), Gunong Danum and Gunong Beeston, which have rounded, dome-like topography in contrast to the surrounding rugged and deeply dissected mountain ranges. Gunong Tambuku is also an upthrust block, but unlike the others it is a towering pyramidal peak with steep, often sheer sides.

Steep hills. These have an absolute relief of less than 300 m (1 000 ft) and slopes of of more than 25°. Steep hills are most widespread in the Kalabakan catchment, on Pulau Sebatik and in the lower Serudong Valley. In the Kalabakan catchment, and on Sebatik, these hills are remnants of several dissected erosion surfaces with accordant summit levels (Stereogram 3-4). The lower erosion surface is in the Kalabakan Valley and is between 30 and 60 m (100-200 ft) above sea level. Higher surfaces occur to the east of the Kalabakan Valley and on Sebatik between 90 and 210 m (300 and 700 ft). They are steep hills with incised valleys and amplitudes of generally less than 45 m (150 ft). In some areas, beds of resistant sandstone form higher ridges which stand out above the surrounding hills. In the lower Serudong Valley, steep high ridges with amplitudes up to 300 m (1 000 ft) and narrow valleys are composed of the same sandstone that forms mountain cuestas to the north. The lack of structural control in this area suggests that it is a fracture zone, related to the synclinal folding that formed the adjacent mountain cuestas.

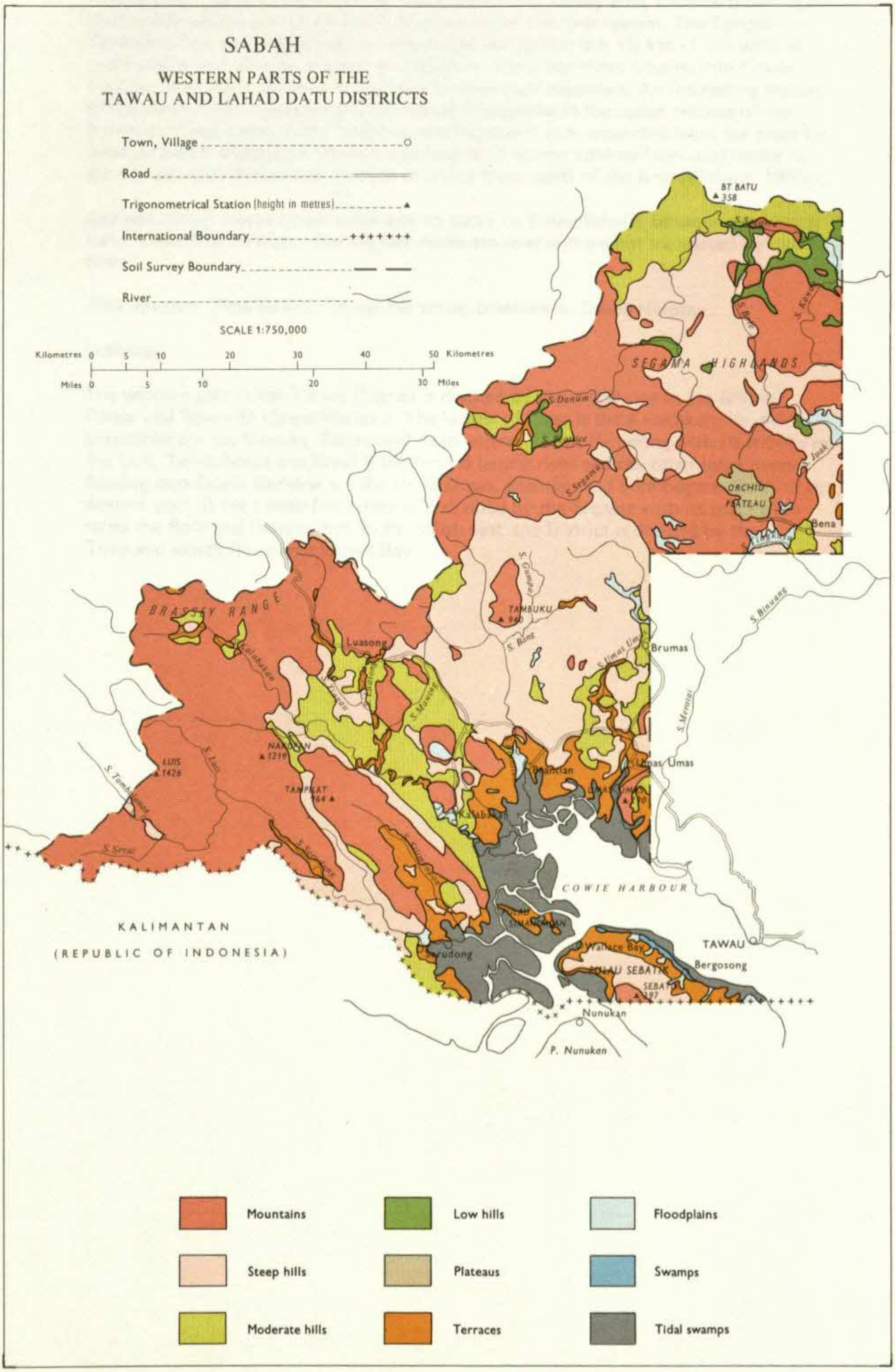
Moderate hills. Moderate hills have amplitudes of less than 150 m (500 ft) and slopes generally between 10° and 25°. In the Kalabakan area, the hills are formed of mudstone and represent the less dissected seaward portions of the two erosion surfaces described in the preceding section. The landscape consists of ridges and hills separated by valleys up to 60 m (200 ft) wide. Elsewhere, moderate hills are generally associated with slump deposits and lack well defined relief and drainage patterns. On the edge of the survey area, notably in the Umas Umas Valley, the upper Danum and on the watershed of the Segama and Kinabatangan, the hills generally have amplitudes of less than 75 m (250 ft) with slopes between 10° and 20°. In the interior of the survey area, the hills are generally steeper and higher with relative relief up to 225 m (750 ft) and slopes ranging from 15° to greater than 25° (Stereogram 3-6).

Low hills. Low hills have a relative relief of less than 75 m (250 ft) and slopes of less than 15°; they are most extensive in the upper Danum lowlands and in the north-east of the survey area where they are formed on slump deposits. The subdued relief with accordant hill tops suggests that they are dissected erosion surfaces, similar to those of the Kalabakan area.

Plateaus. The Orchid Plateau (Plate 3-15 and Stereogram 3-9) is a remarkable feature. It is 40 km^2 (14 mi^2) in extent and stands at approximately 300 m (1 000 ft) above the Tingkayu and Segama Rivers, to which a number of streams descend in a series of spectacular falls. It has a table-like form with steep sides and a weakly dissected surface with accordant hilltops. The plateau was originally thought to be a lava flow (Fitch, 1955), but it is now recognised to be the remnant of a high-level erosion surface (Wilford, 1968c and d; Wong, 1968).

Depositional landforms

Terraces. Recent uplift of the land has resulted in a series of narrow terraces in the river valleys and a broad terrace along the coastline of Cowie Harbour. In the river valleys there are a number of terrace levels; the highest identified is about 25 m (80 ft) above the river at Luasong but the main level appears to be 6-9 m (20-30 ft) above the rivers in most valleys (Plate 3-5). Rejuvenation of the river system is active and all rivers in the survey area have extensive rapids, and the floodplains are often so high above the rivers that they are better described as low terraces. The coastal terrace fringes Cowie Harbour both on the mainland and on Pulau Sebatik; it is up to 6.4 km (4 mi) wide. Only one terrace level has been recognised but this rises from 3 m (10 ft) above sea level at the coast to approximately 30 m (100 ft) inland. There is a corresponding increase in dissection, resulting in a change from an almost level coastal plain to a series of low hills inland. The Silimpopon Valley consists of low, rolling hills with accordant summit levels similar to parts of the coastal terrace. It is possible, however, that the area is a dissected erosion surface, but as the soils are deep and stone free it is difficult to judge whether they are derived from terrace alluvium or deeply weathered sandstone.



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Floodplains. There are no extensive floodplains in the survey area, because recent uplift of the land has caused considerable rejuvenation of the river system. The Sungai Kalabakan has the longest and best developed floodplain; it is 1½ km (1 mi) wide in parts with a well developed series of meanders. The other rivers flowing into Cowie Harbour have short floodplains and poorly developed meanders. An interesting feature of the survey area is the presence of mature floodplains in the upper reaches of the Brantian, Umas Umas, Juak, Tingkayu and Segama Rivers, separated from the coast by series of rapids and gorges. These are remnants of former land surfaces unaffected by the rejuvenation of the river systems resulting from uplift of the land (Wilford, 1968d).

Swamps. Small areas of freshwater swamp occur on Pulau Sebatik between the coastal terrace and tidal swamps; they are just above sea level and are not inundated by high tides.

Tidal swamps. Tidal swamps fringe the whole coastline of Cowie Harbour.

Drainage

The western part of the Tawau District is drained by rivers that rise in the Brassey Range and flow into Cowie Harbour. The largest of these is the Kalabakan; its main tributaries are the Mawing, Tiagau and Anjeranjermut. The Serudong with its tributaries the Luis, Tambulanan and Sesui is the second largest river and the other large rivers flowing into Cowie Harbour are the Umas Umas, Brantian and Silimpopon. Much of the western part of the Lahad Datu district is drained by the Segama with its main tributaries the Bole and Danum, but, in the south east, the District is drained by the Tingkayu which flows into Darvel Bay.

Part 3

The soil associations

The interaction of the soil-forming factors, climate, vegetation, parent materials and landforms, has been described in Volume 1, Part 3, and the classification of the resulting soils has been summarised in terms of the FAO classification scheme and in terms of mapping units, called soil associations. Fifty-one associations are defined in Volume 1 and of these, 21 are recognised in the western parts of the Tawau and Lahad Datu Districts. They are described in the following order:

1. Soils on alluvium (7 associations)
2. Soils on sandstone/mudstone (11 associations)
3. Soils on igneous rocks (4 associations)

Groups 2 and 3 are further subdivided as shown below:

Soils on sandstone/mudstone

1. Soils on mudstone and minor sandstone (as in Text Map 3-4)
2. Soils on sandstone and mudstone ('Sandstone and mudstone' and 'Sandstone and minor mudstone' in Text Map 3-4)
3. Soils on mudstone, sandstone and miscellaneous rocks (as in Text Map 3-4)

Soils on igneous rocks

1. Soils on basic and intermediate igneous rocks
2. Soils on ultrabasic igneous rocks

All soil profiles to which reference is made, are contained in Volume 5, Appendix 1.

Soil associations on alluvium

Seven soil associations have been described on alluvium; they occur in tidal swamps, swamps, floodplains, valley floors and terraces (Table 3-4).

