Land Resource Study

20 The Soils of Sabah
Volume 4
South-Western Districts

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

The soils of Sabah
Volume 4
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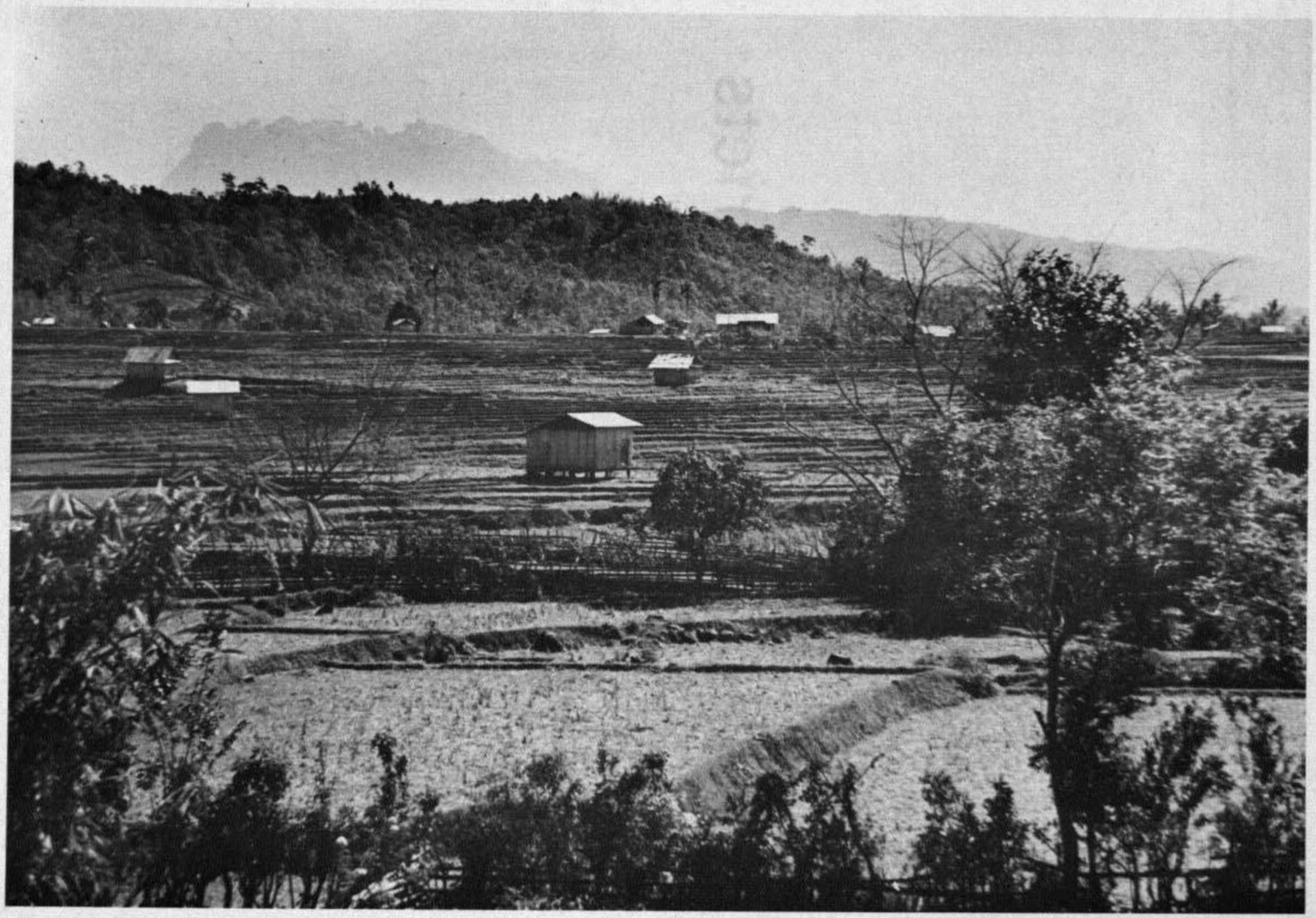

Wet rice in the Tambunan Plain (Binkor Association); Gunong Kinabalu in background

Land Resources Division

The soils of Sabah

Volume 4

South-western districts

R P Bower, P A Burrough, M S Kalsi and P Thomas

Land Resource Study 20

Land Resources Division, ~~Ministry of Overseas Development~~
Tolworth Tower, Surbiton, Surrey, England KT6 7DY
1975

THE LAND RESOURCES DIVISION

The Land Resources Division of the Ministry of Overseas Development assists developing countries in mapping, investigating and assessing land resources, and makes recommendations on the use of these resources for the development of agriculture, livestock husbandry and forestry; it also gives advice on related subjects to overseas governments and organisations, makes scientific personnel available for appointment abroad and provides lectures and training courses in the basic techniques of resource appraisal.

The Division works in close co-operation with government departments, research institutes, universities and international organisations concerned with land resources assessment and development planning.

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.
Volume 5	References and appendixes. B D Acres, R P Bower, P A Burrough, C J Folland, M S Kalsi, P Thomas and P S Wright.

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Part 1

Introduction

ACKNOWLEDGEMENTS

Sources of data are quoted in the text and full acknowledgements are given in the Introduction to Volumes 1-5 at the beginning of this study.

We would like to express our thanks to the Director of Agriculture, the Assistant Director (Research) and staff of the Department of Agriculture and to the District officers and Ketua Kampongs for their help and co-operation while this survey was in progress. The three Land Resources Division authors would like to thank the State and Federal Governments for the opportunity of working and living in Sabah.

We are most appreciative of the hard work cheerfully carried out by the soil survey assistants, drivers and men in the field. We are also grateful to the staff of the laboratory at Tuaran, the ladies of the cartography section and the typists for their assistance in preparing maps and reports.

Thanks are also due to the Director, Malaysian Meteorological Services, for permission to quote climatic data, and to the Forest Botanist, Forestry Department, Sandakan for information on vegetation.

ABSTRACT

This volume describes the soils of the south-western districts of Sabah. The area surveyed covers 19 321 km^2 (7 460 mi^2). Twenty-three soil associations are identified and mapped at a scale of 1: 250 000. The soils in these associations are classified using the FAO World Soil Map Legend and separated into soil families according to parent materials. The suitability of the soil associations is assessed for agricultural development. Five associations covering about 4% of the area are considered suitable for most types of agricultural development; 5 other associations (9% of the area) are considered suitable for a limited range of tree crops such as rubber. The remaining associations which cover over 85% of the area are not recommended for agricultural development.

RÉSUMÉ

Ce volume traite des sols des Districts du sud-ouest de Sabah dont la superficie est 19 321 km^2 (7 460 mi^2). Vingt trois associations de sol ont été distinguées et délimitées sur une carte à l'échelle de 250 000. Les sols des associations sont classés suivant le système FAO et divisés en familles suivant leurs roche-mères. La vocation agricole des associations de sols a été estimée. Cinq associations montant à 4% de la superficie totale seraient valables pour plusieurs types de dévelopement agricole; cinq autres associations (9% de la superficie) seraient utilisables pour la cultivation d'une gamme limitée d'arbres productifs comme l'hévéa. La reste de la superficie (85%) contient des associations considerées comme inutilisables.

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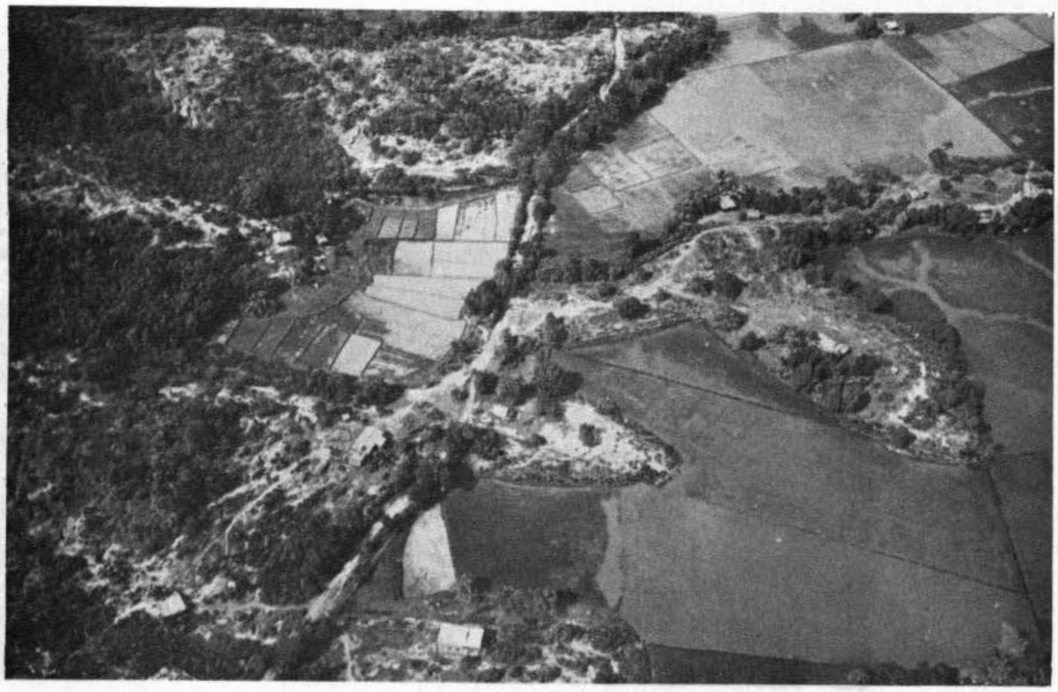
PLATE 4-2 Near Papar. Rice cultivation on soils of the Kinabatangan Association with peatswamps of the Klias Association to the left



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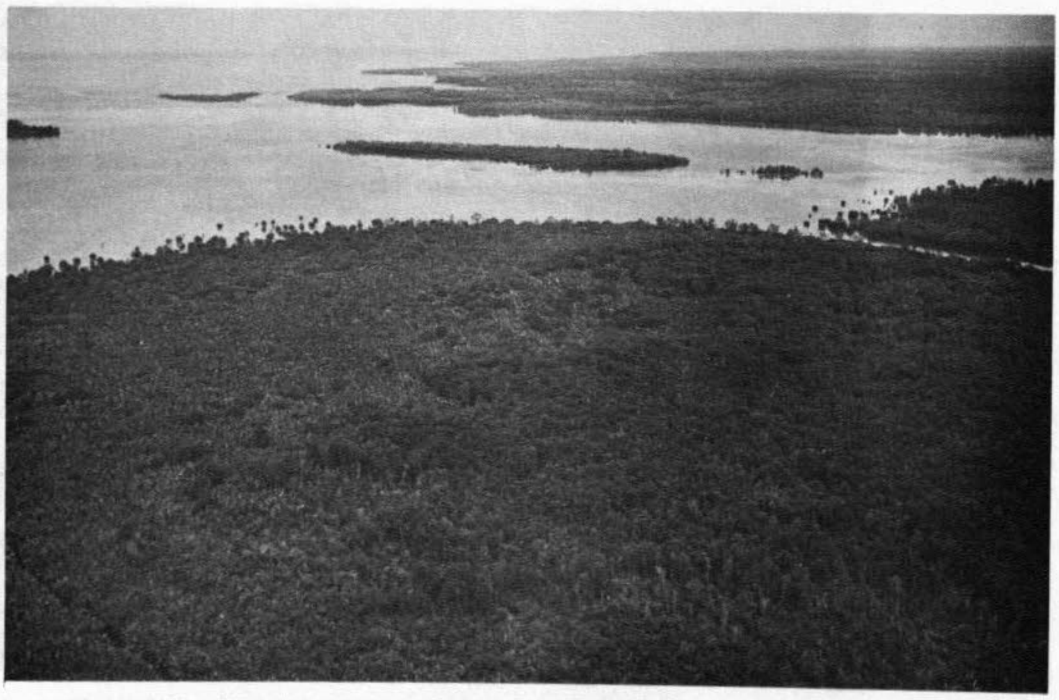

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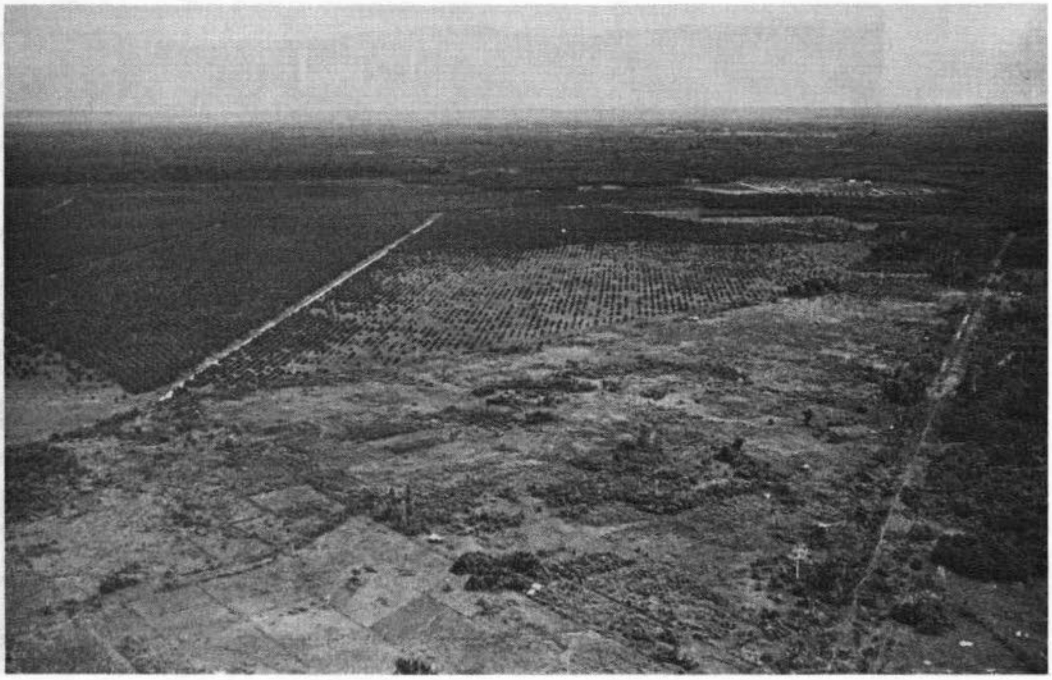