TABLE 3-4 Soil associations on alluvium

Association	Landforms	Parent materials	Soil units	Soil families
Weston	Tidal swamps	Sulphidic alluvium	Thionic Fluvisol Thionic-humic Gleysol	Weston Bergosong
		Sulphidic peat Alluvium	Dystric Histosol Dystric Cambisol	Arang Kelawat
Sapi	Swamps	Alluvium	Humic Gleysol	Guan

TABLE 3-4 (continued)

Association	Landforms	Parent materials	Soil units	Soil families
Kinabatangan	Floodplains	Alluvium	Dystric Gleysol Humic Gleysol Gleyic Acrisol Gleyic Luvisol	Koyah Guan Inanam Buran
Labau	Valley floors	Alluvium	Dystric Gleysol Gleyic Acrisol Ferric Acrisol Orthic Acrisol Gleyic Cambisol Dystric Fluvisol	Koyah Inanam Lumisir Paliu Luba Tenghilan
Karamuak	Valley floors and terraces	Alluvium	Gleyic Luvisol Gleyic Cambisol Orthic Luvisol Xanthic Ferralsol	Buran Sinsulod Darau Tungau
Brantian	Terraces, low hills and minor valley floors	Alluvium	Gleyic Acrisol Ferric Acrisol Orthic Acrisol	Inanam Lumisir Paliu
Kepayan	Terraces	Alluvium	Orthic Podzol Gleyic Podzol	Silimpopon Baiayo

WESTON ASSOCIATION

The Weston Association fringes the whole coastline of Cowie Harbour in a belt which is between 1 km (½ mi) and 22 km (14 mi) wide (Plate 3-6). It covers a total area of 411 km^2 (158 mi^2). The following account is based on observations in the tidal swamps of Cowie Harbour, between Pulau Simandalan and the Kalimantan border.

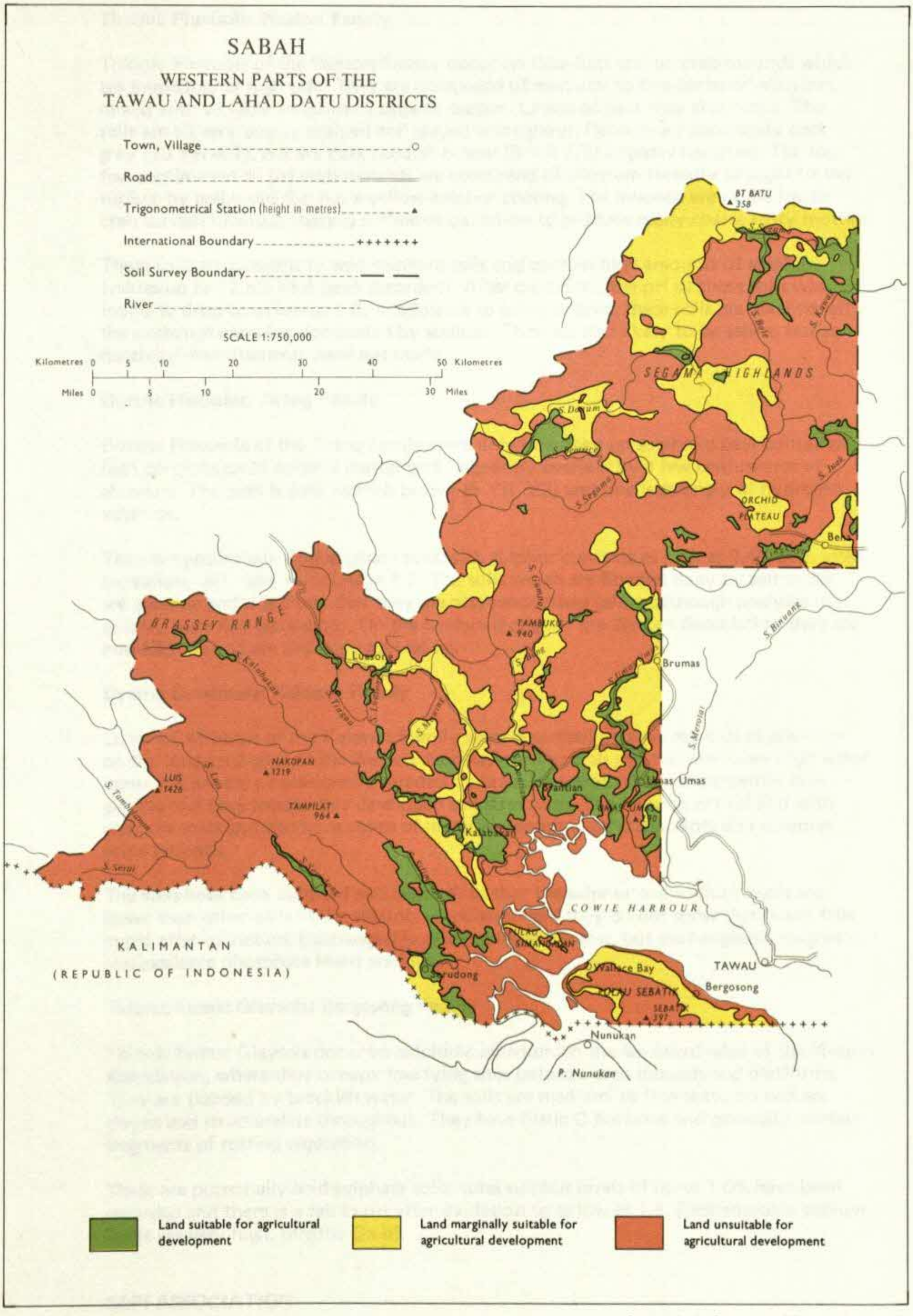
The soils are formed on fine- to medium-textured, mainly sulphidic alluvium, with minor amounts of sulphidic peat. Thionic Fluvisols, Dystric Histosols, Dystric Cambisols and Thionic-humic Gleysols have been defined.

Most of this association is under mangrove forest which includes *Rhizophora* spp, *Bruguiera* spp, *Ceriops tagal*, *Xylocarpus granatum* and *Avicennia* spp. These trees generally occur in association, but single or 2- species stands also occur. For example *Rhizophora* spp frequently form single- species stands on the edge of tidal channels (Plate 3-3) and sometimes occur in association with *Bruguiera* spp. The land surface is finely dissected by gullies and channels. Crab mounds are a striking feature, being low and infrequent on the seaward fringe, but becoming taller and more common towards the land. These crab mounds are usually not more than 1 m (3 ft) in height and are generally submerged at high tide.

In mangrove forests Thionic Fluvisols on sulphidic alluvium are the dominant soils, whilst Dystric Histosols occur sporadically on sulphidic peat.

Forests of nipah (*Nypa fruticans*) (Plate 3-4) occur in the lower tidal courses of rivers, but they do not occur on shorelines. Crab mounds cover about half of the surface, separated by flats and shallow gullies and are almost submerged at high tide. The soils on flats and mounds are classified as Thionic Fluvisols.

Mixed associations of *Nypa fruticans, Heritiera globosa, Xylocarpus granatum, Oncasperma* spp. and *Acrostrichum aureum* occur sporadically in transition zones between the nipah forest and the mainland. At low tide, the land stands about 3 m (10 ft) above water level. Crab mounds cover most of the surface and in places coalesce into platforms which extend above the high tide mark. The soils are classified as Dystric Cambisols. The crab mounds and platforms are occasionally separated by areas of flat land with Dystric Histosols and Thionic-humic Gleysols.



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Thionic Fluvisols: Weston Family

Thionic Fluvisols of the Weston Family occur on tidal flats and on crab mounds which are inundated at high tide. They are composed of medium- to fine-textured alluvium, mixed with variable amounts of organic matter. Layers of peat may also occur. The soils are all very poorly drained and gleyed throughout. Colours are commonly dark grey (10 YR 4/1), but are dark reddish brown (5 YR 2/2) in peaty horizons. The top few centimetres of the crab mounds are composed of alluvium recently brought to the surface by crabs and this has a yellow sulphur coating. The mounds are riddled with crab tunnels in which there is sufficient oxidation to produce many coarse rusty mottles.

These soils are potentially acid sulphate soils and contain high amounts of sulphur (values up to 12.4% have been recorded). After oxidation, the pH of these soils was found to drop to as low as 1.6. In addition to being thionic, these soils are alkaline with the exchange complex dominated by sodium. They are also likely to be saline, but conductivity measurements were not made.

Dystric Histosols: Arang Family

Dystric Histosols of the Arang family were only described on sulphidic peat containing high percentages of mineral matter and frequently overlain by a few centimetres of alluvium. The peat is dark reddish brown (5 YR 3/2) and smells strongly of hydrogen sulphide.

They are potentially acid sulphate soils with sulphur contents as high as 9.4% and, after oxidation, pH falls to as low as 1.7. The soils which are flooded daily by salt water are alkaline and it is likely that they are also moderately saline, although analyses of salinity were not carried out. On the landward edge of the Weston Association they are non-alkaline and are probably non-saline.

Dystric Cambisols: Kelawat Family

Dystric Cambisols of the Kelawat Family were described on crab mounds of alluvium on the landward edge of the Weston Association. The crab mounds are above high water levels and are only occasionally flooded by brackish water. They consequently lack gleying and have moderately developed soil structures. The mounds are riddled with crab channels and also have cones of material deposited by crabs. Ants also colonise some mounds.

The soils have been oxidised and leached, so that the sulphur and sodium levels are lower than other soils in the Weston Association and they do not show significant falls in pH after oxidation. Exchangeable calcium levels are low, but exchangeable magnesium and available phosphate levels are high.

Thionic-humic Gleysols: Bergosong Family

Thionic-humic Gleysols occur on sulphidic alluvium on the landward edge of the Weston Association, where they occupy low lying sites between crab mounds and platforms. They are flooded by brackish water. The soils are medium- to fine-textured and are gleyed and structureless throughout. They have histic O horizons and generally contain fragments of rotting vegetation.

These are potentially acid sulphate soils; total sulphur levels of up to 1.0% have been recorded and there is a fall in pH after oxidation to as low as 1.6. Exchangeable sodium levels are very high. (Profile Gh 6).

SAPI ASSOCIATION

The Sapi Association comprises the soils which occur in swamps between mangrove swamps and a coastal terrace on Pulau Sebatik. The association is inextensive and covers about 8 km^2 (3 mi^2).

The swamps are mainly freshwater swamps, but they become brackish towards the sea. The natural vegetation is swamp forest with a dense undergrowth of rattan (*Calamus* sp.). Brackish conditions are indicated by the presence of the fern *Achrostichum aureum*. Where the forest has been cleared tall sedges take its place.

Humic Gleysols are the dominant soils, but on the seaward edge of the association Thionic-humic Gleysols of the Bergosong Family are developed on sulphidic alluvium (see the Weston Association).

Humic Gleysols: Guan Family

Humic Gleysols of the Guan Family occur on fine-textured alluvium with up to 70% clay. They are gleyed throughout with histic surface horizons and contain fragments of rotting plant debris. Some profiles have yellowish red mottles and concretions.

These soils have medium to high cation exchange capacities and clay fractions dominated by vermiculite with moderate amounts of illite. The base saturation percentage is very low and sodium is the commonest cation, being present in low to medium amounts.

KINABATANGAN ASSOCIATION

The Kinabatangan Association consists of soils on river floodplains and also includes, as minor features, soils on levees, meander cutoffs and backswamps. It covers a total area of only 44 km^2 (17 mi^2) in the lower courses of the Serudong, Kalabakan, Brantian and Umas Umas rivers, on Pulau Sebatik, on the Sungai Segama for a few kilometres above Kuala Kawag and in the upper Tingkayu Valley (Stereogram 3-1).

The vegetation of this association is broadly defined as riverain dipterocarp forest, but in some areas this has been disturbed by shifting cultivation and in meander cutoffs there are occasionally sedges rather than trees.

The soils are developed on fine- to coarse-textured alluvium of varying base status. Coarse-textured alluvium is confined to levees, whilst medium- to fine-textured alluvium occurs on the floodplains and in the backswamps. The alluvium is largely derived from sandstone and mudstone, but in the Segama and Tingkayu Valleys it is partly derived from basic rocks.

The Kalabakan floodplain is up to 1½ km (1 mi) wide but there are no pronounced levees. The alluvium is dominantly fine-textured and the soils are mainly poorly drained Dystric Gleysols, very poorly drained Humic Gleysols in backswamps. The alluvium of the floodplains of the Serudong, Brantian and Umas Umas rivers is mainly moderately fine- and medium-textured. Gleyic Acrisols and Dystric Gleysols are the dominant soils, with Gleyic Cambisols on levees composed of medium-textured alluvium and very poorly drained Humic Gleysols in backswamps. On Pulau Sebatik narrow valleys cross the coastal terrace (Plate 3-7); here the alluvium is moderately fine-textured with high amounts of magnesium and the soils are mainly poorly drained Gleyic Luvisols. The alluvium on the floodplain of the Segama above its confluence with the Kawag is moderately fine-textured and the majority of soils are poorly drained Gleyic Luvisols, with very poorly drained soils in backswamps, Eutric Fluvisols and Eutric Cambisols occur on coarse- to medium-textured alluvium on levees. The majority of the soils on the floodplain are imperfectly and poorly drained Gleyic Luvisols; Orthic Luvisols occur in sites with better drainage (see the Karamuak Association) and Eutric Fluvisols and Cambisols occur on coarse- to medium-textured alluvium on levees.

In brief, the dominant soils of the Association are Gleyic Acrisols and Luvisols and Dystric and Humic Gleysols. The Cambisols and Fluvisols which occur on levees are inextensive; they would otherwise be separated as the Tuaran Association. Similarly the Orthic Luvisols in the Tingkayu Valley are too inextensive to be separated as the Karamuak Association.

Gleyic Acrisols: Inanam Family

Gleyic Acrisols of the Inanam Family are moderately fine- to medium-textured and imperfectly drained. Horizons which are not gleyed have yellowish brown to yellowish red colours and the majority of gleyed horizons contain red mottles. They normally have ochric surface horizons but thin histic horizons may occur.

These soils are strongly to extremely acid, and have low to very low base saturation percentages and low to medium cation exchange capacities.

Gleyic Luvisols: Buran Family

Gleyic Luvisols of the Buran Family are imperfectly to poorly drained, moderately fine- to fine-textured and contain small concretions. They have ochric A horizons and the B horizons, which are not gleyed, have 10 YR hues.

These soils have high to very high base saturation percentages and are slightly acid to near neutral. Levels of exchangeable calcium are medium to high and magnesium is high to very high; cation exchange capacities are medium. The dominant clay mineral in a soil on Pulau Sebatik was vermiculite, with moderate amounts of kaolinite and illite.

Dystric Gleysols: Koyah Family

Dystric Gleysols of the Koyah Family have ochric A and gleyic C horizons; they are fine- and moderately fine-textured, stone-free and poorly drained. The gleyed horizons may contain rust mottles.

Base saturation percentages are very low, cation exchange capacities are medium to low and the soils are extremely acid. (Profile Gd 2).

Humic Gleysols: Guan Family

Humic Gleysols of the Guan Family have moderately fine to fine textures and are stone free. They are very poorly drained and have thin histic O and gleyic C horizons with red mottles in the latter.

These soils have very low base saturation percentages and they are strongly to extremely acid. Cation exchange capacities are low. In a soil on the Kalabakan floodplain illite was the dominant clay mineral, with moderate amounts of kaolinite and vermiculite.

Gleyic Cambisols: Luba Family

Gleyic Cambisols of the Luba Family are medium-textured, stone-free and imperfectly drained. They have ochric A horizons and the horizons which are not gleyed have 10 YR hues; gleyic horizons contain rust mottles and many soft concretions.

They have very low base saturation percentages and are strongly acid; cation exchange capacities are low.

Eutric Cambisols: Bulanat Family

Only one profile of the Bulanat Family has been described; it is medium-textured, becoming coarse with depth, and contains a few gravels. It is well drained with 10 YR hues throughout.

This soil is slightly acid and has a high base saturation percentage, with the exchange complex dominated by magnesium.

Eutric Fluvisols: Pegalan Family

Two coarse-textured and poorly drained profiles of the Pegalan Family have been described. One profile on a levee consists of gleyed loamy sand, interbedded with leaves.

The other profile, which occupies a higher position on a levee and which is flooded less frequently, consists of loamy sand in which the depositional layers are clearly observable. It is gleyed below 33 cm (13 in) and contains prominent rust mottles and concretions.

These soils have high to very high base saturation values and are moderately to slightly acid. Cation exchange capacities are medium to high and the exchange complexes are dominated by calcium.

LABAU ASSOCIATION

The Labau Association occurs on valley floors and terraces in the upper Umas Umas and upper Brantian and in the interior of sandstone basins near Kalabakan; it covers a total area of 21 km^2 (8 mi^2).

The landforms of the association consist of narrow floodplains, with levees and meander cutoffs, backed by low terraces standing about 6 m (20 ft) above the floodplains. The terraces have gentle slopes and rounded tops.

The vegetation is mixed; riverain dipterocarp forest occurs on the valley floors with dipterocarp forest on the terraces.

The soils are formed on moderately fine- to coarse-textured alluvium of low base status and, although inextensive the association includes a broad range of soils.

On the terraces, Ferric and Orthic Acrisols occur on medium- to moderately fine-textured alluvium (see the Brantian Association); and Dystric and Humic Gleysols, Gleyic Acrisols and Gleyic Cambisols occur on the narrow floodplains mainly on medium- and moderately fine-textured alluvium (see the Kinabatangan Association). Dystric Fluvisols and Dystric Cambisols are restricted to the levees.

Dystric Fluvisols: Tenghilan Family

Dystric Fluvisols of the Tenghilan Family, which are coarse-textured and well to moderately well drained occur on the levees; they generally have 10 YR hues and show depositional layering.

Dystric Cambisols: Kelawat Family

Dystric Cambisols of the Kelawat Family form on some well drained sites. They are moderately fine-textured and moderately well drained, yellowish brown soils with a few gley mottles at depth. They have low cation exchange capacities, low base saturation and are strongly acid.

KARAMUAK ASSOCIATION

This association occurs in the headwaters of the Bole and the tributaries of the upper Segama; it covers 21 km^2 (8 mi^2).

Vegetation is similar to that of the Labau Association with riverain dipterocarp forest on the floodplains and dipterocarp forest on the terraces.

The valley of the upper Bole is wide with a well developed system of meanders (Plate 3-9). The alluvium is medium- to fine-textured, sometimes stony, and has a high base status. It is derived from basic and intermediate igneous rocks and sedimentary rocks in the headwaters of the Bole and partly from ultrabasic rocks to the north-east. The soils of the floodplain on the eastern side of the river are mainly imperfectly drained, fine-textured Gleyic Luvisols and Gleyic Cambisols, which are locally stony. On the western side of the river the soils are moderately well drained, medium-textured Orthic Luvisols. Eutric Cambisols are a minor part of this association; they occur on levees of medium-textured alluvium. River terraces with weak dissection occur on the northern side of the valley about 8 m (25 ft) above the river; here the alluvium is strongly weathered, fine-textured and stony. Xanthic Ferralsols occur on these terraces and would be separated as the Binalik Association if they were more extensive. The Gleyic Luvisols and Eutric Cambisols are described in the Kinabatangan Association.

Gleyic Cambisols: Sinsulod Family

Gleyic Cambisols of the Sinsulod Family are fine-textured and contain fragments of basic and ultrabasic rocks. They have ochric A horizons, brown to dark brown cambic horizons and gleyic C horizons.

Cation exchange capacities are medium and base saturation percentages are very high with magnesium the dominant cation. The soils are acid to near neutral in reaction. (Profile Bg 1).

Orthic Luvisols: Darau Family

Soils of the Darau Family are moderately well drained, medium-textured and slightly stony. They have ochric A horizons and dark yellowish brown argillic horizons with gley mottling at depth.

Base saturation percentages are high to very high with medium exchangeable calcium and very high exchangeable magnesium levels; cation exchange capacities are medium. The soils are moderately acid to near neutral.

Xanthic Ferralsols: Tungau Family

A soil of the Tungau Family was described on a terrace of the Sungai Bole at the foot of an ultrabasic mountain. It was well drained with an ochric A horizon, and strong brown fine-textured oxic horizons containing common dolerite and tuff gravel and stones. It has very low base saturation percentages and a strongly acid reaction. The cation exchange capacities of the oxic horizons are low and the CEC/100 g clay is as low as 10 meq.

BRANTIAN ASSOCIATION

The Brantian Association includes soils on terraces, low hills and minor valley floors. It is extensive on the coastal terrace of Cowie Harbour between the mouths of the Serudong and Merotai rivers, on Pulau Sebatik and on Pulau Simandalan; it also occurs in the valleys of the Serudong, Silimpopon, Kalabakan, Brantian, Umas Umas and Danum rivers, and east of the Orchid Plateau. The total area of the Brantian Association is 347 km^2 (134 mi^2).

The soils are formed on medium- to fine-, occasionally coarse-textured alluvium.

Poor dipterocarp forest is the natural vegetation of the terraces and low hills with riverain dipterocarp forest on valley floors and heath forest on small areas of coarse-textured alluvium. Oil palm, rubber and coconuts have been planted mainly on coastal terraces.

The coastal terrace is between 3 to 30 m (10-100 ft) above sea level rising from flat land near the coast and becoming hilly inland (Plate 3-10; Stereogram 3-2). The majority of the terrace is flat or rolling, with amplitudes of less than 8 m (25 ft). In the hilly areas the terrace tops are generally rounded, contrasting with adjacent ridges of sandstone and mudstone. Gleyic Acrisols of the Inanam Family are formed on moderately fine- and fine-textured alluvium and occupy about 60% of the area on flat or slightly dissected land where water is only slowly removed. In the hilly areas Ferric Acrisols of the Lumisir Family are the commonest soils; they occur on moderately fine-textured alluvium. Gleyic and Orthic Podzols of the Baiayo and Silimpopon Families and Orthic Acrisols of the Paliu Family occur sporadically, adjacent to sandstone hills to the north-west of Brantian and between the mouths of the Serudong and Silimpopon, but are unlikely to be significant elsewhere. The soils of valley floors, which are minor features of the coastal terrace are Gleyic Acrisols of the Inanam Family and Dystric Gleysols of the Koyah Family on moderately fine-textured alluvium. Humic Gleysols of the Guan Family occur on coarse-textured alluvium close to sandstone hills. Low hills of sandstone and mudstone with Orthic Acrisols of the Tanjong Lipat Family occur on the landward edge of the terrace.