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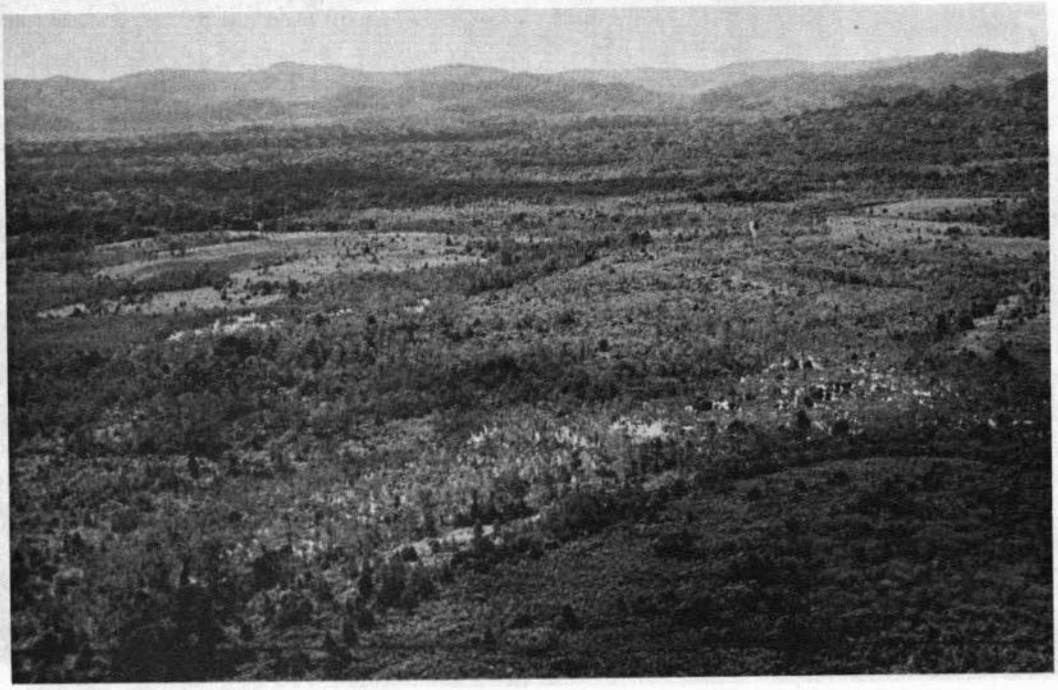

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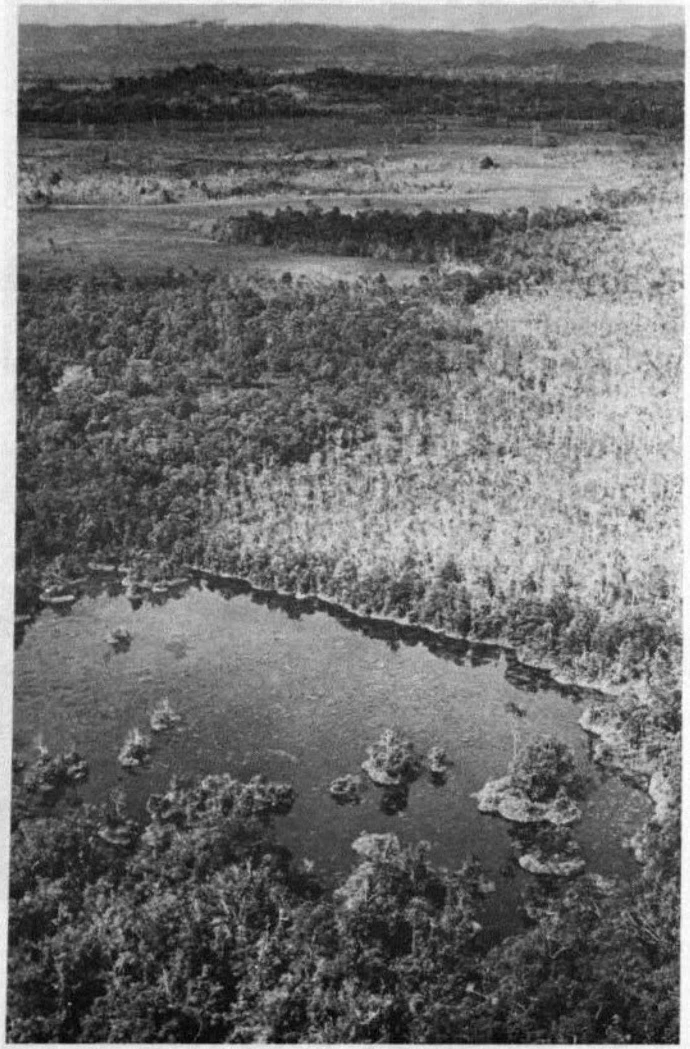

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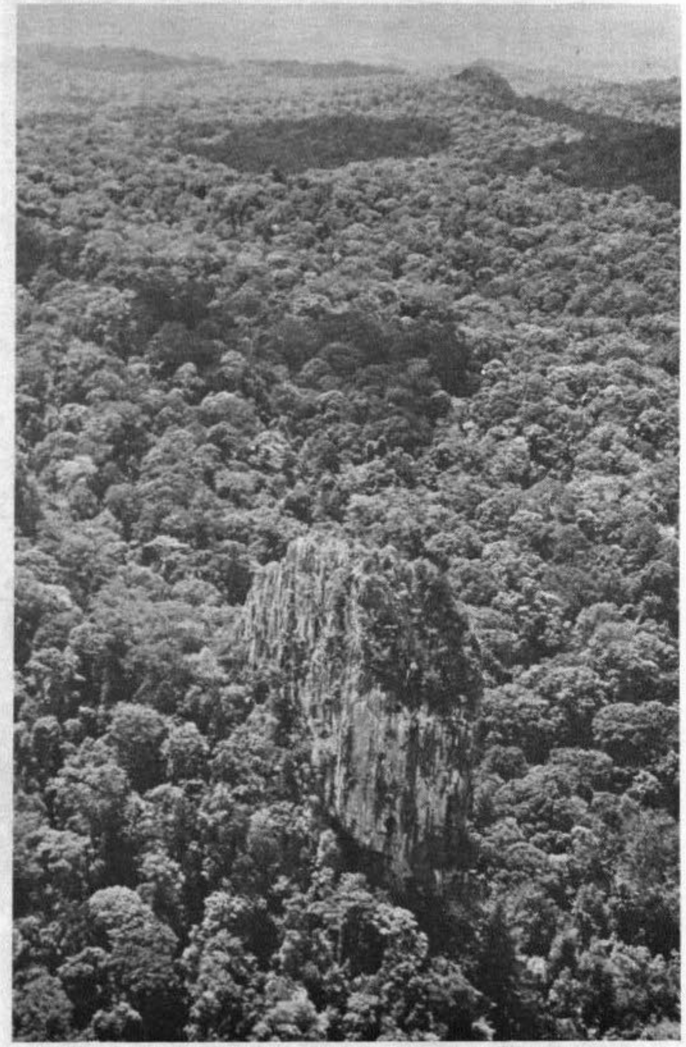

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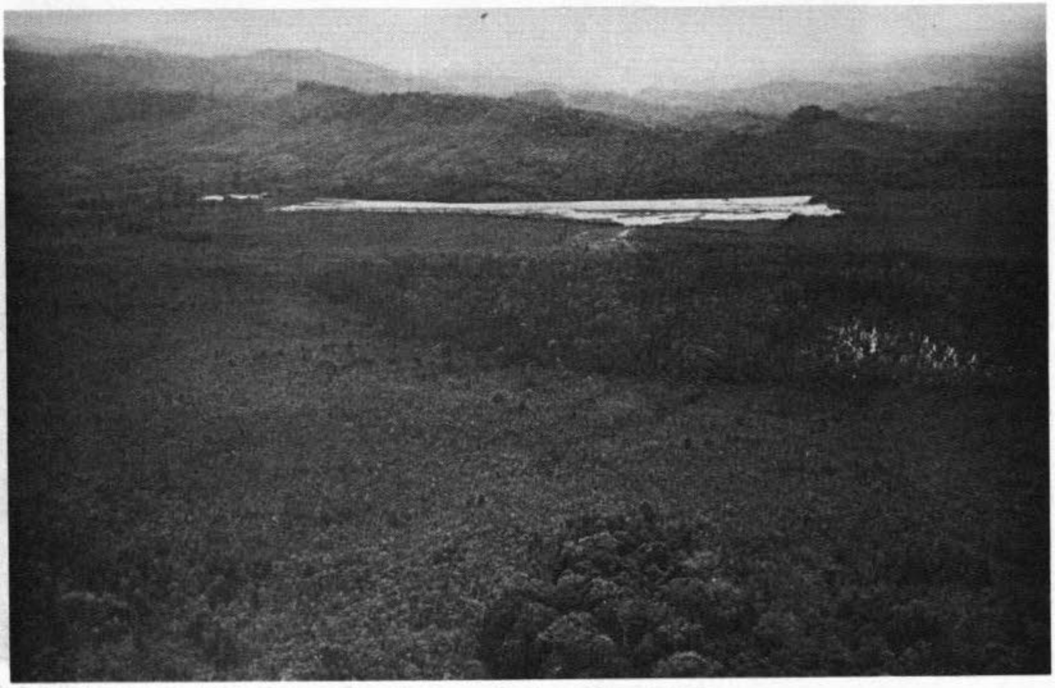

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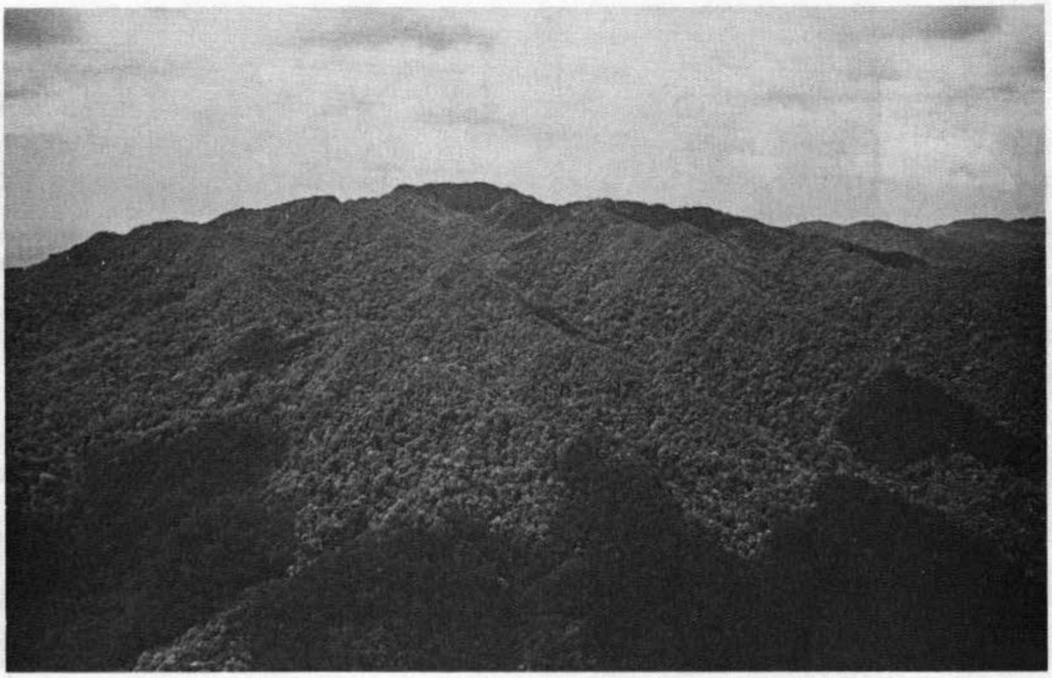

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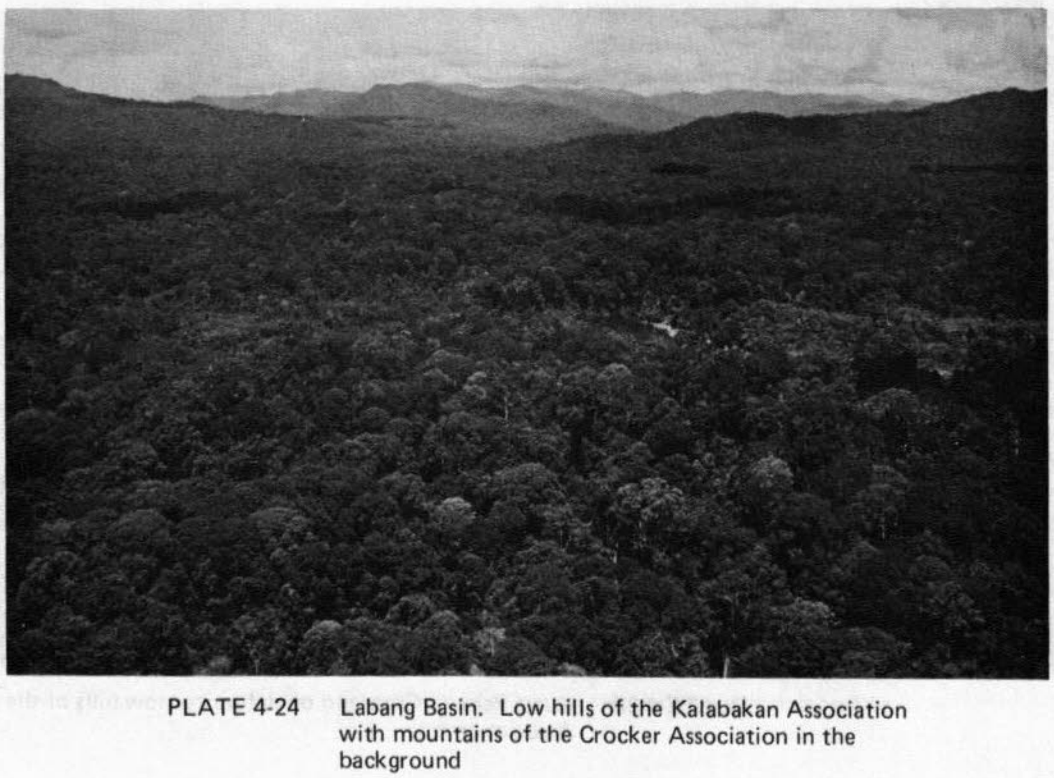

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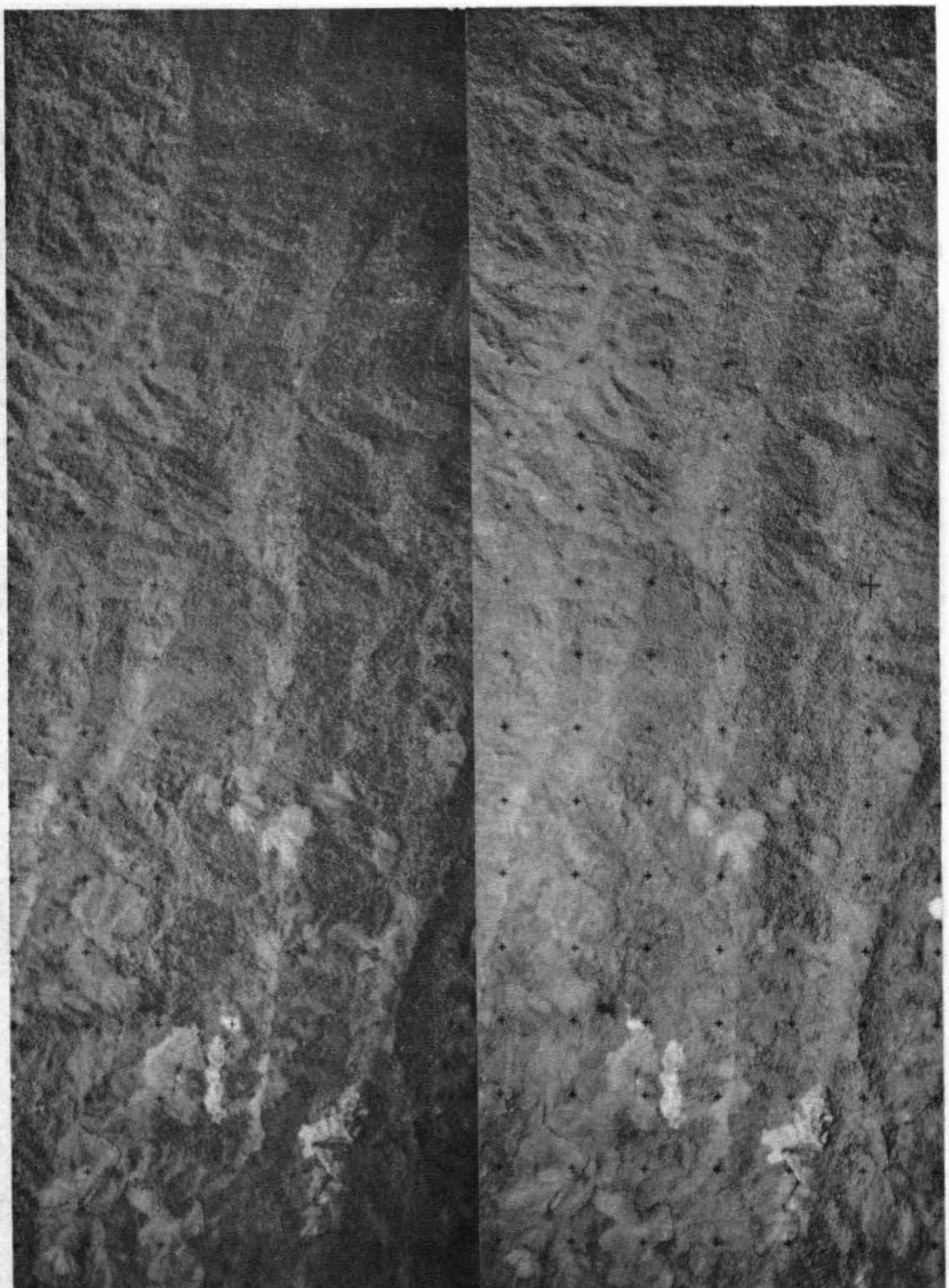

STEREOGRAM 4-1 The Crocker Range (Crocker Association) in the south of the Tenom District (Scale 1 : 64 000)

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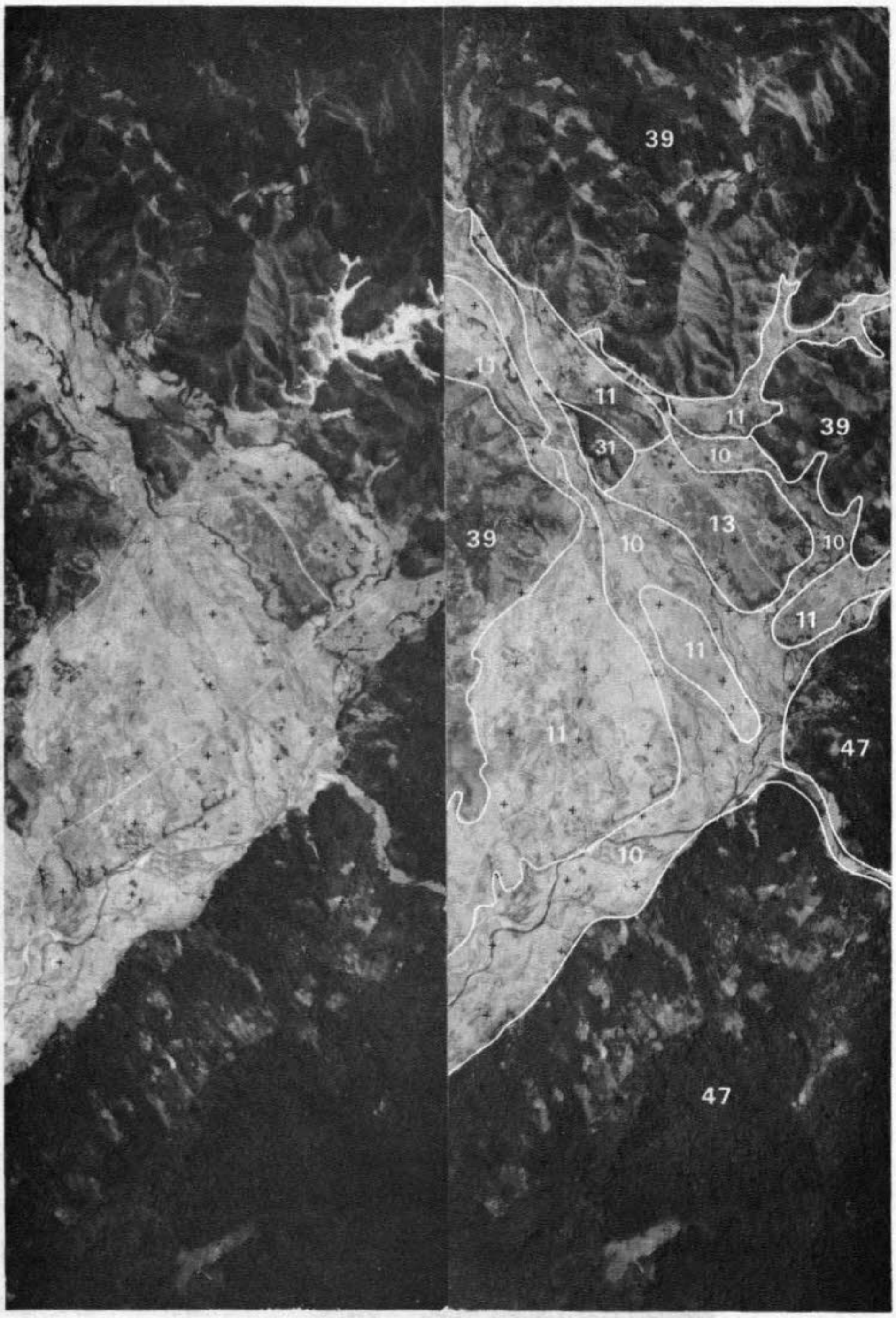

STEREOGRAM 4-2 The Tambunan valley with river terraces of the Labau (10), Binkor (11) and Kepayan (13) Associations. Sandstone and mudstone hills and mountains are included in the Dalit (31) Lokan (39) and Crocker (47) Associations (Scale 1 : 64 000)

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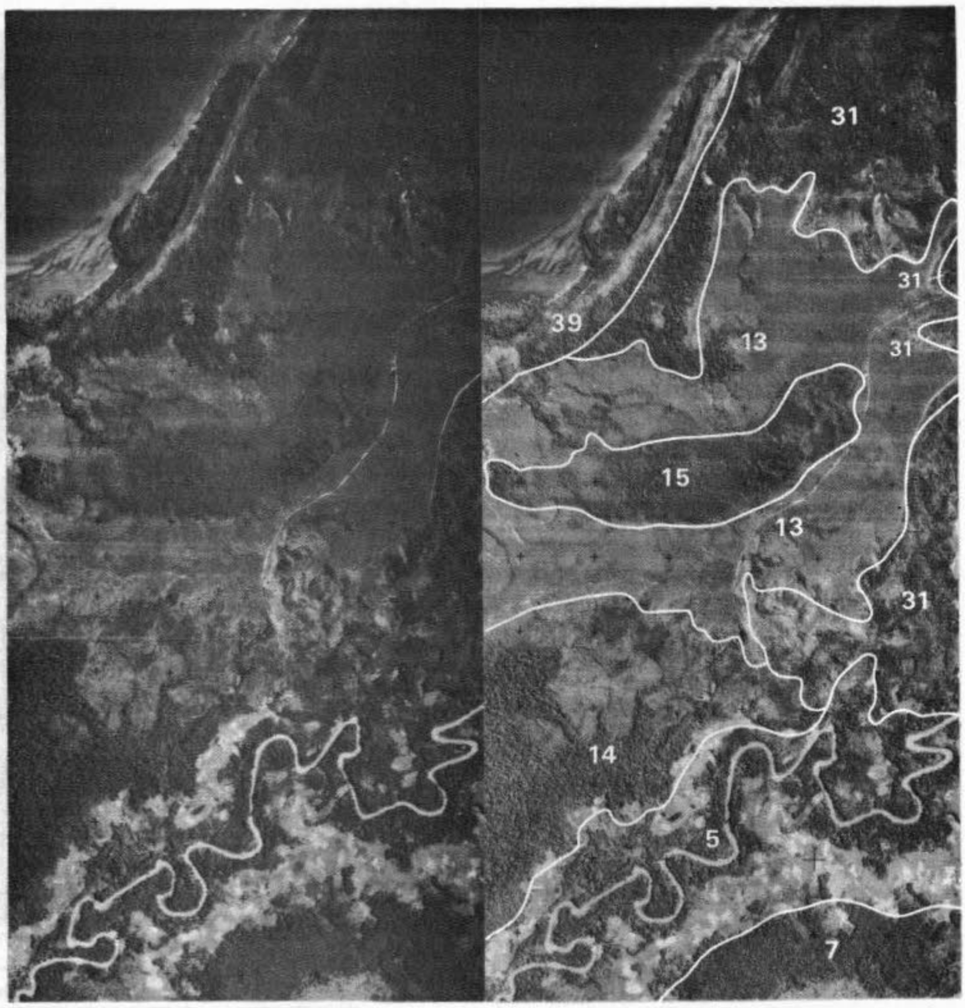

STEREOGRAM 4-3 The Kepayan (13), Sipitang (15) and Sook (14) Associations on coastal terraces south of Sipitang. The Dalit (31) and Lokan (39) Associations, on sandstone and mudstone hills and the Kinabatangan (5) and Klias (7) Associations, on the floodplain of the Sungai Mengalong, are also shown (Scale 1 : 64 000)

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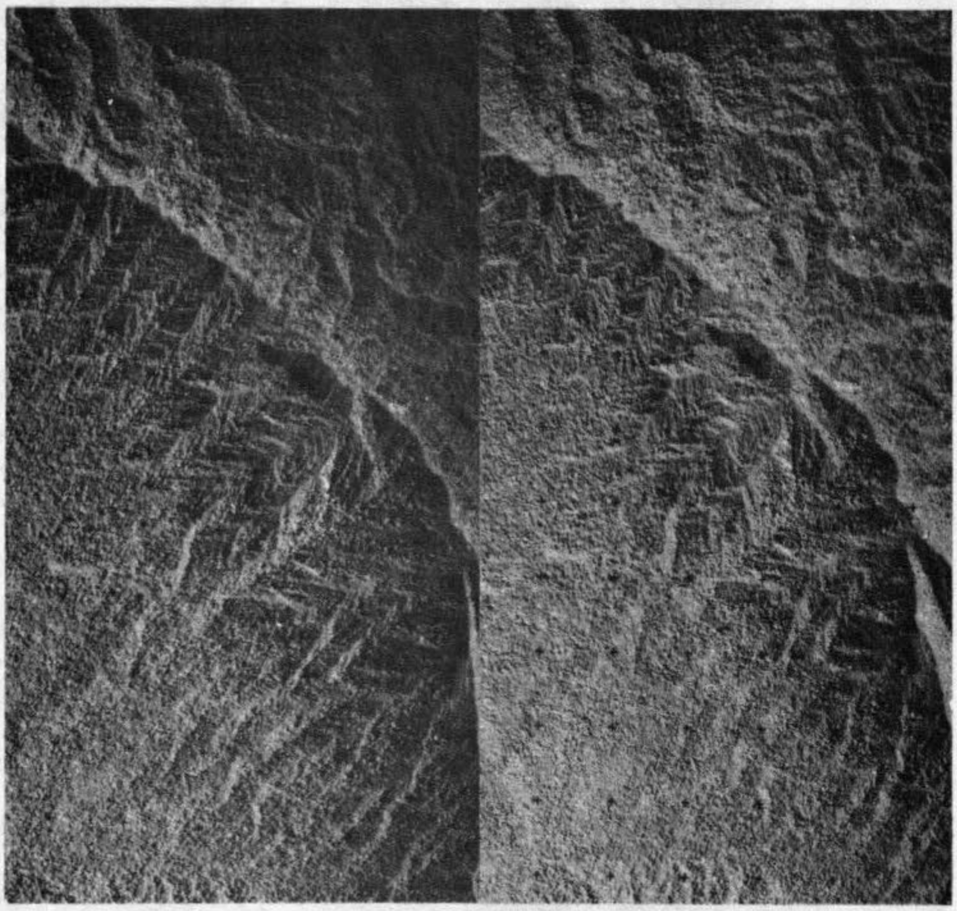

STEREOGRAM 4-4 The Maliau Association in the Pensiangan District
(Scale 1 : 64 000)

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Part 2

Geographical background

INTRODUCTION

This volume describes the soils of the south-western part of Sabah comprising the Kota Kinabalu, Penampang, Papar, Beaufort, Kuala Penyu, Labuan, Sipitang, Tambunan, Keningau, Tenom and Pensiangan Districts (Text Map 4-1; Table 4-1).