On Pulau Sebatik slopes of the inland parts of the coastal terrace are steeper than on the mainland, ranging from 15-25^{O}. (Plate 3-11; Stereogram 3-3). Here the soils are predominantly moderately fine-textured Ferric Acrisols of the Lumisir Family. Gleyic Acrisols of the Inanam Family are restricted to the less dissected seaward edge of the terrace. Orthic Acrisols of the Tanjong Lipat Family occur on low sandstone hills and moderately fine-textured Gleyic Luvisols of the Buran Family occur on narrow valley floors.

The relief of Pulau Simandalan is low and rolling with a soil sequence from west to east of fine-textured Gleyic Acrisols of the Inanam Family, moderately fine-textured Ferric Acrisols of the Lumisir Family and Orthic Acrisols of the Tanjong Lipat Family. Coarse-textured Orthic Podzols of the Silimpopon Family and medium-textured Orthic Acrisols of the Paliu Family occur sporadically near the coastline.

In the Silimpopon valley there is a large area of low hills with accordant summit levels. The majority of slopes are less than 15^{O} and amplitudes range from 3-24 m (10-75 ft). The parent material of soils in this valley is considered to be alluvium, but it is possible that the soils are developed on deeply weathered sandstone and mudstone. The soils are deep and stone free and are mainly medium-textured and well drained Orthic Acrisols of the Paliu Family. Valley floors are narrow and, here, the soils are medium- and moderately fine-textured Gleyic Acrisols and Gleyic Cambisols of the Inanam and Luba Families respectively.

There are a number of terraces in the Serudong, Kalabakan, Brantian and Umas Umas Valleys. They are generally between 6 and 12 m (20 and 40 ft) above the rivers (Plate 3-5), but at Luasong there is a boulder terrace about 25 m (80 ft) above the river. The soils are mainly medium- and moderately fine-textured Ferric Acrisols of the Lumisir Family. Many contain concretions and stones and are frequently present in the terrace deposits below 125 cm (50 in.). Orthic Acrisols occur sporadically on stony alluvium. On narrow floodplains the alluvium is generally medium- or moderately fine-textured and the commonest soils are Dystric Cambisols of the Kelawat Family and Orthic Acrisols of the Paliu Family. The floodplains are sufficiently high above the rivers for these soils to be moderately well drained. Dystric Gleysols of the Koyah Family and Gleyic Acrisols of the Inanam Family occur in poorly drained sites.

In the upper Danum Valley, terraces stand about 6 to 9 cm (20-30 ft) above the river. The alluvium is fine-textured and the soils are Ferric and Orthic Acrisols of the Lumisir and Paliu Families respectively. Medium-textured Gleyic Luvisols of the Buran Family are dominant on the narrow floodplain.

In brief, the dominant soils on the terraces in the Brantian Association are Gleyic, Ferric and Orthic Acrisols of the Inanam, Lumisir, and Paliu Families respectively. Gleyic and Orthic Podzols of the Baiayo and Silimpopon Families also occur on the terraces and are described in the Kepayan Association. The Gleysols, Cambisols and Luvisols which occur on the valley floors, with the exception of coarse-textured Humic Gleysols of the Guan Family, are described in the Kinabatangan and Labau Associations. Orthic Acrisols of the Tanjong Lipat Family, which occur on sandstone hills, are described in the Lokan Association.

Gleyic Acrisols: Inanam Family

Imperfectly to poorly drained Gleyic Acrisols of the Inanam Family occur on moderately fine- to fine-textured alluvium. There is a pronounced increase in clay content with depth, the majority of soils having loamy topsoils with clay contents of about 20% and subsoils with clay contents ranging from 30-70%. The eluvial horizons are frequently weakly structured, but the argillic horizons are moderately structured. Red mottles are prominent in the argillic horizons. The majority of soils have ochric A horizons and some have thin histic horizons.

Cation exchange capacities are generally between 6 and 12 meq% and base saturation values are generally less than 10% below the A horizon. Calcium is frequently absent from the exchange complex and magnesium, sodium and potassium are present in only trace amounts. Available phosphate levels are low. The soils are strongly acid. Vermiculite is the dominant clay mineral with moderate amounts of kaolinite and traces of illite. (Profile Ag 3).

Ferric Acrisols: Lumisir Family

Ferric Acrisols of the Lumisir Family are moderately fine- to medium-textured and are generally stone free. The majority are moderately well drained, but well drained soils have also been described. There is a marked clay increase with depth and textures range from sandy loam or loam in the eluvial horizons to clay loam or clay in the subsoils. The argillic horizons are mottled yellow and red and some contain concretions.

Cation exchange capacities are generally between 8 and 12 meq% and base saturation levels are less than 12% below the A horizons. Exchangeable calcium is frequently absent from the soil and exchangeable magnesium, sodium and potassium are only present in trace amounts. Available phosphate levels are low and the soils are strongly acid. In the only profile analysed for clay minerals, vermiculite was dominant with moderate amounts of kaolinite.

Orthic Acrisols: Paliu Family

Orthic Acrisols of the Paliu Family are medium-textured soils, which may contain stones and gravel. The majority are well drained, but moderately well drained soils have been described. They show pronounced clay increases with depth, and textures range from loamy sand or sandy loam in the eluvial horizons to loam or clay loam in the argillic horizons. The eluvial horizons commonly have brownish yellow colours and argillic horizons have strong brown or reddish yellow colours. Most soils have ochric A horizons and some have thin histic O horizons.

Cation exchange capacities are between 6 and 12 meq% and base saturation values are less than 10% below the A horizons. Calcium is frequently absent from the exchange complex and magnesium, sodium and potassium are only present in trace amounts. Available phosphate levels are generally very low. These soils are strongly to extremely acid.

Humic Gleysols: Guan Family

A coarse-textured soil of the Guan Family was described on the valley floor of a stream flowing from a sandstone hill. It was poorly drained with an histic O horizon and a gleyic C horizon, the latter having brownish yellow and strong brown mottles. The soil had a strongly acid reaction and an extremely low base saturation percentage.

KEPAYAN ASSOCIATION

The Kepayan Association occurs between the mouths of the Serudong and Silimpopon rivers on a flat to gently rolling terrace about 3 m (10 ft) above sea level. It covers an area of only 3½ km^2 (1½ mi^2).

The soils are developed on coarse-textured alluvium, which is derived in part from adjacent sandstone mountains. The natural vegetation is heath forest and this is clearly identified on aerial photographs by its dense pattern and light tone.

The soils of this association are predominantly Orthic and Gleyic Podzols.

Orthic Podzols: Silimpopon Family

Orthic Podzols of the Silimpopon Family have thick histic horizons of raw humus, Albic horizons of bleached sand and indurated spodic horizons underlain by pale yellow and yellowish red mottled horizons of loamy sand to sandy loam. They are extremely acid and have very low base saturation percentages.

A soil described near the Kuala Serudong had a two-tier profile of a podzol with histic, albic and spodic horizons overlying what appeared to be the remains of a Ferric Acrisol. It is thought that either the removal of clay from the topsoil of the original Ferric Acrisol had induced podzolisation or alternatively that the Ferric Acrisol had been overlain by sandy deposits from adjacent sandstone mountains.

Gleyic Podzols: Baiayo Family

Gleyic Podzols of the Baiayo Family have histic O horizons, eluvial horizons of bleached sand and indurated spodic horizons composed mainly of humus. Beneath the spodic horizon the soils are moderately fine-textured and are gleyed; yellowish red mottles are prominent. The clay increase below the spodic horizon suggests that these soils may be formed on tiered deposits and the sandy surface deposits may well be derived from the adjacent sandstone hills. The soils are strongly acid and have extremely low base saturation percentages.

Soil associations on mudstone/sandstone 1. Mudstone and minor sandstone

The Kalabakan and Mawing Associations occur on mudstone of the Kalabakan Formation (Table 3-5). The formation consists of poorly bedded argillaceous rocks with rare beds of siltstone, sandstone and conglomerate (Collenette, 1965b) although Wilford (1968c) suggests that the formation is in fact a slump deposit and noted such rocks as conglomerate and limestone. Chert conglomerate is common at Batu Puteh near Kalabakan. Known areas of chert conglomerate have rounded relief which is similar to certain areas of slump deposits and they have been included in the Kretam and Bang Associations (see below). Apart from these small areas, however, inclusions of other rocks appear to be very minor and mudstone and sandstone are the only significant parent materials.

TABLE 3-5 Soil associations on mudstone and minor sandstone

Association	Landforms	Parent materials	Main soil units	Soil families
Kalabakan	Moderate hills: amplitudes <75 m (250 ft) with 10-20° slopes	Mudstone and minor sandstone	Orthic Acrisol Orthic Luvisol	Kumansi Lumpongon
Mawing	Moderate hills: amplitudes <75 m (250 ft) with slopes >25°	Mudstone and minor sandstone	Orthic Acrisol Orthic Luvisol Dystric Cambisol	Kumansi Lumpongon Laab

KALABAKAN ASSOCIATION

The Kalabakan Association is composed of soils developed on mudstone, sandstone and alluvium. It is mapped mainly in the Kalabakan Valley to the west and south of Kalabakan Camp, and also to the east of the valley, covering a total area of 96 km^2 (37 mi^2).

It is formed on hills which are the remnants of a former erosion surface, the accordant summit levels occurring at between 30 to 60 m (100-200 ft) above sea level. The hills have amplitudes of approximately 30 m (100 ft) and slopes of 15-20°.

Ridge tops are generally narrow. Valleys up to 60 m (200 ft) wide are minor features of this association. The natural vegetation is dipterocarp forest much of which has been logged.

The majority of soils are Orthic Acrisols and Orthic Luvisols formed on mudstone. Gleyic Acrisols and probably Gleyic Luvisols occur on some lower slopes, although no examples of the latter have been described. Dystric Cambisols occur infrequently on ridge tops. Orthic Acrisols of the Tanjong Lipat Family occurring on sandstone, which is a minor feature of the association are described in the Lokan Association.

The soils of the valley floors are moderately fine- to fine-textured Gleyic Luvisols of the Buran Family and on associated terraces the soils are moderately fine-textured Ferric Acrisols of the Lumisir Family. These soils are described in the Kinabatangan and Brantian Associations respectively.

MAWING ASSOCIATION

The Mawing Association is composed of soils developed on mudstone and sandstone in and to the east of the Kalabakan Valley (Stereogram 3-4) covering a total area of 200 km^2 (77 mi^2). It occurs on steep hills with amplitudes up to 75 m (250 ft) and slopes of more than 25^o. The hills are largely in the form of steep, narrow ridges with deeply incised valleys. Erosion is very active and landslips are common on hillsides. The hills apparently represent remnants of an erosion surface at between 90 to 200 m (300-700 ft) above sea level.