TABLE 4-1 Administrative districts and their areas

District	Area	
	km^2	mi^2
Kota Kinabalu	308	119
Penampang	409	158
Papar	1 396	539
Beaufort	1 572	607
Kuala Penyu	515	199
Labuan	57	22
Sipitang	2 732	1 055
Tambunan	1 484	573
Keningau	3 028	1 169
Tenom	2 277	879
Pensiangan	5 543	2 140
Total	19 321	7 460

Apart from the Klias Peninsula, the coastal plains, and the valleys and plains of the interior, the survey area is rugged country with extensive areas of land over 600 m (2 000 ft*). The Crocker Range lies between the coastal plains and main inland valleys; it is seldom less than 900 m (3 000 ft) and in the northern part of the area often exceeds 1 500 m (5 000 ft). Gunong Alab 1 963 m (6 442 ft) and Gunong Lamaku 1 966 m (6 450 ft) are the 2 highest peaks of the range within the survey area. To the south of Gunong Lamaku, the Crocker Range merges into the Maligan Range which continues to the Sarawak State boundary. Parallel to and south-east from the Crocker Range in the north of the area is the Trusmadi Range, in which lies Gunong Trusmadi, 2 642 m (8 669 ft), the second highest mountain of Sabah; this range forms part of the eastern boundary of the survey area. The Witti Range lies to the south of the Trusmadi Range and much of the land in the southern parts of the Sipitang, Tenom and Pensiangan Districts is over 900 m (3 000 ft); parts are over 1 500 m (5 000 ft).

The Padas and the Pensiangan are the two major rivers in the area. The Padas and its tributaries drain the land between the Crocker and Maligan Ranges in the west and the Trusmadi and Witti Ranges in the east; the Padas itself cuts through the Crocker

*a.m.s.l.

Range near Tenom forming the Padas Gorge and flows across the Klias Peninsula into Brunei Bay. The Pensiangan drains the area to the east of the Witti Range and south of the Trusmadi Range; it flows south into Kalimantan.

SETTLEMENT AND POPULATION

Until the latter years of the 19th Century the area was under the loose control of the Sultans of Brunei and Sulu. As a result of negotiations with these rulers, and with the approval of the British Government, the Chartered Company of North Borneo was established in 1881. This company administered the whole of present day Sabah except Labuan until the Japanese occupation in 1942. In 1945 Labuan and the mainland became the British colony of North Borneo and in 1963 North Borneo was renamed Sabah and became a member state of the Federation of Malaysia.

The total population of the south-western Districts at the time of the 1970 Census was 259 758 (Sabah, Department of Statistics, 1971); this represents an apparent increase of 43% between 1960 and 1972 but how much is due to greater census efficiency is not known (Robertson, 1970). The people are concentrated along the coast and the interior plains (Text Map 4-3) and there has been appreciable movement to the towns from rural areas since 1960. About one-fifth of the people live in the 5 towns of the survey area and Kota Kinabalu, the State capital, has a population of almost 41 000 people. The average distribution of population by Districts is very uneven, ranging from 302 people/km^2 (781/mi^2) in Labuan and 200/km^2 (518/mi^2) in Kota Kinabalu to 1 person/km^2 (3/mi^2) in Pensiangan. The number of people per unit area of land in agricultural use emphasises the concentration of the population in relatively small areas, leaving large areas of hills and mountains uninhabited. In the Pensiangan District there are 203 people/km^2 (525/mi^2) of land in agricultural use (Table 4-2). (Malaysia, Department of Agriculture, 1972).

There are many ethnic groups. The Kadazans are numerically the largest indigenous race; they live mainly in the northern parts of the area. The Muruts are found mainly in the central and south-eastern areas and the Bajaus are confined to the coast since they are essentially fishing people. About 1/5 of the people are Chinese; they live mostly in the towns and larger villages. Various other races are present in small numbers.

COMMUNICATIONS

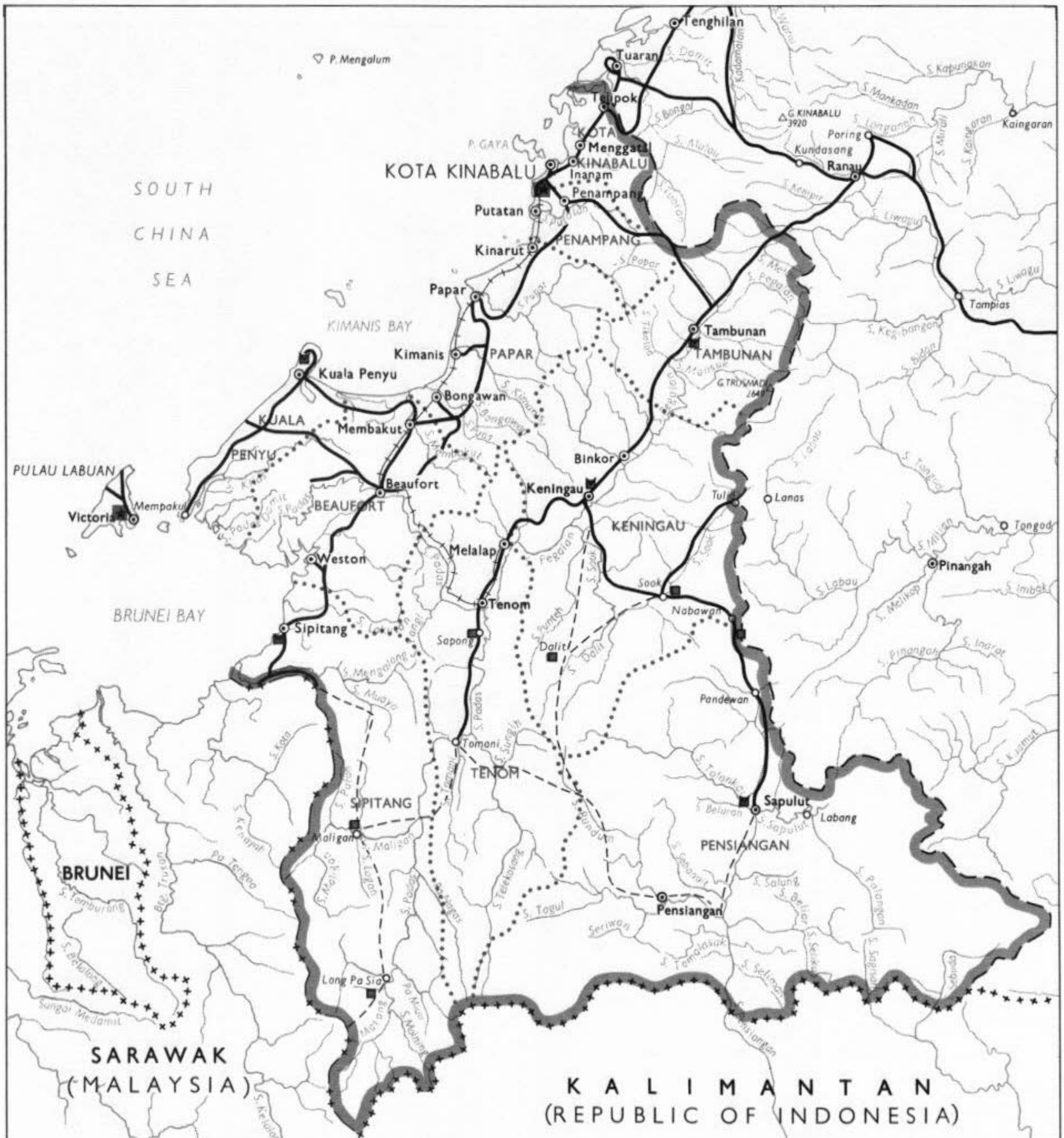
The main communications are shown in Text Map 4-1. The only public railway in Sabah runs along the coast from Kota Kinabalu to Beaufort and through the Padas Gorge to Tenom. The recently built Kota Kinabalu to Tambunan road also links the interior plains of Tenom, Keningau and Tambunan with the west coast and a road to Ranau joins the main road linking the west and east coasts of the State. The west coast road is complete from the Sarawak border to north of Kota Kinabalu. There are regular flights between Kota Kinabalu and Keningau, Labuan and Sapulut; most of the isolated villages which are linked by bridle paths can be reached by helicopter. Boats are a major means of transport in the Pensiangan District and many of the coastal rivers are navigable.

The routes traversed during the course of the survey are shown in Text Map 4-2.

ECONOMY

The economy of the area is dominated by agriculture. Subsistence farming has been practised for centuries in the interior and also along the coast. Rice is the traditional staple crop with lesser amounts of tapioca, yams, vegetables and fruit. Rubber has been the major agricultural export since about 1920. Sago was a major export crop until the 1940's. In the last few years there have been attempts to diversify agriculture by introducing such crops as oil palm and cocoa.

SETTLEMENT AND COMMUNICATIONS TEXT MAP 4-1



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SCALE 1:1,425,000

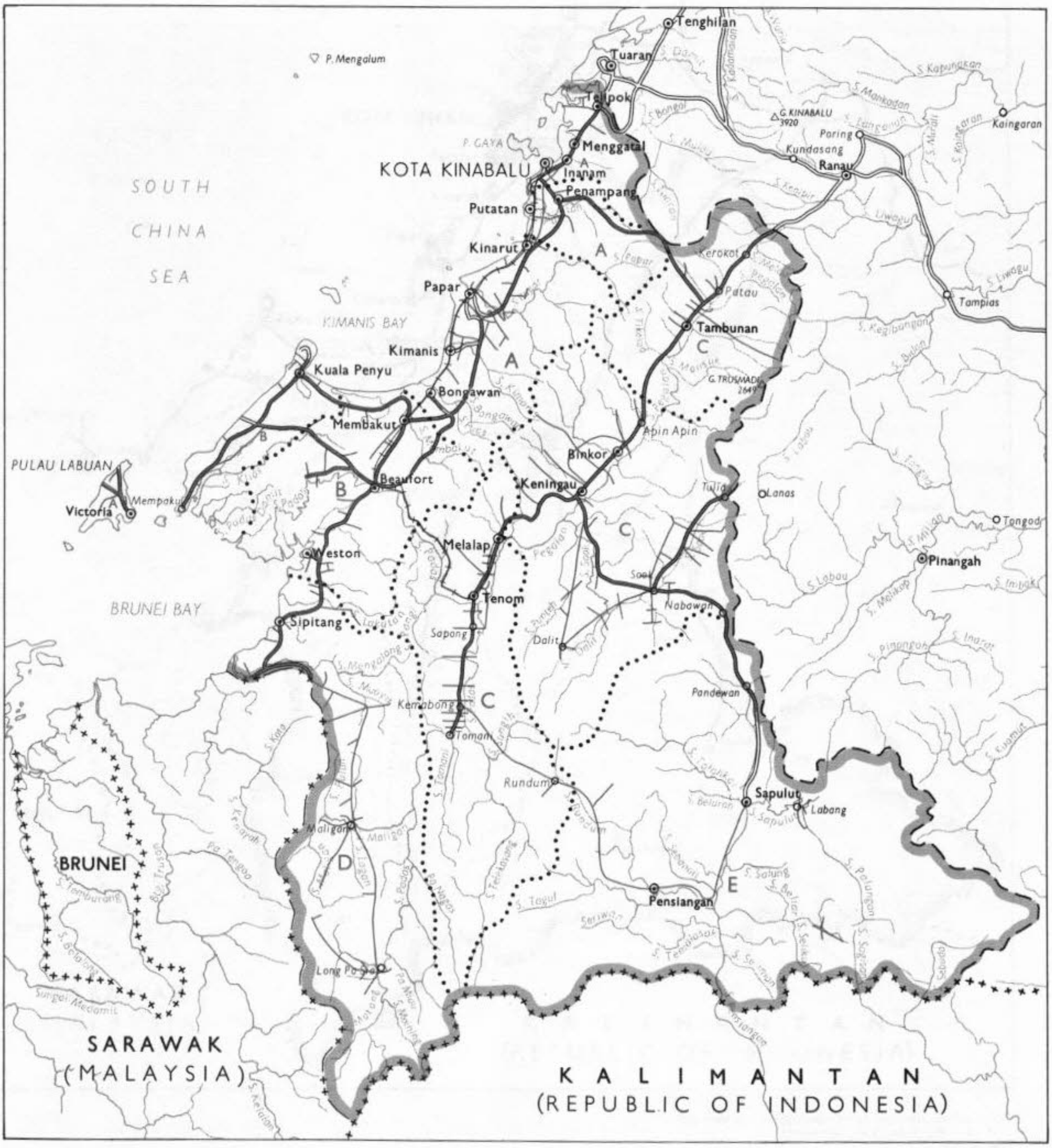
Miles 10 0 10 20 30 40 50 Miles

Kilometres 10 0 20 40 60 80 Kilometres

International Boundary	+ + + + + + +	Railway	
State Boundary	—— + + ——	River	
District Boundary	• • • • • • • • •	Trigonometrical Station (ht. in metres)	△
Soil Survey Boundary		Airport	
Motorable Road	——	Airstrip	
Track	— — — — —	Airstrip (Disused)	

AREAS TRAVERSED

TEXT MAP 4-2



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SCALE 1:1,425,000

Miles 10 0 10 20 30 40 50 Miles

Kilometres 10 0 20 40 60 80 Kilometres

International Boundary ++++++++

State Boundary —++—

District Boundary ....

Soil Survey Boundary

Motorable Road

Railway

Trigonometrical Station (ht. in metres) △

Routes traversed

Surveyed by:-

P. Thomas — A

M. S. Kalsi — B

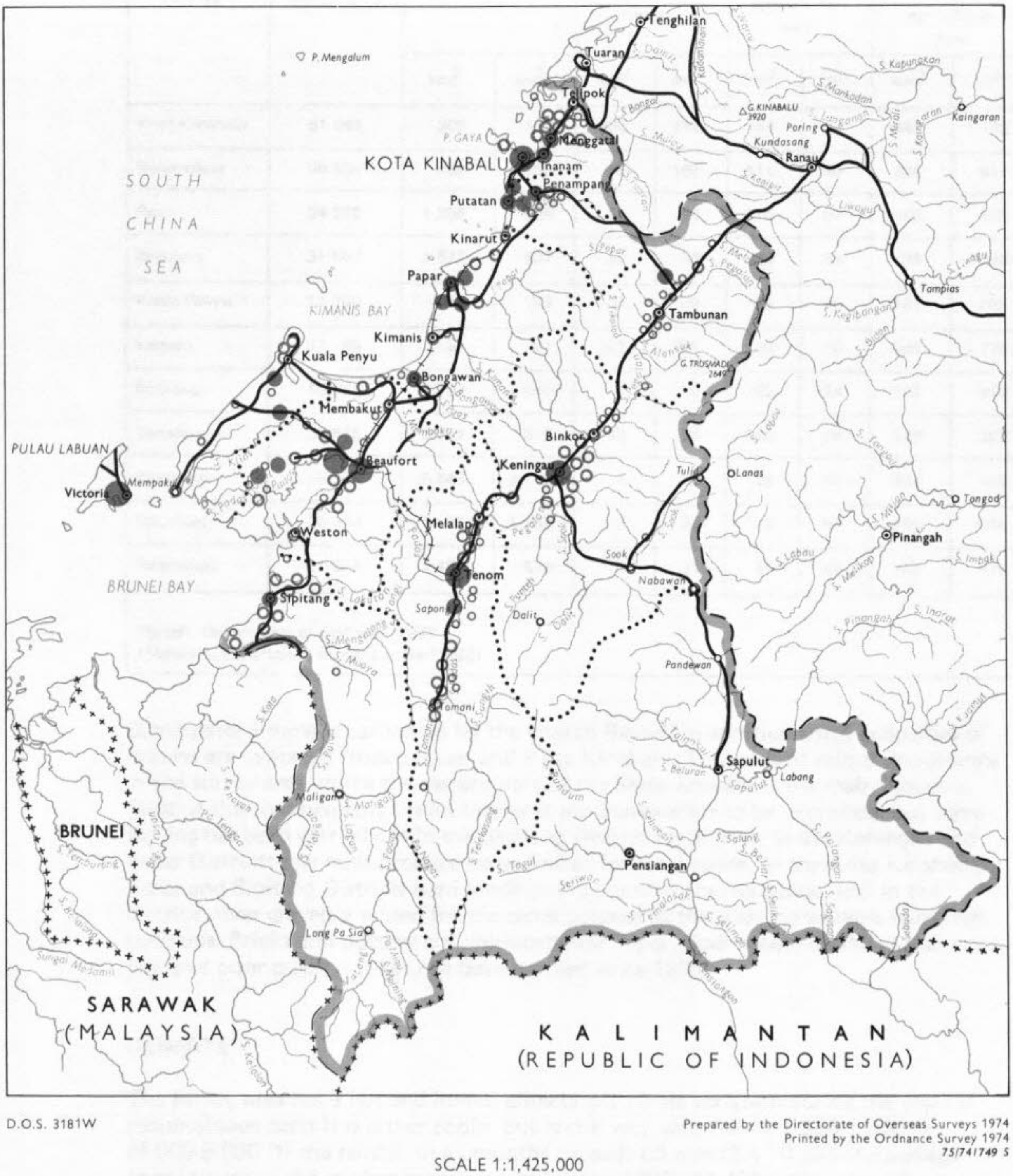
P. A. Burrough — C

R. P. Bower — D

P. A. Burrough and R. P. Bower — E

POPULATION DENSITY

TEXT MAP 4-3



D.O.S. 3181W

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SCALE 1:1,425,000

Miles 10 0 10 20 30 40 50 Miles

Kilometres 10 0 20 40 60 80 Kilometres

International Boundary	+ + + + + + +
State Boundary	—+ +—
District Boundary	....
Soil Survey Boundary	
Motorable Road	
Railway	
Trigonometrical Station (ht. in metres)	△

No of persons per settlement :-

> 2000

1000-2000

500-1000

200-500

TABLE 4-2 Population density

District	Population*	Area		Population density		Land in agricultural use†		Population density on agricultural land	
		km²	mi²	km²	mi²	km²	mi²	km²	mi²
Kota Kinabalu	61 645	308	119	200	518	140	54	441	1 142
Penampang	26 534	409	158	65	168	111	43	238	617
Papar	34 285	1 396	539	25	64	215	83	159	413
Beaufort	31 667	1 577	607	20	53	228	88	139	360
Kuala Penyu	11 700	515	199	23	59	65	25	181	468
Labuan	17 189	57	22	302	781	26	10	664	1 719
Sipitang	10 054	2 732	1 055	4	10	62	24	162	419
Tenom	23 516	2 277	879	10	27	168	65	140	362
Pensiangan	5 770	5 543	2 140	1	3	29	11	203	525
Keningau	26 334	3 028	1 169	9	23	132	51	199	516
Tambunan	11 954	1 484	573	8	21	65	25	185	478

*Sabah, Department of Statistics, 1971
†Malaysia, Department of Agriculture (1973)

Subsistence fishing is carried on by the coastal Bajaus; in addition small quantities of prawns are exported from Labuan and Kota Kinabalu. Timber is of minor importance in the survey area unlike the eastern part of the State where it is the main industry. Most of the commercially useful timber is too inaccessible to be exploited, but some logging has been carried out in the Sipitang District for export; in the Keningau and Papar Districts saw mills produce sawn timber for local needs. In the Kota Kinabalu, Papar and Sipitang Districts hard sandstone is quarried for roadstone, and in the interior, river gravels are used for the same purpose as there are no suitable hard rock outcrops. Bricks and pottery are produced near Papar. Coal occurs on Pulau Labuan but is of poor quality; it has not been worked since 1897.

CLIMATE

The survey area has a hot and humid climate with little variation during the year; in mountainous parts it is rather cooler but is still very wet. Below 1 200-1 500 m (4 000-5 000 ft) the rainfall in all months exceeds 60 mm (2.4 in) and the average temperature of the coolest month is higher than 18°C (64.4°F); the range of temperature between the warmest and coolest months is less than 5°C (9°F). This climatic zone is referred to as the Tropical Rainforest Climate (Afi) (Trewartha, 1954). In the upland areas above 1 200-1 500 m there is no distinct dry season and no month receives less than 30 mm (1.2 in) of rain. The range of temperature between the warmest and coolest months is less than 5°C (9°F). This is a Warm Rainy Climate (Cfi) (Trewartha, 1954).

Temperature and rainfall are the 2 aspects of the climate that have the most direct influence on pedogenesis. Temperature is one of the controlling factors in chemical processes, reaction rates doubling for each 10°C (18°F) rise in temperature.

Air temperature

Air temperature data are available for 6 stations (Table 4-3); Kota Kinabalu and Labuan are coastal, Kaiduan is in the western foothills of the Crocker Range, Keningau is in one of the main interior plains and Kundasang and Kambarangan are high altitude sites just to the north of the survey area. There is very little annual variation in temperature; on the coast, mean maximum values are in the 29-32°C (84-89°F) range and mean minimum values are in the 20-25°C (68-77°F) range; these temperatures decrease with increasing altitude (Figure 4-1) and the calculated decrease in temperature for over 100 m agrees well with the figure of 0.6°C per 100 m (1.1°F per 330 ft) quoted by Mohr and van Baren (1959).

The yearly pattern of temperature is similar in all parts of the area; the coolest months are January and February and the temperature rises relatively sharply to a maximum in April and May and then slowly declines. Absolute maximum temperatures range from 37.2°C (99.0°F) at Keningau, 35.1°C (95.2°F) at Kota Kinabalu to 24.4°C (76.0°F) at Kambarangan; the absolute minimum temperatures are 16.1°C (61.0°F), 18.9°C (66.0°F) and 6.7°C (44.0°F) respectively.

Soil temperature

Soil temperature records taken at depths of 30 cm (12 in.) and 120 cm (48 in.) at Kota Kinabalu from 1956 to 1971 and Labuan from 1956 to 1966 are shown in Figure 4.2 and the ranges of mean annual soil and air temperatures are shown in Table 4-4. In general, soil temperatures parallel air temperatures, but at both stations the 30 cm temperature drops below that of the air temperature in the second half of the year. The 120 cm depth is generally warmer than the 30 cm depth and is less variable.

TABLE 4-3 Mean monthly maximum and minimum temperatures (°C and °F)

Station	Altitude			Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.		Mean	
	m	ft		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Kota Kinabalu	3	9	Max	30	85	30	85	30	87	31	88	31	88	31	88	31	87	31	87	31	87	30	87	30	86	30	86	30	87
(1951-1971)			Min	23	73	23	73	23	73	24	75	24	75	24	74	23	74	23	74	23	74	23	74	23	74	23	73	23	74
Labuan	30	100	Max	30	86	30	86	31	87	31	89	31	89	31	88	31	88	31	88	31	87	31	87	30	87	30	87	31	87
(1951-1966)			Min	25	76	25	76	25	77	25	77	25	77	25	77	25	76	25	76	25	76	25	76	25	76	25	77	25	77
Kaiduan	105	350	Max	30	87	31	88	32	89	32	90	32	90	32	90	32	89	32	89	32	89	32	89	31	89	31	88	32	89
(1965-1971)			Min	20	68	20	68	20	69	21	69	21	70	21	70	21	69	21	69	21	69	21	70	21	69	20	69	21	69
Keningau	285	950	Max	30	86	30	86	31	87	31	88	31	88	31	87	31	87	31	87	31	87	30	86	30	86	30	86	30	87
(1965-1971)			Min	20	68	20	68	20	68	20	69	21	69	20	68	20	68	20	68	20	68	20	69	20	68	20	69	20	68
Kundasang	1 290	4 300	Max	22	72	22	72	24	75	25	77	25	78	25	76	24	76	24	75	24	76	24	75	24	74	23	73	24	75
(1967-1971)			Min	15	60	15	58	15	60	15	60	16	61	16	61	16	61	16	61	16	61	16	61	16	61	16	61	16	60
Kambarangan	2 220	7 400	Max	17	63	17	63	18	64	18	64	17	63	17	63	17	63	17	63	17	62	17	62	17	63	17	63	17	63
(1965-1968)			Min	11	52	11	52	11	52	11	52	12	53	12	53	12	53	11	53	11	52	11	53	11	52	12	53	11	52

TABLE 4-4 Mean soil and air temperature ranges (°C and °F)

Station	Soil temperature range				Air temperature range	
	30 cm		120 cm			
	°C	°F	°C	°F	°C	°F
Kota Kinabalu	3.0	5.4	2.0	3.6	2.1	3.8
Labuan	1.5	2.7	1.1	2.0	1.3	2.3

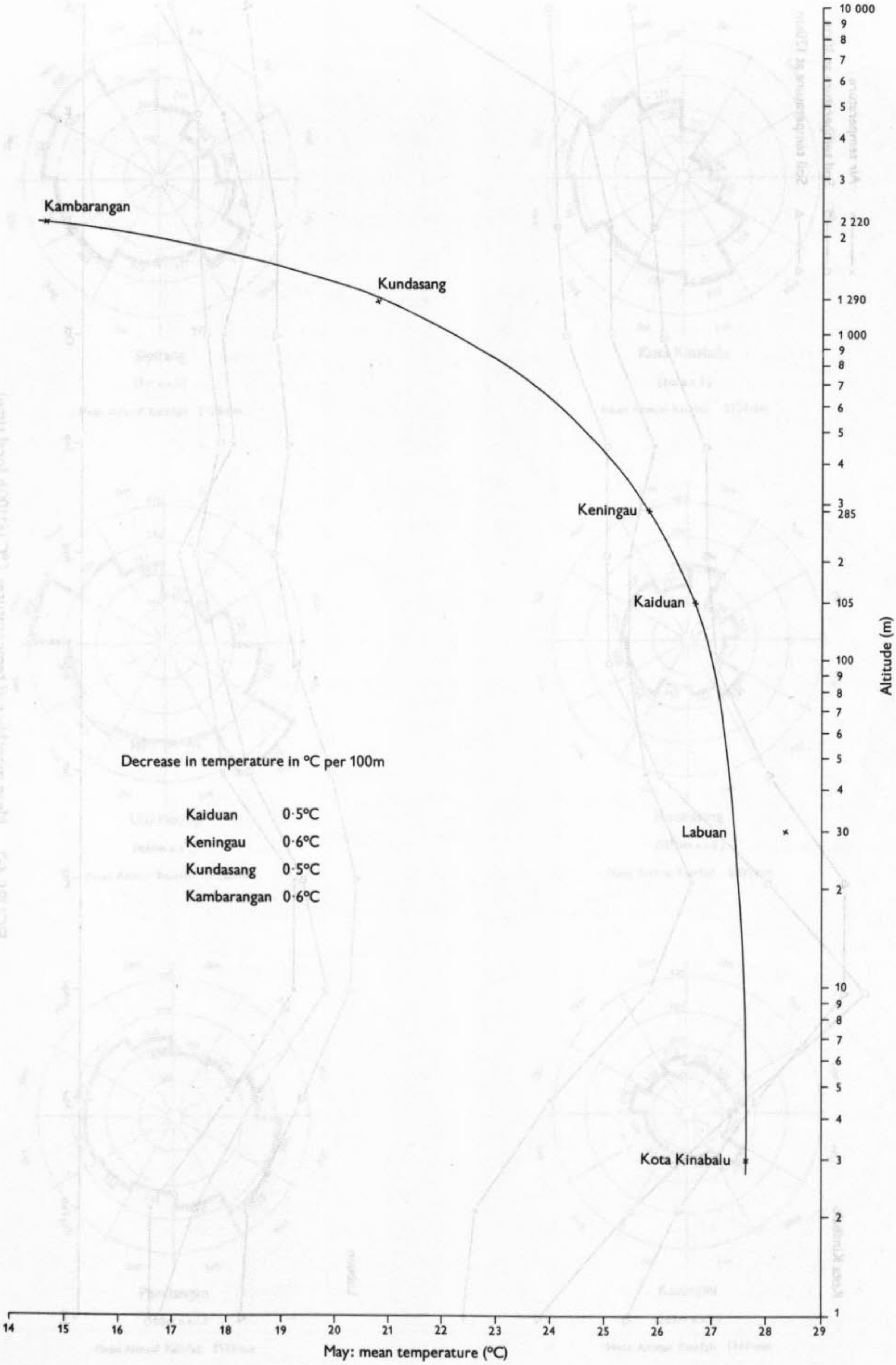

FIGURE 4-1 Decrease of temperature (°C) with altitude (m)