The majority of soils are Orthic Acrisols and Orthic Luvisols developed on mudstone. Dystric Cambisols occur on ridge tops and unstable steep slopes. Orthic Acrisols also occur on sandstone and mudstone and they are described in the Lokan Association.

Orthic Acrisols and Orthic Luvisols: Kumansi and Lumpongon Families

The Kumansi and Lumpongon Families are formed on mudstone and are similar in all main characteristics apart from their chemistry. Soils of the Kumansi Family appear to be more common. They have ochric A horizons, yellowish brown colours throughout and fine-textured argillic horizons. They are well drained and generally stony, with mudstone fragments frequently occurring at the surface. Moderately deep and deep profiles have been described.

Base saturation percentages range from 15 to 60% and magnesium is the dominant cation. Exchangeable calcium and sodium levels are low to very low and potassium levels are low to medium. Soils of the Lumpongon Family are usually moderately acid, but soils of the Kumansi family are strongly acid. Illite and vermiculite were co-dominant in the only soil of the Kumansi Family which was analysed for clay minerals.

Gleyic Acrisols: Masaum Family

Gleyic Acrisols of the Masaum Family are formed on mudstone. Only one imperfectly drained, moderately deep and stony profile with a fine-textured argillic horizon was described. The horizons which are not gleyed are yellowish brown in colour and there is a surface ochric horizon.

Base saturation percentages below the ochric horizon range from 44-68%, but are below 50% in the agrillic horizon. Magnesium levels are high to very high and levels of other cations are low to very low. Cation exchange capacities are medium. The soil is strongly to moderately acid.

Soils with argillic horizons having base saturation values greater than 50% (i.e. Luvisols of the Buran Family) have not been described, but they must also occur.

Dystric Cambisols: Laab Family

Dystric Cambisols of the Laab Family are formed on mudstone with minor amounts of sandstone. The soils are shallow and stony with ochric A horizons and brownish yellow colours throughout.

They have low base saturation percentages and strongly acid reactions. Exchangeable magnesium levels are medium and levels of other cations are low to very low; cation exchange capacities are low.

Soil associations on mudstone/sandstone 2. Sandstone and mudstone

The Dalit, Lokan and Crocker Associations are formed on hills and mountains of sandstone and mudstone (Table 3-6). Most of the area is steepland and only the Dalit Association is mapped on low, rolling hills.

The Maliau and Serundong Associations occur on sandstone with minor inclusions of mudstone (Table 3-7) and are mapped on high mountains extending westwards from the Kalabakan and Tiagau Valleys, up to and beyond the Tawau District boundary. The mountains are formed of sandstones of the Kapilit formation (Collenette, 1965b). These sandstones are medium- to fine-grained and are generally hard and grey, weathering to reddish or brownish yellow or white. The Kapilit Formation has been folded into a series of synclines with well developed dip and scarp slopes. In the Serudong, Luis and Silimpopon Valleys the dip slopes are long and gentle and the scarp slopes are precipitous; elsewhere the strata are more strongly folded and both dip and scarp slopes are steep.

TABLE 3-6 Soil associations on sandstone and mudstone

Association	Landforms	Parent materials	Main soil units	Soil families
Dalit	Moderate hills: amplitudes $<$75 m (200 ft) with 5-15° slopes	Sandstone and mudstone	Ferric Acrisol	Sipit
			Orthic Acrisol	Tanjong Lipat
Lokan	Very high hills: amplitudes $<$300 m (1 000 ft) with slopes $>$25°	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kumansi
			Dystric Cambisol	Laab Antulai
Crocker	Mountains: slopes $>$25°	Sandstone and mudstone	Orthic Acrisol	Kapilit Tanjong Lipat
			Dystric Cambisol	Laab Antulai

TABLE 3-7 Soil associations on sandstone with minor inclusions of mudstone

Association	Landforms	Parent materials	Main soil units	Soil families
Maliau	Mountains with distinctive dip and scarp topography	Sandstone and minor mudstone	Orthic Acrisol	Kapilit Tanjong Lipat
			Dystric Cambisol	Antulai
			Gleyic Podzol	Pa Sia
Serudong	Mountain dipslopes	Sandstone	Gleyic Podzol	Pa Sia
			Orthic Acrisol	Kapilit

DALIT ASSOCIATION

The Dalit Association is restricted to the colluvial footslopes of high hills and mountains of sandstone and mudstone near Brantian and Umas Umas. It covers a total area of only 8 km^2 (3 mi^2) and is formed on low hills with amplitudes of less than 30 m (100 ft) and slopes of 5-15^o.

Orthic and Ferric Acrisols of the Tanjong Lipat and Sipit Families are dominant (see the Lokan Association).

LOKAN ASSOCIATION

The Lokan Association occurs most extensively to the west of the Sungai Kalabakan and covers a total area of 365 km^2 (140 mi^2). It is formed on steep sandstone and mudstone hills with amplitudes up to 300 m (1 000 ft). The hills are often in the form of long, narrow ridges with steep slopes and narrow boulder strewn valleys (Stereogram 3-4); slopes are generally between 30 and 40^o and rock outcrops and landslides are common.

Orthic Acrisols of the Tanjong Lipat and Kumansi Families are dominant with Dystric Cambisols of the Laab Family (Profile Bd 6) (see the Mawing Association) on ridge tops and unstable steep slopes. Orthic Acrisols of the Kapilit Family (Profile Ao 15) and Dystric Cambisols of the Antulai Family occur on ridges of sandstone notably in the lower Serudong Valley and are described in the Maliau Association. Lithosols occur in close association with Cambisols. Luvisols of the Lumpongon Family (see the Kalabakan Association) occur on Pulau Sebatik where some of the sandstone is feldspathic and the mudstone is rich in magnesium (Kirk, 1962).

CROCKER ASSOCIATION

The Crocker Association occurs most extensively in the Brassey Range to the east of the Sungai Tiagau and has a total area of 238 km^2 (92 mi^2). It occurs on some of the steepest land in the survey area and consists of mountains of more than 330 m (1 000 ft) amplitude, with very high, narrow ridges and long slopes with angles generally between 30^o and 45^o. There are frequent precipices; slopes are rocky and prone to landslips, valleys are narrow and boulder strewn, and the streams and rivers are fast flowing. The soils are similar to those of the Lokan Association.

Orthic Acrisols: Tanjong Lipat and Kumansi Families

The Tanjong Lipat and Kumansi Families are divided according to the texture of the argillic horizon, the former containing 25-40% clay and the latter containing more than 40% clay. Soils of the Tanjong Lipat Family are more common in the Dalit, Lokan and Crocker Associations because sandstones are more common than mudstones.

The soils are well drained and both deep and moderately deep profiles have been described. Many profiles are stony and near the source of the Sungai Luasong the stones were composed of quartzite. They generally have ochric A horizons, but thin histic horizons of raw humus may occur. The eluvial horizons commonly consist of yellowish brown loam, while the argillic horizons consist of strong brown to yellowish red clay loam to clay. Soil structures are moderately strong subangular blocky in the eluvial horizons becoming angular blocky in the argillic horizons.

These soils have low cation exchange capacities and base saturation levels are frequently less than 10%; they are strongly to extremely acid.

Ferric Acrisols: Sipit Family

The soils of the Sipit Family are well to moderately well drained with medium to moderately fine textures and sometimes stony argillic horizons. They contain red mottles and many contain soft yellowish red concretions.

These soils generally have very low base saturation percentages and strongly to extremely acid reactions.

MALIAU ASSOCIATION

The Maliau Association covers about 750 km^2 (290 mi^2) of the sandstone mountains of the Kapilit Formation.

Dipterocarp forest is the dominant forest type with small areas of heath forest. Much of the dipterocarp forest is of poor quality, particularly on the steep scarp slopes.

Orthic Acrisols of the Kapilit and Tanjong Lipat Families are the commonest soils on the dipslopes and they also occur on scarp slopes where Dystric Cambisols of the Antulai Family are dominant. Gleyic Podzols of the Pa Sia Family occur in the small areas of heath forest (see the Serudong Association).

Orthic Acrisols: Kapilit Family

Orthic Acrisols of the Kapilit Family contain less than 25% clay in their argillic horizons and are derived almost entirely from sandstone. They are well drained and stony, with textures ranging from sandy loam in eluvial horizons to loam in the argillic horizons. Profiles with shallow histic horizons are common. The soils on steep slopes are derived largely from colluvium and contain more stones than those on gentle dipslopes, which are developed on bedded sandstone. Colours are commonly brownish yellow or yellowish brown, but some profiles have strong brown or reddish yellow argillic horizons.

These soils have low to very low cation exchange capacities and very low base saturation percentages; they are strongly to extremely acid.

Orthic Acrisols: Tanjong Lipat Family

Orthic Acrisols of the Tanjong Lipat Family are less common than those of the Kapilit Family. They contain between 25 and 40% clay in their argillic horizons, being derived in part from mudstone. Eluvial horizons commonly consist of brownish yellow or yellowish brown sandy loam and the argillic horizons consist of strong brown or yellowish red clay loam. Most soils are well drained and stony, but moderately well drained soils occur on some dipslopes. They all have ochric A horizons and some have shallow histic horizons at the surface.

In one deep stone-free soil on a gentle dipslope, many prominent fine red mottles were noted in the argillic horizons. The mottles were not sufficiently coarse for the soil to be classed as a Ferric Acrisol (see Volume 1) but the distinction is clearly fine. In the same soil the CEC per 100 g of clay of the mottled horizon was only 20 meq indicating strong weathering and the transition to a Ferralsol.

The soils of the Tanjong Lipat Family are chemically similar to those of the Kapilit Family.

Dystric Cambisols: Antulai Family

Soils of the Antulai Family are generally well drained and on ridge tops they are frequently excessively drained. They are shallow to moderately deep and stony, with yellowish brown colours and loam or sandy loam textures. Some have thin histic O horizons of raw humus and others have ochric A horizons.

These soils have low to very low cation exchange capacities, very low base saturation percentages and extremely acid reactions.

SERUDONG ASSOCIATION

The Serudong Association is most extensive in the Gunong Luis area, covering a total area of 68 km^2 (26 mi^2). It usually occurs above 700 m (2,000 ft) on long dipslopes under heath forest. The soils are dominantly Gleyic Podzols of the Pa Sia Family. Orthic Acrisols of the Kapilit Family occur sporadically (see the Maliau Association).

Gleyic Podzols: Pa Sia Family

A shallow imperfectly drained soil of this family was described near the summit of Gunong Nakopan at 1 900 m (3 000 ft). It had a thin histic O horizon of raw humus overlying an eluvial horizon of light grey to grey loamy sand and a spodic horizon beginning at 35 cm (14 in). In the sandstone bedrock, just below the spodic horizon, there was a thin discontinuous iron pan.