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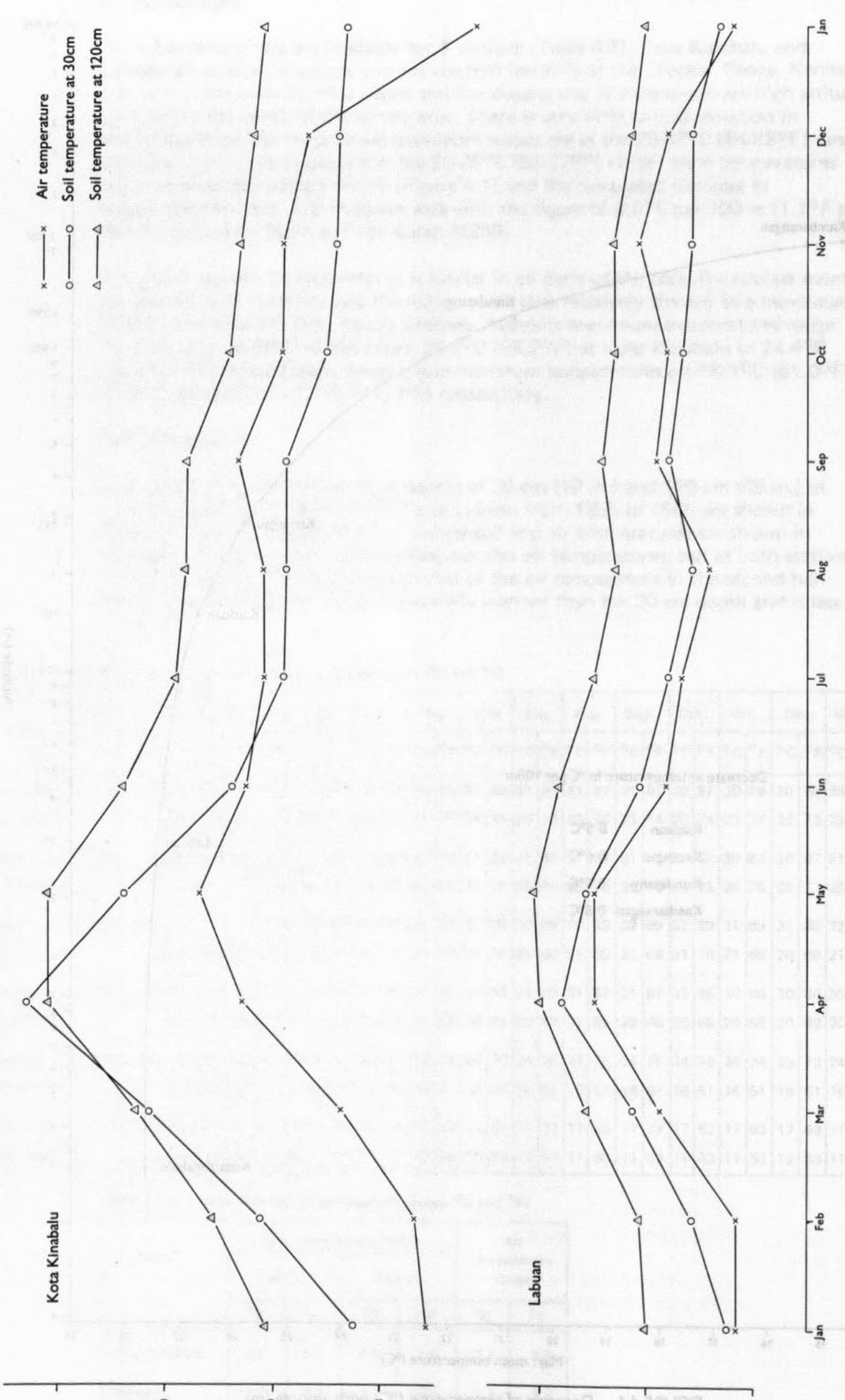

FIGURE 4-2 Mean monthly soil temperatures (°C) (1100h local time)

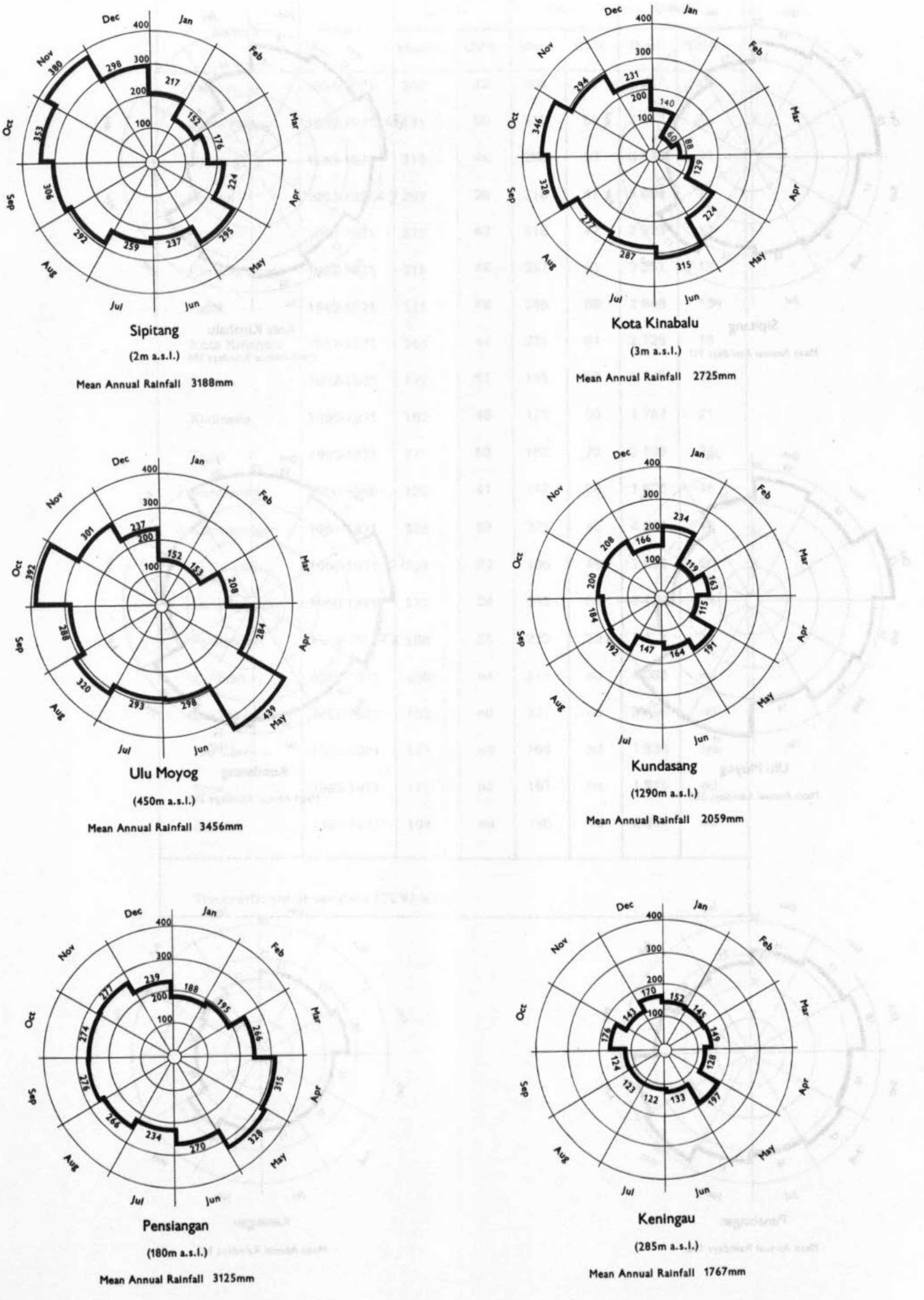

FIGURE 4-3 Mean monthly rainfall (mm)

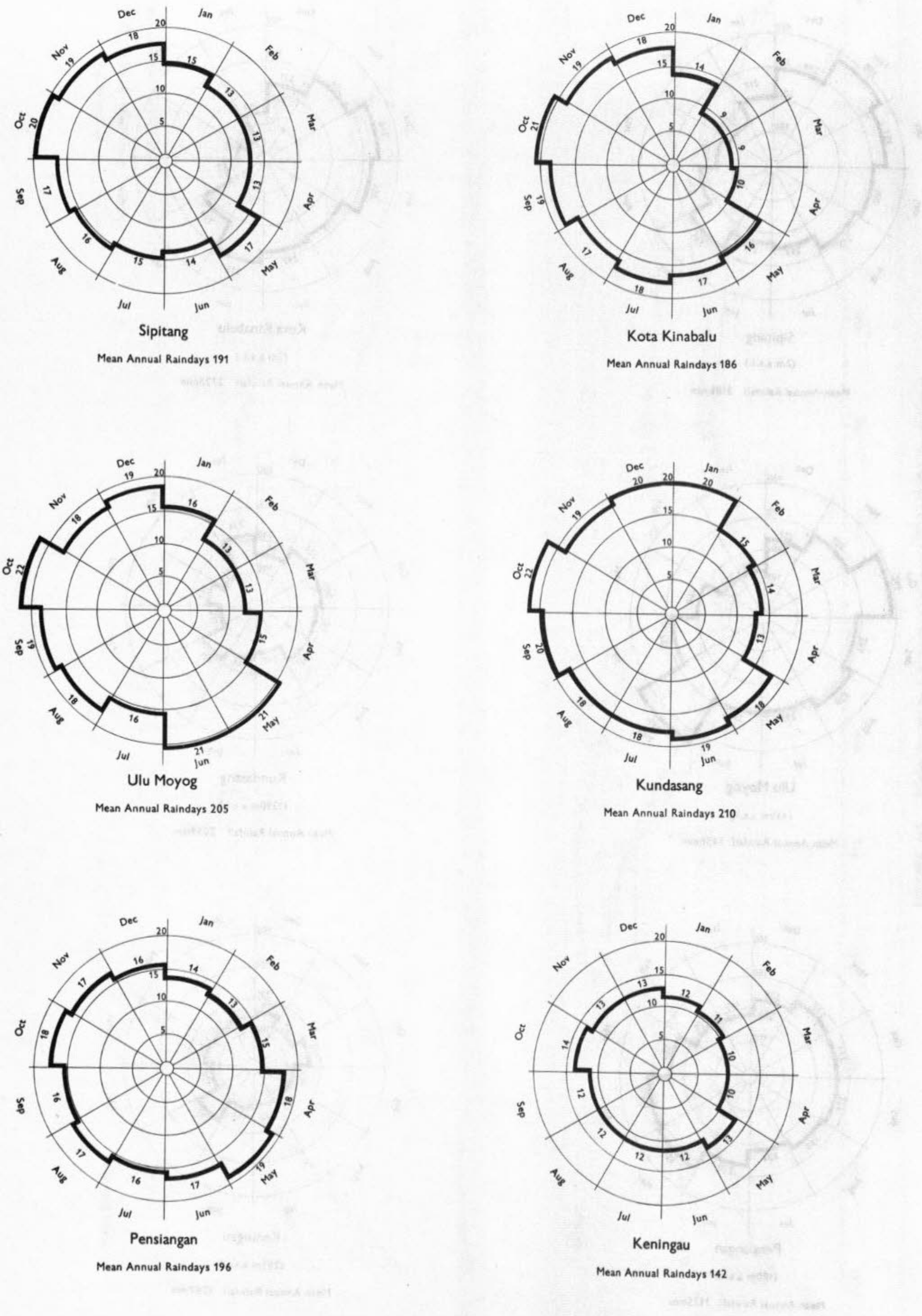

FIGURE 4-4 Mean monthly raindays

D.O.S. 3182V

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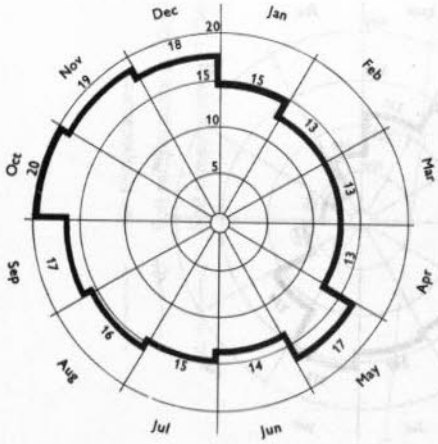
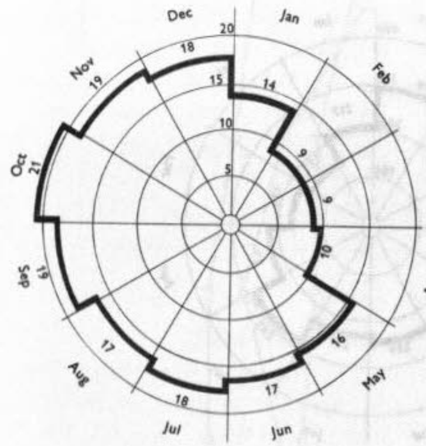