The soil has a very low cation exchange capacity, a very low base saturation percentage with negligible amounts of exchangeable cations and an extremely acid reaction. The spodic horizon contained more total iron and organic carbon than the eluvial horizon and turned redder on ignition.

Soil associations on mudstone/sandstone 3. Mudstone, sandstone and miscellaneous rocks

The Rumidi, Kretam, Bang and Gumpal Associations (Table 3-8) occur on slump deposits (see Part 2) in which sandstone and mudstone are dominant with tuffaceous rocks, chert, ultrabasic, basic and intermediate igneous rocks and volcanic agglomerate also occurring in varying proportions.

The vegetation of these associations is dipterocarp forest generally containing good stands of commercial timber. In some areas, however, notably in the Segama Valley between the mouths of the Kawag and Bole Rivers, small and medium height trees are interspersed with open areas of thick scrub vegetation and there are few large trees. The instability of the slump formations in such areas is believed to be the cause, as slipping of the unconsolidated deposits probably interupts the normal forest development. Medium height trees are frequently tilted or have curved trunks to compensate for gradual downhill movement.

TABLE 3-8 Soil associations on mudstone, sandstone and miscellaneous *rocks

Association	Landforms	Parent materials	Main soil units	Soil families
Rumidi	Low hills and minor valley floors: amplitudes < 30 m (100 ft) with slopes < 15°.	Mudstone/ sandstone	Orthic Acrisol	Tanjong Lipat Kumansi
			Ferric Acrisol	Sipit
			Gleyic Acrisol	Masaum
			Orthic Luvisol	Lumpongon
			Gleyic Luvisol	Lunparai
		Alluvium	Gleyic Luvisol	Buran
			Gleyic Acrisol	Inanam
Kretam	Moderate hills; amplitudes <75 m (250 ft) with slopes < 20°.	Mudstone/ sandstone	Orthic Acrisol	Tanjong Lipat Kumansi
			Orthic Luvisol	Lumpongon
		Chert	Chromic Cambisol	Juak

TABLE 3-8 (continued)

Association	Landforms	Parent materials	Main soil units	Soil families
Bang	Steep hills: amplitudes < 300 m (1 000 ft) with slopes 15-25°.	Mudstone/sandstone	Orthic Acrisol Dystric Cambisol	Tanjong Lipat Kumansi Laab
Gumpal	Hills and mountains: slopes $< 25°$.	Mudstone/sandstone	Orthic Acrisol Dystric Cambisol	Tanjong Lipat Kumansi Kapilit Laab Antulai

*Soil units and soil families on miscellaneous rocks, with the exception of Chromic Cambisols of the Juak Family, are not listed here but are described in the text.

RUMIDI ASSOCIATION

The Rumidi Association is most extensive in the Segama Valley between the mouths of the Kawag and the Bole and in the upper Danum lowlands. It covers a total area of 90 km^2 (35 mi^2).

In the Segama Valley (Plate 3-12, Stereogram 3-5) the Rumidi Association consists of low hills with amplitudes of 10-15 m (30-50 ft) and narrow valley floors. There is an accordance of hilltops, which suggests that the hills represent a former erosion surface.

The majority of soils are well drained and moderately well drained Orthic Acrisols of the Tanjong Lipat and Kumansi Families. They are composed mainly of sandstone in a mudstone matrix, but in many soils there are stones or boulders of other rocks and in addition some of the sandstone is possibly tuffaceous (Fitch, 1955). Orthic and Chromic Luvisols are less common but are found in areas where the soil is solely composed of, or contains, a high proportion of magnesium rich mudstone (Lumpongon Family), ultrabasic igneous rocks (Tingkayu Family), basic and intermediate igneous rocks (Kobovan and Beeston Families) or tuffaceous rocks (Talid and Libong Families). Chert commonly occurs as fragments in the soil and occasionally forms bouldery outcrops with shallow or moderately deep, reddish brown stony Chromic Cambisols of the Juak Family. On some lower slopes, with imperfect drainage, there are Gleyic Acrisols and Gleyic Luvisols of the Masaum and Lunparai Families respectively. Ferric Acrisols of the Lumisir Family and stony Orthic Acrisols of the Paliu Family occur on a narrow terrace of the Sungai Segama (see the Brantian Association); Gleyic Acrisols of the Inanam Family (Profile Ag 2) and Gleyic Luvisols of the Buran Family, occur on fine- to medium-textured, frequently stony, alluvium on the narrow valley floors.

In the upper Danum lowlands the hills are low with both rounded and level tops. The soils are derived mainly from sandstone and mudstone with minor inclusions of other rocks, notably chert and dolerite. The soils of the hill tops are deeply weathered and strongly leached Ferric Acrisols of the Sipit Family. Orthic Acrisols of the Tanjong Lipat Family occur on the hillsides and stony Gleyic Acrisols of the Inanam Family occur on the valley floors.

The soils of the Rumidi Association are described in detail in the Gumpal Association.

KRETAM ASSOCIATION

This association consists of soils developed on sandstone, mudstone and miscellaneous rocks on moderate hills up to 75 m (250 ft) amplitude with slopes of less than 20°. This association is extensive, covering a total area of 360 km^2 (140 mi^2).

The soils of this association are similar to those of the Rumidi Association in the Segama Valley, but because slopes are generally steeper, imperfectly drained soils are less common. In the Umas Umas Valley the Orthic Acrisols of the Tanjong Lipat and Kumansi Families are formed on parent materials composed almost entirely of sandstone and mudstone, but elsewhere they often contain fragments of other rocks, particularly chert. To the north of Kalabakan, chert conglomerate is locally dominant with moderately deep or shallow, stony Chromic Cambisols of the Juak Family. These soils are described in the Gumpal Association.

BANG ASSOCIATION

The Bang Association occurs extensively in the western parts of the Lahad Datu District and also on the southern slopes of the Brassey Range in the Tawau District; it covers a total area of 562 km^2 (217 mi^2). It occurs on steep hills of up to 300 m (1 000 ft) amplitude, with slopes averaging between 15^o and 25^o (Plate 3-13; Stereogram 3-6). There is a higher proportion of bedded rocks than in the Kretam and Rumidi Associations. The majority of soils are Orthic Acrisols of the Tanjong Lipat and Kumansi Families on sandstone and mudstone; inclusions of fragments of other rocks do not appear to be as common as in the Rumidi Association. The soils which are developed on miscellaneous rocks include Orthic and Chromic Luvisols described in the Rumidi and Kretam Associations. Cambisols and Lithosols occur on many steep slopes and ridges. These soils are described in the Gumpal Association.

GUMPAL ASSOCIATION

The Gumpal Association is extensive in the western parts of the Lahad Datu District and in the Tawau District east of the Sungai Brantian, covering a total area of 904 km^2 (350 mi^2). It occurs on hills and mountains with slopes of more than 25^o (Plate 3-13; Stereogram 3-6). Interbedded sandstone and mudstone are the dominant parent materials with only minor inclusions of miscellaneous rocks. Orthic Acrisols of the Tanjong Lipat and Kumansi Families are the most common soils. However, between the Sungai Umas Umas and the Sungai Brantian there are large areas of sandstone with Orthic Acrisols of the Kapilit Family. The soils which are formed on miscellaneous rocks are similar to those in the Bang Association, but because the land is steeper, Cambisols and Lithosols are more common.

In the following paragraphs the dominant soil families in the Rumidi, Kretam, Bang and Gumpal Associations are described; these are the Tanjong Lipat, Kumansi, Masaum, Lunparai and Sipit Families. In addition examples of soils which are formed on miscellaneous rocks and alluvium are also described; they include soils of the Libong, Talid, Kawa and Hatton Families on miscellaneous rocks and the Inanam and Buran Families on alluvium. For information on soils on igneous rocks to which reference has been made, the reader is referred to the section under that heading.

Orthic Acrisols: Tanjong Lipat and Kumansi Families

Orthic Acrisols of the Tanjong Lipat Family are described in the Lokan and Crocker Associations and Orthic Acrisols of the Kumansi Family are described in the Kalabakan and Mawing Associations. In the Rumidi, Kretam, Bang and Gumpal Associations, however, the soils of these families contain fragments of other rocks. Chert is the commonest, probably because it is the most resistant to weathering, whilst tuffaceous rocks and basic, intermediate and ultrabasic igneous rocks also occur. Consequently the soils are very variable in their characteristics. Some soils are brownish yellow throughout; others have strong brown or reddish yellow argillic horizons. They are frequently stony and both deep and moderately deep profiles have been described. Clay percentages range from about 30% to over 60% in the argillic horizons; in the eluvial horizons they are commonly between 20 and 35%.

Base saturation percentages vary from very low to medium and magnesium is the dominant cation. The soils are moderately to extremely acid. (Profile Ao 12 is an example of a soil of the Tanjong Lipat Family.)

Gleyic Acrisols and Gleyic Luvisols: Masaum and Lunparai Families

These soils are physically similar and are separated on the degree of base saturation. The Masaum Family is described in the Kalabakan and Mawing Associations. In the Rumidi and Kretam Associations, however, the soils may contain fragments of other rocks. The soils of both families are imperfectly drained, generally contain common or more stones and have fine textures. Horizons, which are not gleyed, have yellowish brown colours.

Base saturation percentages range from low to medium and magnesium is the dominant cation. The soils are moderately to strongly acid. (Profiles Ag and Lg 6).

Ferric Acrisols: Sipit Family

Ferric Acrisols of the Sipit Family occur in the upper Danum area in the Rumidi Association and they may also occur on gentle slopes in the Kretam and Bang Associations. They are derived chiefly from sandstone and mudstone with fragments of chert and dolerite in some profiles.

The soils are generally moderately fine-textured and moderately well drained; they have moderately strong subangular blocky structures and textures range from sandy loam in the eluvial horizons to clay loam in the argillic horizons. They are brownish yellow, becoming strong brown in the argillic horizons with yellowish red mottles throughout and light grey mottles normally occurring at depth. Coarse-textured soils are less common. They have thin histic horizons over thin upper eluvial horizons of light grey structureless sand containing yellowish red mottles and lower eluvial horizons of pale yellow loamy sand, with yellowish red mottles and weak subangular blocky structures. Argillic horizons consist of pale yellow sandy loam, with yellowish red mottles, few soft yellowish red concretions and weak subangular blocky structures.

These soils are strongly acid and have base saturation percentages of less than 10% below the ochric horizons. They are strongly weathered and closely related to Ferralsols with reported values of CEC/100 g clay ranging between 17 and 22 meq%. (Profile Af 3.)

Chromic Luvisols: Libong Family

Chromic Luvisols of the Libong Family are formed on tuffaceous rocks. One profile only was described on tuffaceous sandstone and mudstone; it was stony and consisted of an eluvial horizon of brown loam overlying an argillic horizon of yellowish red clay.

The soil was moderately to slightly acid with medium cation exchange capacity and a medium base saturation level. Calcium was the dominant cation, but magnesium levels were also high.

Orthic Luvisols: Talid Family

Soils of the Talid Family occur on tuffaceous rocks mixed with other rocks. They are well or moderately well drained and deep to moderately deep stony soils. Colours are brown to yellowish brown and textures in the argillic horizons are fine or moderately fine.

These soils have high cation exchange capacities and high to very high base saturation percentages. Magnesium contents are very high and calcium levels are medium to high (Profile Lo 9).

Eutric Cambisols: Hatton Family

Eutric Cambisols of the Hatton Family are formed on tuffaceous rocks. One profile was described which was moderately deep and moderately fine-textured with dark yellowish brown colours.

It had very high cation exchange capacities and high to very high base saturation percentages. Exchangeable magnesium levels were very high (30 meq%) and calcium levels were medium. The soil was moderately to slightly acid (Profile Be 3).

Chromic Cambisols: Kawa Family

Chromic Cambisols of the Kawa Family are formed on basic and intermediate igneous rocks. The only soil described was mainly derived from basalt. It was moderately deep and stony and contained sandstone boulders. It had a moderately fine texture and dark reddish brown colours throughout.

The soil was saturated with bases and exchangeable calcium values were up to 50 meq%, although magnesium levels were low to medium. Cation exchange capacities were very high and available phosphorus levels were extremely high with values between 250 and 670 ppm.

Chromic Cambisols: Juak Family

Chromic Cambisols formed on chert are included in the Juak Family. They are generally shallow or moderately deep, extremely stony soils with reddish brown colours.

No chemical analyses were carried out on the soils of this family.

Gleyic Acrisols and Gleyic Luvisols: Inanam and Buran Families

Soils of the Inanam and Buran Families occur on valley floors. They are imperfectly or poorly drained with yellowish brown colours in the horizons which are not gleyed. Gleyed horizons commonly contain rust mottles or concretions. Textures range from medium to fine and many profiles contain stones, chert being the most common. The base status of the alluvium is very variable, depending largely on the nature of the rocks in the surrounding hills.

Associations on igneous rocks 1. Basic and intermediate igneous rocks

The Orchid Plateau, Mentapok and Malubok Associations have been recognised on basic and intermediate igneous rocks (Table 3-9).

TABLE 3-9 Soil associations on basic and intermediate igneous rocks

Association	Landforms	Parent materials	Main soil units	Soil families
Orchid Plateau	Low hills: amplitude <30 m (100 ft) with slopes >25°	Basic and intermediate igneous rocks	Orthic Acrisol	Kinabutan
			Chromic Luvisol	Beeston
			Orthic Luvisol	Kobovan
Mentapok	Mountains with slopes > 25°	Basic and intermediate igneous rocks	Orthic Luvisol	Kobovan
			Chromic Luvisol	Beeston
			Eutric Cambisol	Bombalai
			Lithosol	
Malubok	Mountains with slopes > 25°	Basic, intermediate and ultrabasic igneous rocks	As for Mentapok and Bidu Bidu Associations	

ORCHID PLATEAU ASSOCIATION

This association is restricted to the Orchid Plateau and covers an area of about 36 km^2 (14 mi^2). The plateau is about 700 m (2 250 ft) above sea level and is bounded by steep slopes (Plate 3-15; Stereogram 3-9). It is believed to be a former erosion surface and although it has been slightly dissected, the old land surface is still distinct in the form of broad accordant hill tops with gentle slopes separated by moderately steep to steep sided valleys up to 30 m (100 ft) deep. Dipterocarp forest is the natural vegetation and in two plots which were enumerated, the commonest dipterocarps were *Hopea nervosa* and *Shorea bracteolata*; in one plot *H. nervosa* comprised 75% of the total and in the other plot the two species each comprised 42% of the dipterocarps present. Certain other dipterocarps which were identified, such as *Shorea leptoclados, S. smithiana Parashorea tomentella* are described by Wood and Meijer (1964) as generally occurring in lowland environments below 300 m (1 000 ft).

The plateau appears to be formed of dioritic rocks of the Crystalline Basement Formation. These rocks are largely metamorphosed and gneiss-like, but in the north they are unmetamorphosed.

Deeply weathered and well drained Orthic Acrisols are the dominant soils with occasional deep to moderately deep stony Chromic Luvisols. Orthic Luvisols are less common, but occur on some hillsides in the northern part of the plateau. The Chromic and Orthic Luvisols (Kobovan and Beeston Families) are described in the Mentapok Association.

Orthic Acrisols: Kinabutan Family

Orthic Acrisols of the Kinabutan Family are deep, strongly weathered and generally stone free, but may contain few gravel sized rock fragments at depth. They are fine-textured with clay percentages ranging from about 35% in the ochric horizons to 70% in the argillic horizons, the latter horizons having moderately thick cutans. Structures are generally subangular blocky throughout and colours range from yellowish brown in eluvial horizons to yellowish red in the argillic horizons.

The soils contain only trace amounts of exchangeable bases and are strongly to extremely acid. In spite of high clay contents these soils have very low cation exchange capacities; CEC/100 g clay values range from 20 to less than 1 meq%.Thus they clearly have strong affinities with Ferralsols.

MENTAPOK ASSOCIATION

The Mentapok Association is the most extensive association in the western part of the Lahad Datu District and it also occurs in the western part of the Tawau District in the vicinity of Gunong Tambuku. It covers an area of 895 km^2 (345 mi^2) (Plate 3-16; Stereogram 3-8).

The mountains, on which the association occurs, have an amplitude greater than 330 m (1 000 ft) and consist of steep interconnecting ridges with slopes averaging between 25° and 35°; ridge tops and valley floors are narrow and slopes are boulder strewn with occasional rock outcrops.

Basic and intermediate igneous rocks are the main parent materials although acid igneous rocks also occur sporadically.

Dipterocarp Forest is the natural vegetation.

Orthic and Chromic Luvisols are the dominant soils with Eutric Cambisols and Lithosols on very steep slopes and ridge tops.

Orthic Luvisols: Kobovan Family

The majority of these soils are moderately deep and well drained, and they commonly contain stones, weathering feldspar crystals and small black concretions. They are yellowish brown or dark yellowish brown in colour and consist of clay loam overlying clay; most argillic horizons have clay contents of between 35 and 65%.

Cation exchange capacities and base saturation percentages of these soils are generally high; exchangeable calcium levels are medium to high, magnesium levels are high to very high and exchangeable sodium levels are medium to high. Potassium levels, however, are low. The soils are moderately to slightly acid.

Chromic Luvisols: Beeston Family

These soils are physically and chemically similar to those of the Kobovan Family but have strong brown to yellowish red argillic horizons (Profile Lc 6).

Eutric Cambisols: Bombalai Family

These soils are well drained, shallow and stony with medium textures and yellowish brown colours.

Cation exchange capacities are high and base saturation percentages are very high. Exchangeable calcium levels are very high and sodium is high, but magnesium and potassium levels are low to very low. The soils are slightly acid.

MALUBOK ASSOCIATION

The Malubok Association occurs in the headwaters of the Danum and Segama, where it covers about 150 km^2 (58 mi^2). The landform consists of mountain ranges and occasional isolated dome-like mountains with sharp peaks frequently standing out above the rest of the landscape (Plate 3-17). Slopes are very steep and cliff faces are common. Much of the vegetation is stunted.

The parent materials of this association are mixed, but basic and intermediate igneous rocks are probably dominant. Ultrabasic rocks are also common and sandstones may occur sporadically. The soils which occur are described in the Mentapok and Bidu Bidu Associations and soils of the Gumpal Association may also be present.

Associations on igneous rocks 2. Ultrabasic igneous rocks

BIDU BIDU ASSOCIATION

The Bidu Bidu Association is the only association mapped on ultrabasic rocks (Table 3-10).

TABLE 3-10 The Bidu Bidu Association

Landforms	Parent materials	Main soil units	Soil families
Hills and mountains; slopes generally >25°	Ultrabasic igneous rocks	Chromic Luvisol	Malawali
		Orthic Luvisol	Tingkayu
		Eutric Cambisol	Binuang

The Bidu Bidu Association occurs on Gunong Ambun, Gunong Danum and Gunong Beeston, which are upthrust blocks with dome-like topography (Plate 3-14;

Stereogram 3-7). The association also occurs on hills and ridges within mountain masses composed of rocks of the Chert-Spilite and Kuamut Formations (Stereograms 3-1 and 3-6). It covers a total area of 112 km^2 (43 mi^2).

The ultrabasic rocks in the areas investigated are serpentinite and peridotite (see Table Table 3-3 for analyses). Chromium, nickel and cobalt are examples of elements which may be present in such high amounts as to limit the growth of certain plants.

The forest on ultrabasic rocks is low and dense with few trees exceeding 120 cm (48 in.) in girth or 12 m (40 ft) in height. On aerial photographs this is distinguishable from the surrounding forests by its dense pattern and light tone. It is interesting to note that some of the trees and plants are also associated with sandy soils of low base status. Examples include *Shorea vanulosa, S.smithiana, S.acuminatissima, S.scabrida, S.multiflora, Dryobanalops beccarii, Dipterocarpus lowii, Casuarina sumatrana* and *Nepenthes spp.* (pitcher plants).

The soils are predominantly Orthic and Chromic Luvisols with Eutric Cambisols and, more rarely, Lithosols on ridges and very steep slopes. On Gunong Beeston and in the upper Tingkayu Valley it is surprising that Ferralsols were absent in the areas examined, for they are the dominant soils of this association in other parts of Sabah; it is possible, however, that Ferralsols occur elsewhere in the survey area.

Chromic Luvisols: Malawali Family

Chromic Luvisols of the Malawali Family are generally moderately deep, well drained and stony. They have ochric A horizons, eluvial horizons with clay loam textures and reddish brown argillic horizons with clay textures. Structures are strongly developed subangular blocky throughout.

These soils have very high cation exchange capacities and base saturation percentages, with magnesium as the dominant exchangeable cation; values between 29 and 50 meq% being recorded. Calcium levels are medium, but potassium, sodium and available phosphorus levels are low. The soils are slightly acid to near neutral in reaction (Profile Lc 5).

Orthic Luvisols: Tingkayu Family

These soils are physically and chemically similar to Chromic Luvisols of the Malawali Family, differing only in their colours, which are commonly yellowish brown to dark yellowish brown.

Eutric Cambisols: Binuang Family

Eutric Cambisols of the Binuang Family have ochric A and cambic B horizons. They are shallow, stony and fine-textured with strong subangular blocky structures throughout.

These soils have high cation exchange capacities and very high base saturation percentages. Magnesium is the dominant exchangeable cation whilst exchangeable calcium levels are medium and sodium, and potassium levels are low. Available phosphorus levels are very low and the soils are slightly acid.

Part 4

Agriculture and soil suitability

AGRICULTURE

There has been very little use of land for agriculture in the western parts of the Tawau and Lahad Datu Districts. Until recent times shifting cultivation was the only form of agriculture and it is still being carried out in the Serudong and Kalabakan Valleys, and on on Pulau Sebatik. Some of the Serudong Muruts left the settlement scheme near Tawau after Confrontation and returned to the Serudong Valley where they now grow hill rice and tapioca (Plate 3-8). Along the Sungai Kalabakan, up to 16 km (10 mi) above Kalabakan, Muruts from the settlement scheme plant hill rice, maize and tapioca. On Pulau Sebatik there are a number of small settlements to the east of Bergosong. There has been no shifting cultivation on the Sungai Segama, upstream from the mouth of the Kawag, in recent times.