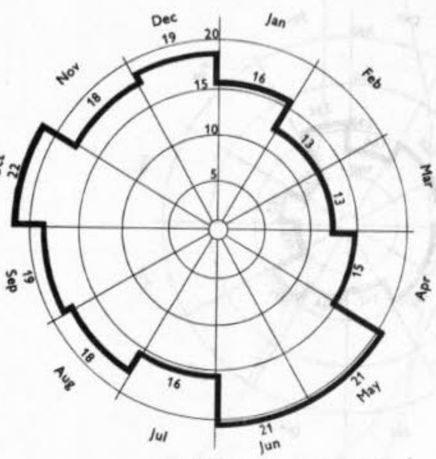
Sipitang

Mean Annual Raindays 191



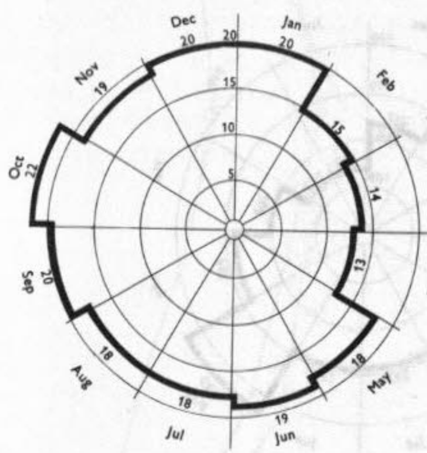
Kota Kinabalu

Mean Annual Raindays 186



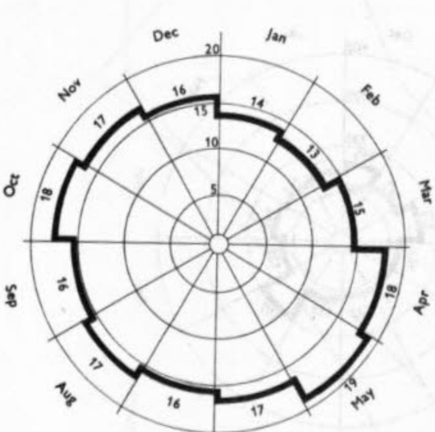
Ulu Moyog

Mean Annual Raindays 205



Kundasang

Mean Annual Raindays 210



Pensiangan

Mean Annual Raindays 196

Keningau

Mean Annual Raindays 142

FIGURE 4-4 Mean monthly raindays

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TABLE 4-5a Mean monthly and annual rainfall in millimetres and coefficient of variation (CV%)

Station	Period	Jan.		Feb.		Mar.		April		May		June		July		Aug.		Sept.		Oct.		No		Dec.		Annual	
		Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%	Mean	CV%
Labuan	1951-1971	240	78	92	79	162	48	220	53	330	36	301	26	315	51	321	55	348	42	440	36	398	32	308	42	3 487	15
Kuala Penyu	1953-1971	171	77	72	125	90	72	103	74	255	48	282	44	210	48	257	48	274	47	328	39	327	50	212	53	2 577	23
Sipitang	1949-1971	217	64	152	52	176	50	224	44	295	41	237	46	259	56	292	50	306	45	353	43	380	44	298	59	3 188	22
Weston	1953-1968	297	72	165	43	252	57	326	48	348	36	296	33	314	36	269	46	350	44	372	46	408	28	316	41	3 689	11
Beaufort	1953-1971	273	67	214	61	276	37	288	29	397	29	285	30	291	46	320	47	371	41	446	43	384	42	316	47	3 823	11
Kimanis Estate	1952-1971	215	77	118	63	137	59	214	65	348	44	349	39	287	54	323	48	355	37	398	33	350	49	287	51	3 351	12
Papar	1949-1971	131	101	65	82	85	86	160	65	286	42	298	48	293	47	279	41	327	40	345	36	290	49	255	59	2 848	15
Kota Kinabalu	1951-1971	140	113	60	70	88	72	129	74	224	36	315	40	287	29	271	39	328	39	346	36	294	44	231	61	2 725	16
Tenom	1952-1971	127	62	126	71	149	41	135	55	213	60	135	43	115	51	120	46	127	42	171	29	161	51	158	50	1 745	14
Keningau	1950-1971	152	75	145	64	149	47	128	57	197	40	133	38	122	43	123	60	124	41	176	49	143	48	170	50	1 767	21
Tulid	1953-1971	171	61	146	77	139	63	160	59	284	47	188	71	176	62	172	60	192	49	167	41	213	59	162	73	2 108	24
Tambunan	1950-1968	120	81	111	45	129	39	166	46	223	25	175	46	156	49	126	49	134	44	154	31	158	41	149	38	1 806	16
Kambarangan	1957-1971	326	70	218	100	245	56	240	73	340	23	350	39	328	29	390	30	445	40	548	37	455	53	325	46	4 271	14
Kundasang	1956-1971	234	68	119	86	163	76	115	59	191	46	164	44	147	36	192	43	184	46	200	33	208	60	166	49	2 059	20
Long Semado	1950-1971	172	45	170	52	233	49	237	29	259	37	181	52	178	39	190	43	202	31	264	35	220	24	245	54	2 422	4
Pensiangan	1953-1971	188	51	195	52	266	47	315	46	326	34	270	27	234	41	266	35	276	40	274	32	277	35	239	52	3 125	11
Kaiduan	1965-1971	220	nd	152	nd	150	nd	303	nd	441	nd	397	nd	318	nd	408	nd	333	nd	524	nd	517	nd	317	nd	4 083	nd
Ulu Moyog	1965-1971	152	nd	153	nd	208	nd	284	nd	439	nd	298	nd	293	nd	320	nd	288	nd	392	nd	301	nd	237	nd	3 456	nd
Ulu Tomani	1965-1971	143	nd	118	nd	169	nd	167	nd	222	nd	141	nd	130	nd	250	nd	114	nd	106	nd	150	nd	168	nd	1 838	nd
Sook	1965-1971	110	nd	96	nd	213	nd	162	nd	234	nd	157	nd	163	nd	182	nd	144	nd	211	nd	167	nd	157	nd	1 915	nd
Sapulut	1965-1971	194	nd	175	nd	185	nd	321	nd	360	nd	286	nd	209	nd	261	nd	198	nd	282	nd	235	nd	186	nd	2 827	nd

The coefficient of variation (CV%) is the ratio of the standard deviation to the mean.

Rainfall

The area is only slightly affected by the North-East Monsoon, so that the period from December to March is generally the driest period of the year. The South-West Monsoon from May to September is rather wetter and May is one of the wettest months especially on and to the east of the Crocker Range. April and October to November generally have unsettled weather and these months may be even wetter than May. Mean annual rainfall is between 2 200 and 4 000 mm (87-158 in.) along the coast, rising to 5 000 mm (200 in.) on the western side of the Crocker Range; the increase with altitude is about 50 mm (2 in) for every 30 m (100 ft). The interior valleys and plains are in the rain shadow of the Crocker Range and therefore have lower annual rainfall than on the coast; mean annual values are 1 500-2000 mm (60-80 in.). Further to the east and south, the rainfall increases again to more than 2 500 mm (100 in).

Mean monthly and annual rainfall, and coefficients of variation for stations with records for 10 years or more are shown in Tables 4-5a and 4-5b; monthly means for 6 representative stations are shown diagrammatically in Figure 4-3.

Monthly variation in rainfall is much greater than the annual variability; it is therefore possible to predict with some confidence the annual rainfall at a given station, but it is less easy to say in which months the rain will fall (Table 4-6).

TABLE 4-5b Mean monthly and annual rainfall inches

Station	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Labuan	9.4	3.6	6.4	8.7	13.0	11.9	12.4	12.6	13.7	17.3	15.7	12.1	137.3
Kuala Penyu	6.7	2.8	3.5	4.0	10.0	11.1	8.3	10.1	10.8	12.9	12.9	8.4	101.4
Sipitang	8.5	6.0	6.9	8.8	11.6	9.3	10.1	11.5	12.0	13.9	14.9	11.8	125.5
Weston	11.7	6.5	9.9	12.8	13.7	11.7	12.4	10.6	13.8	14.6	16.1	12.4	145.2
Beaufort	10.8	8.4	10.9	11.4	15.6	11.2	11.5	12.6	14.5	17.5	15.1	12.4	152.5
Kimanis Estate	8.5	4.6	5.4	8.4	13.7	13.8	11.3	12.7	14.0	15.7	13.8	11.3	131.9
Papar	5.2	2.6	3.3	6.3	11.3	11.8	11.5	11.0	12.9	13.6	11.4	10.0	111.8
Kota Kinabalu	5.5	2.4	3.5	5.1	8.8	12.4	11.3	10.9	12.9	13.6	11.6	9.1	107.3
Tenom	5.0	4.9	5.9	5.3	8.4	5.3	4.5	4.7	5.0	6.7	6.4	6.2	68.7
Keningau	6.0	5.7	5.9	5.0	7.8	5.2	4.8	4.8	4.9	6.9	5.6	6.7	69.5
Tulid	6.8	5.8	5.5	6.3	11.2	7.4	7.0	6.8	7.6	6.6	8.4	6.4	83.0
Tambunan	4.7	4.3	5.1	6.6	8.8	6.9	6.2	4.9	5.3	6.1	6.2	5.9	71.1
Kambarangan	12.8	8.6	9.6	9.4	14.4	14.8	12.9	15.4	17.5	21.6	17.9	12.8	168.2
Kundasang	9.2	4.7	6.4	4.5	7.5	6.5	5.8	7.5	7.2	7.9	8.2	6.6	81.1
Long Semado	6.8	6.7	9.2	9.3	10.2	7.1	7.0	7.5	7.9	10.4	8.7	9.6	95.4
Pensiangan	7.4	7.7	10.5	12.4	12.9	10.6	9.2	10.5	10.9	10.8	10.9	9.4	123.0
Kaiduan	8.7	6.0	5.9	12.0	17.4	15.6	12.5	16.1	13.1	20.6	16.4	12.5	160.7
Ulu Moyog	6.0	6.0	8.2	11.2	17.3	11.7	11.6	12.6	11.4	15.4	11.9	9.3	136.1
Ulu Tomani	5.6	4.6	6.7	6.6	8.8	5.5	5.1	9.8	4.5	4.2	5.9	6.6	72.4
Sook	4.3	3.8	8.4	6.4	9.2	6.2	6.4	7.1	5.7	8.3	6.6	6.2	75.4
Sapulut	7.7	6.9	7.2	12.6	14.2	11.3	8.3	10.3	7.8	11.1	9.2	7.3	111.3

TABLE 4-6 Mean rainfall values for the wettest and driest months and annually in millimetres and inches with coefficient of variation

Station	Length of record (years)	Wettest month			Driest month			Annual		
		Mean			Mean			Mean		
		mm	in	CV%	mm	in	CV%	mm	in	CV%
Kota Kinabalu	21	346	13.6	36	60	2.4	70	2 725	107.3	16
Papar	23	345	13.6	36	65	2.6	82	2 848	111.8	15
Labuan	21	440	17.3	36	92	3.6	79	3 487	137.3	15
Sipitang	23	380	14.9	44	152	6.0	52	3 188	125.5	22
Keningau	22	197	7.8	40	122	4.8	43	1 767	69.5	21
Tulid	19	284	11.2	47	139	5.5	63	2 108	83.0	24
Pensiangan	19	328	12.9	34	188	7.4	51	3 125	123.0	11

There are generally 8-12 raindays during the drier months and 18-22 raindays during the wetter months (Figure 4-4). To the east of the Crocker Range there is a larger proportion of raindays with less than 25 mm (1 in) of rain than on, and to the west of the Crocker Range (Table 4-7). It is estimated that on 10-20 days each year the rainfall will exceed 25 mm (1 in) in all parts of the survey area.

Since 1965 some hourly recording guages have been in operation and the maximum recorded rainfall in 1 hour is 219 mm (8.63 in) at Kiansom in September 1971; 5 other stations have recorded more than 100 mm (3.94 in) of rain in 1 hour on at least 1 occasion.

TABLE 4-7 Percentage of raindays in three rainfall classes

Station	Mean annual rainfall		Mean annual raindays	Percentage of raindays mm (in)		
	mm	in		0.3-12.9 (0.01-0.5)	13.0-25.4 (0.51-1.0)	>25.4 (>1.0)
Western area						
Lawas	4 146	163.2	204	52	19	28
Kota Kinabalu	2 725	107.3	178	69	12	17
Kiansom	3 126	123.1	177	60	20	21
Terian	4 317	170.0	220	49	24	26
Ulu Moyog	3 456	136.1	205	58	23	19
Eastern area						
Kemabong	1 762	69.3	164	71	20	9
Apin Apin	1 907	75.1	190	76	14	9
Sook	1 915	75.4	189	72	16	11
Long Semado	2 422	95.4	211	70	19	12

A 'dry month' is defined as one with less than 60 mm (2.37 in.) of rain (Trewartha, 1954); the frequency of such dry months is shown in Table 4-8. January to April is the most likely period for dry months in the survey area, with June to September an additional potentially dry period in the interior plains. The risk of drought is greater in the interior plains than along the coast. One dry month in isolation will probably have very little effect on plant growth, since the water holding capacity within the rooting zone of most of the soils is in the 100-150 mm (3.93-5.91 in) range (Baillie, 1972). Spells of two or more successive dry months occurred in 10 years out of 19 at Papar and in 9 years out of 19 at Kota Kinabalu. The corresponding figures for Labuan, Sipitang, Keningau, Tulid and Pensiangan are 1, 2, 4, 6 and 1 respectively. Papar had 2 years during the period with 4 consecutive dry months and Kota Kinabalu had 1 period of 2 dry months and 1 period of 5 dry months, each of which had less than 76 mm (3 in) of rain. The use of mean monthly and annual rainfall figures tends to obscure the surprisingly frequent periods of moisture stress that occur in this area, which is, nonetheless, classified as part of the humid, 'ever-wet' tropics.

TABLE 4.8 Frequency and distribution of 'dry' months (1953-1971)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Kota Kinabalu	5	10	7	5	–	–	–	–	–	–	–	–
Papar	6	11	9	6	–	–	–	–	1	–	1	1
Labuan	1	8	2	3	–	–	–	–	–	–	–	1
Sipitang	1	1	1	1	–	–	1	1	1	–	–	1
Keningau	4	5	1	4	1	2	3	5	3	2	2	–
Tulid	3	4	2	3	1	5	2	4	3	1	2	3
Pensiangan	2	3	–	–	–	–	–	–	–	–	–	–

Effective rainfall (ER) for pedogenesis, plant growth and human use is invariably smaller than total rainfall and can be defined as:

$$ER = TR - (1+E+S)$$

where TR is total rainfall, I is the amount of rain intercepted by the vegetation, E is the total evaporation from the soil surface and S is surface runoff.

The lack of information on these factors makes it possible to only generalise on effective rainfall; it is probable, however, that effective rainfall in the area is between one third and two thirds of the total rainfall. It is likely that effective rainfall is even lower than this in places such as Keningau with relatively low total rainfall and high evaporation.

Evaporation

Figures for evaporation from Standard US Class A Pans are available for Kota Kinabalu and Kaiduan (1965-1971) and for Keningau and Kundasang (1968-1971) (Tables 4-9a and 4-9b). The amount of evaporation at any place depends on many factors including temperature, relative humidity, wind speed and sunshine; values, however, generally decrease with altitude.