In the coastal settlements, the Tidongs grow tapioca and coconuts in addition to fishing. In the 1930s an abaca estate was opened near Brantian but this closed before the war.

The main agricultural development occurred during Confrontation with Indonesia between 1963 and 1965 when the people living along the Sungai Serudong and the Sungai Kalabakan, and on Pulau Sebatik and Pulau Simandalan were moved to more secure areas and housed in settlement schemes. The Serudong Muruts were settled at Mile 17 on the Apas road near Tawau, Muruts and Tidongs were settled at Kalabakan and the Tidongs of Pulau Simandalan were moved to Kuala Merotai and were given land to grow oil palm (Plate 3-10). The Tidongs of Pulau Sebatik were moved to settlement schemes on the island at Bergosong and Tamang where they are now growing rubber. These schemes, apart from the one at Kalabakan, are now administered by the Sabah Land Development Board. The largest area of coconuts under cultivation is at the scheme at Kalabakan where, however, many trees have been destroyed by wild pigs. Cocoa is grown by North Borneo Plantations Ltd at Bergosong on Pulau Sebatik.

SOIL SUITABILITY

The soil associations have been classified in terms of the suitability of their soils for agricultural use; three broad suitability classes are recognised (Text Map 3-6).

1. Suitable land. Suitable land has no more than minor limitations and is suited to a wide range of crops.

2. Marginal land. Marginal land has limitations that restrict the range of crops that can be grown and requires improvement or soil conservation measures.

3. Unsuitable land. Unsuitable land has severe limitations which preclude its use for agriculture.

Table 3-11 shows the approximate correspondence between the 3-category system of soil-suitability classification used here and the 5-category system used in the *Sabah Land Capability Classification* (Sabah, State Development Planning Committee, 1973) and also to be used in the forthcoming Land Resource Study *The Land Capability Classification of Sabah*. The broader, 3-category classification has been found more appropriate for the purpose of this report.

TABLE 3-11 Approximate correspondence between the soil suitability classification of (a) this report and (b) that of The Land Capability Classification of Sabah

Soil suitability classification			
(a)		(b)*	
Category 1.	Suitable land: minor limitations	Group 1.	No limitations to agricultural development. A wide range of crops can be grown and yields can be expected to be good with a moderate input of fertiliser.
		Group 2.	Few minor limitations to agricultural development. Choice of crops more restricted than in Group 1 and expected yield is lower.
Category 2.	Marginal land	Group 3.	At least one serious limitation to agricultural development. Unsuited to diversified agriculture.
Category 3.	Unsuitable land: severe limitations	Group 4.	More than one serious limitation to agricultural development. Generally a strong risk for agriculture, even with a high standard of management.
		Group 5.	At least one very serious limitation to agricultural development. Agriculture is generally impossible.

*For full details of Groups 1 to 5 see *The Land Capability Classification of Sabah.*

About 78% of the survey area is considered to be unsuitable, 14% is marginal and only 8% is considered to be suitable for agriculture. Most of the suitable and marginal agricultural land occurs on the coastal lowlands of Cowie Harbour including the lower Umas Umas, Kalabakan and Silimpopon Valleys and on Pulau Sebatik. An extensive area of suitable and marginal agricultural land also occurs in the Segama Valley. Other suitable and marginal areas occur on the eastern boundary of the survey area.

The limitations and potential for development of each soil association are discussed in the following paragraphs.

Weston Association

The Weston Association has a number of very severe limitations to agricultural development, namely strongly saline soils, potential acid sulphate conditions, very poor drainage and tidal flooding. The presence of peat is a further limitation in some areas. This association is capable of reclamation but it would not be justifiable while there is agricultural land available on the mainland.

Sapi Association

The Sapi Association has severe drainage limitations and on its seaward edge may have a localised, potential acid-sulphate problem. Since the soils are fine-textured and naturally poorly drained the land would be suitable for wet rice cultivation. Drainage of this land for other crops would probably not be feasible.

Kinabatangan Association

This association has limitations due to imperfect to very poor soil drainage and liability to occasional floods of short duration. Flooding is unlikely to be the serious hazard that it is in the Kinabatangan and lower Segama Valleys (see Volume 2) because none of the rivers are long and floodwaters are quickly drained. Floods may be more severe on the Segama, but downstream from where the Kinabatangan Association is mapped, there are many rapids so that floodwater would soon be removed.

With adequate drainage the Kinabatangan Association would be suited to a wide range of arable and tree crops; cocoa for example is already grown at Bergosong on Pulau Sebatik.

Karamuak Association

The Karamuak Association has only minor limitations to agricultural development. On the floodplains some soils have imperfect and poor drainage and some areas are liable to occasional floods of short duration. In addition some soils are stony below 50 cm (20 in). The terraces have a minor slope limitation.

With adequate drainage this association would be suited to a wide range of arable and tree crops. The terrace soils, however, are strongly weathered and low in bases and are not recommended for demanding crops.

Labau Association

The Labau Association has identical limitations to the Karamuak Association, but in addition some of the soils have minor nutrient limitations.

With adequate drainage of the floodplains, tree crops such as rubber, oil palm and coconuts could be grown.

Brantian Association

On the flat seaward portions of the terraces on the mainland and on Pulau Simandalan there are minor drainage limitations where the soils are imperfectly and poorly drained, whilst further inland where the terraces are undulating there are minor slope limitations. The majority of soils also have minor nutrient limitations. In addition the area has a relatively low rainfall; at Umas Umas for example there have been 11 dry periods of 10 consecutive dry days in the last 10 years and at Brantian there have been 17 dry periods in 5 years. It has been found that such dry periods can adversely affect the production of oil palms on well drained soils (Lamb, 1972). On the flatter portions of the terraces the fine-textured subsoils will probably retain sufficient moisture to compensate for the dry periods, but further inland water shortage might be a problem for oil palm. Oil palm is in fact grown on the flat seaward portion of the terrace at Kuala Merotai, but the palms are still too young for an assessment of their yield to be made. Rubber could probably be grown anywhere, but coconuts would grow best on the better drained inland portions of the terraces, and they have already been planted on the settlement scheme at Kalabakan. Soils and topography would permit the cultivation of sugarcane but rainfall is too high; it appears that sugarcane should have two months prior to harvest in which the total rainfall does not exceed 100 mm (4 in) (Bower, 1973).

On Pulau Sebatik there is a minor to locally severe slope limitation and the majority of the soils have minor nutrient limitations. Rubber is already grown on two settlement schemes and could be grown more widely. Coconuts could also be grown. At Wallace Bay there have been 15 dry periods of 10 consecutive days in 8 years and such periods could adversely affect oil palm production.

Of the river valleys, in which the Brantian Association occurs, only the Silimpopon Valley is considered suitable for agriculture; about 40 km^2 (16 mi^2) with only minor slope and nutrient limitations would be suitable for the less demanding arable and tree crops.

Kepayan Association

The soils of this association have severe nutrient deficiencies and the sandy surfaces have low moisture-holding capacities. They are not suitable for agriculture.

Dalit Association

This association has severe slope and minor nutrient limitations. It is suited to tree crops such as rubber, coconuts and oil palm.

Rumidi Association

This association has minor slope limitations, and localised nutrient limitations and is in general suited to a wide range of arable and tree crops. In the Segama Valley many of the soils are rich in bases and would be suited to the more demanding crops such as cocoa, but in the upper Danum lowlands the majority of the soils are deficient in nutrients and would be suited to crops such as coconuts and rubber.

Kretam Association

This association has severe slope limitations and localised nutrient limitations. With erosion control measures these soils would have a similar potential to those of the Rumidi Association.

Kalabakan Association

This association has a severe slope limitation and requires erosion control measures before it is suitable for agriculture. The soils are generally rich in bases and are suited to a wide range of arable and tree crops.

Orchid Plateau Association

The Orchid Plateau Association has minor nutrient limitations and severe relief limitations on valley sides. It is restricted to the Orchid Plateau which occurs at an altitude of about 750 m (2 500 ft) and the low temperatures at this altitude, which have been calculated to range from about 20-28°C (68-82°F), would limit the range of crops. It may be possible, however, to introduce vegetables and fruits which grow well in areas of lower temperatures in tropical regions.

Bang Association

A high proportion of the Bang Association has very severe slope limitations but hilly areas with less severe slope limitations have a similar potential to the Kretam Association.

Associations on mountains and steep hills

The Mawing, Lokan, Crocker, Maliau, Serudong, Gumpal, Mentapok, Bidu Bidu and Malubok Associations all occur on either mountains or steep hills and are not suitable for agriculture because cultivation would result in severe erosion and increased water runoff. With the exception of the Serudong, Bidu Bidu and Malubok Associations, these associations have large reserves of commercial forest and their economic future will be with timber production.

Water catchment conservation

Consideration should be given to the conservation of water catchment areas as a number of large rivers — the Segama, Kalabakan and Tingkayu rise in the mountains of the survey area and flow through settled agricultural land in their lower courses. Indescriminate logging of the headwaters of these rivers will cause severe soil erosion and increased water runoff resulting in a disturbance of the regime of these rivers which could cause serious flooding in their populated lower reaches. A policy of conservation of water catchment areas would serve the additional function of allowing game reserves to be established.

CONCLUSIONS

The main agricultural development in the near future is likely to be on the coastal lowlands of Cowie Harbour and on Pulau Sebatik where there are approximately 492 km^2 (190 mi^2) of suitable and marginal agricultural land. There is an existing network of timber roads which link up with the Tawau road system and in addition there are a number of abandoned timber roads which could be re-opened. Large parts of these lowlands are not included in designated Forest Reserves so there are no administrative restrictions on their use.

The area of suitable land on the Sungai Segama is more remote and has not yet been reached by timber roads but it will become important in the future when Lahad Datu is linked by road to Sandakan via Lamag on the Sungai Kinabatangan. In this area there are approximately 260 km^2 (100 mi^2) of suitable and marginal agricultural land adjoining a larger area of similar land in the Sandakan Residency. All this land, however, is included in a designated Forest Reserve.

In the upper Tingkayu Valley and on the Orchid Plateau, there are approximately 62 km^2 (24 mi^2) of suitable and marginal agricultural land which adjoin similarly suitable land in the middle Tingkayu and Binuang Valleys outside the survey area. There is an expanding network of timber roads in these areas with links to Tawau and Lahad Datu. Suitable land in the valley of the upper Bole adjoins a larger area in the Lunkosa Valley and this area is also linked by a network of timber roads to Lahad Datu and Tawau.

Thus the main agricultural potential of the survey area is on its southern, northern and eastern edges. In the mountains of the interior and the mangrove swamps of Cowie Harbour the economic potential lies in the exploitation of timber resources.

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