Sunshine

Five stations are equipped with Campbell-Stokes pattern sunshine recorders and the mean number of hours of sunshine per day for these stations is shown in Figure 4-5. The maximum and minimum sunshine months correspond with the periods of lowest and highest rainfall.

Relative humidity

Records of relative humidity are available for Labuan from 1951-1966 and Kota Kinabalu from 1963 to 1971. Monthly mean values at both stations range from 81.3% in July to 84.7% in January and February; there is very little variation during the year. The daily progress of change in relative humidity is also the same at both stations; as the temperature rises humidity decreases from about 90% at dawn to 65-70% in the early afternoon.

Wind

Kota Kinabalu and Labuan are both equipped with totalising cup anenometers. Kota Kinabalu northerly winds are dominant in January and February with south-easterlies dominant for the remainder of the year. The mean wind speeds range from 7 to 12 km/h (4-6 knots). At Labuan northerly winds are dominant from January to April with south westerlies predominant for the rest of the year; mean wind speeds are slightly higher than at Kota Kinabalu. In Sabah as a whole, gusts of 37-55 km/h

TABLE 4-9a Mean monthly and annual evaporation in millimetres

Station	Altitude (m)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Annual rainfall
Kota Kinabalu (1965-1971)	3	157	159	183	190	182	170	166	169	173	160	156	153	2 017	2 684
Kaiduan (1965-1971)	105	111	112	119	126	133	124	126	129	118	123	111	107	1 428	4 123
Keningau (1968-1971)	285	132	130	164	174	154	145	155	155	153	152	142	133	1 797	1 624
Kundasang (1968-1971)	1 290	97	100	117	131	135	120	141	138	136	132	109	102	1 449	3 408

TABLE 4-9b Mean monthly and annual evaporation in inches

Station	Altitude (ft)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Annual rainfall
Kota Kinabalu	9	6.2	6.2	7.2	7.5	7.2	6.7	6.5	6.7	6.8	6.3	6.1	6.0	79.4	105.7
Kaiduan	350	4.4	4.4	4.7	5.0	5.3	4.9	4.9	5.1	4.6	4.8	4.4	4.2	56.2	162.3
Keningau	950	5.2	5.1	6.5	6.9	6.1	5.7	6.1	6.1	6.1	6.0	5.6	5.3	70.8	63.9
Kundasang	4 500	3.8	4.0	4.6	5.2	5.3	4.7	5.5	5.4	5.3	5.2	4.3	4.0	57.3	134.2

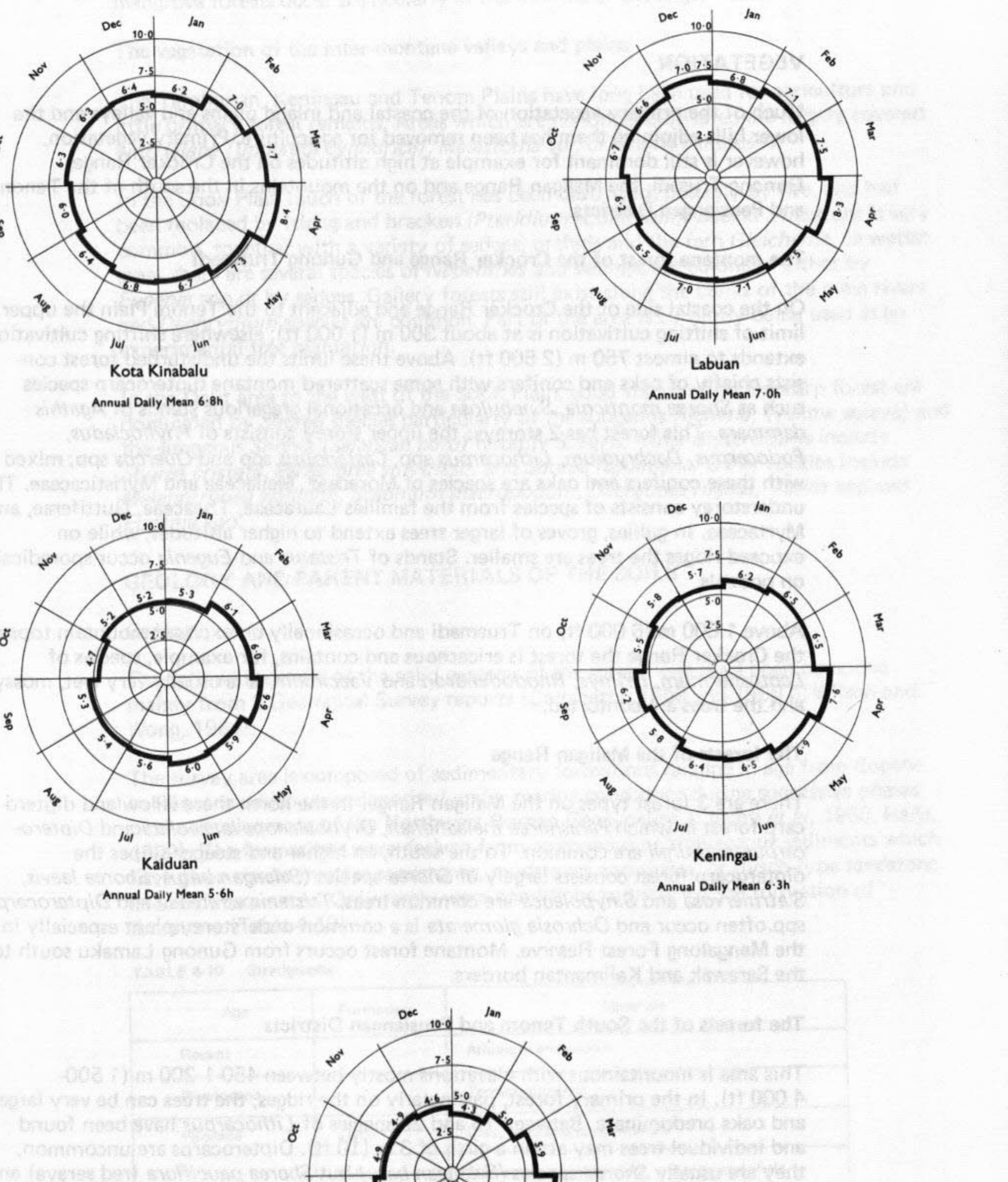

FIGURE 4-5 Mean daily sunshine (h)

Prepared by the Directorate of Overseas Surveys 1974

(20-30 knots) are often experienced during heavy thundery showers, but gusts of more than 65 km/h (35 knots) occur on fewer than 5 days per year (Preedy, 1966).

VEGETATION

Much of the primary vegetation of the coastal and inland plains and valleys and the lower hills adjoining them has been removed for agriculture. Primary vegetation, however is still dominant for example at high altitudes on the Crocker Range, Gunong Trusadi, the Maligan Range and on the mountains in the south of the Tenom and Pensiangan Districts.

The montane forest of the Crocker Range and Gunong Trusmadi

On the coastal side of the Crocker Range and adjacent to the Tenom Plain the upper limit of shifting cultivation is at about 300 m (1 000 ft); elsewhere shifting cultivation extends to almost 750 m (2 500 ft). Above these limits the undisturbed forest consists chiefly of oaks and conifers with some scattered montane dipterocarp species such as *Shorea monticola, S.nebulosa* and occasional gregarious stands of *Agathis dammara.* This forest has 2 storeys: the upper storey consists of *Phyllocladus, Podocarpus, Dachrydium, Lithocarpus* spp, *Castanopsis* spp and *Quercus* spp; mixed with these conifers and oaks are species of Moraceae, Meliaceae and Myristicaceae. The understorey consists of species from the families Lauraceae, Theaceae, Guttiferae, and Myrtaceae. In gullies, groves of larger trees extend to higher altitudes, while on exposed ridges the trees are smaller. Stands of *Tristania* and *Eugenia* occur sporadically on podzols.

Above 1 800 m (6 000 ft) on Trusmadi and occasionally on exposed mountain tops of the Crocker Range the forest is ericaceous and contains, for example, species of *Leptospermum, Drimys, Rhododendron* and *Vaccinium;* it is usually very wet, mossy and the trees are contorted.

The forests of the Maligan Range

There are 3 forest types on the Maligan Range. In the north there is lowland dipterocarp forest in which *Parashorea malaanonan, Dryobalanops lanceolata* and *Dipterocarpus warburgii* are common. To the south, on higher and steeper slopes the dipterocarp forest consists largely of *Shorea* species (*Selangan batu*); *Shorea laevis, S.atrinervosa* and *S.hypoleuca* are common trees. *Tristania whiteana* and *Dipterocarpus* spp.often occur and *Ochrosia glomerata* is a common understorey plant especially in the Mengalong Forest Reserve. Montane forest occurs from Gunong Lamaku south to the Sarawak and Kalimantan borders.

The forests of the South Tenom and Pensiangan Districts

This area is mountainous with elevations mostly between 450-1 200 m (1 500-4 000 ft). In the primary forest, particularly on the ridges, the trees can be very large and oaks predominate. Between 15 and 20 species of *Lithocarpus* have been found and individual trees may attain a girth of 3 m (10 ft). Dipterocarps are uncommon; they are usually *Shorea* species *(Selangan batu)* but *Shorea pauciflora* (red seraya) and *Parashorea* (white seraya) have been found. Lauraceae, Guttiferae, Myristicaceae and Myrtaceae are commonly interspersed with the oaks. In some places, large tracts of bamboo and softwoods such as Macarangas have grown up after shifting cultivation. Near streams and rivers the original vegetation has been removed by shifting cultivation, and secondary regrowth has been observed on hillsides up to 900 m (3 000 ft).

The swamp forests of the Klias Peninsula

Most of the peatswamp forest on the Klias Peninsula has now been logged; it covered about 1 650 km^2 (250 mi^2) and consisted in the main of *Dactylocladus stenostachys, Gonystylus bancanus* and *Dryobalanops rappa.* A similar forest also occurs in the Mengalong Forest Reserve. Beach forests fringe the Klias coast and include, for example, *Casuarina, Pandanus odoratissimus* and *Hibiscus tiliaceas.* Similar beach forests also occur on the coast south-west of Kota Kinabalu and poorly developed mangrove forests occur particularly at the mouths of the larger rivers.

The vegetation of the inter-montane valleys and plains

The Tambunan, Keningau and Tenom Plains have long been used for agriculture and little primary forest remains. Areas which are no longer cultivated are largely covered with *lalang (Imperata cylindrica), Melastoma* sp., or *Baekia frutescens.*

In the Sook Plain much of the forest has been destroyed, possibly by fire, and had been replaced by lalang and bracken *(Pteridium aquilinium). Baekia frutescens* is very common, together with a variety of sedges, orchids and the fern *Gleichenia.* In wetter areas there are several species of *Nepenthes* and swamps are colonised either by *Eugenia* spp.or by sedges. Gallery forests still exist along the banks of the main rivers and *Dachrydium* species are common. Part of the area is currently being used as an experimental tree plantation.

In the Dalit area to the west of the Sook Plain, good stands of dipterocarp forest are dominated by *Shorea* species particularly of the subgenus *Richetia,* (yellow seraya) and the subgenus *Shorea (Selangan batu)* notably *S.leavis;* other dipterocarps include *Shorea cristata, Parashorea smythesii,* and *Shorea faguetiana.* Other species include *Melanorrhoea wallichii, Scaphium macropodum, Dacryodes rugosa, Vatica* spp.and *Eugenia* spp.

GEOLOGY AND PARENT MATERIALS OF THE SOILS

Geology

The following details of the solid geology of the survey area have been compiled mainly from 3 Geological Survey reports (Collenette, 1958 and 1965 b; Wilson and Wong, 1964).

The survey area is composed of sedimentary formations ranging in age from Eocene to Pliocene which were deposited under marine conditions during successive phases of the development of the Northwest Borneo Geosyncline (Liechti *et al*, 1960, Haile, 1969). The formations were derived from arenaceous or argillaceous sediments which have given rise to massive sandstones, mudstones and shales, or flysch-type sandstone and shale sequences. Only rarely were conditions suitable for the formation of limestone (Table 4-10).

TABLE 4-10 Stratigraphy

Age	Formation	Materials
Recent		Alluvium and peat
Pleistocene		Terrace alluvium
Pliocene	Liang	Clay, sand and conglomerate
	Belait	Sandstone, conglomerate, siltstone and shale
Upper Miocene	Setap Shale	Mudstone and clay
	Maligan	Massive sandstone with shale
Lower Miocene	Labang	Sandstone and mudstone with limestone
Oligocene	Temburong	Siltstone and shale
	Crocker	Flysch-type sandstone and shale
Eocene	Trusmadi	Shale and phyllite with siltstone and sandstone
	Sapulot	Mudstone and sandstone with limestone

The oldest rocks found in the survey area are those of the Sapulot Formation (Collenette, 1965b); these occur over an extensive area in the south-west, forming the greater part of the Witti and Maitland ranges. The formation consists of predominantly argillaceous facies in the form of soft poorly bedded grey mudstone with intercalations of siltstone and fissile mudstone. Although sandstone is generally subordinate to the argillaceous rocks it may occur in beds up to 90 m (300 ft) thick. Grey crystalline limestone outcrops particularly to the west of Sapulut in the Witti Range. Beds of conglomerate consisting of blocks and cobbles of limestone, chert, sandstone and quartzite also occur in the Sapulut Valley.

The Trusmadi Formation (Collenette, 1958) originated at the same time and under similar conditions as the upper part of the Sapulot Formation. It occurs in the east of the area and forms the major part of the Trusmadi Range. This formation is noted for its mildly metamorphosed sandstone and shale beds; quartz-veined subphyllites and slates are common.

The stratigraphical position of the Crocker Formation (Collenette, 1958 and 1965b; Wilson and Wong, 1964) has not been conclusively established, but it is thought to be largely of similar age to the Trusmadi Formation. The strata are composed of flysch-type sequences (Raj, 1971) of closely intercalated sandstone and shale, or mudstone and massive sandstone beds. Thick bedded shales are also locally important. These strata comprise the most extensive rocks of the area, forming most of the Crocker Range and the western part of the Witti Range.

The Temburong Formation (Wilson and Wong, 1964) is considered to be a time equivalent of the upper part of the Crocker Formation. It is dominantly an argillaceous sequence characterised by beds of shale and siltstone. Massive shale strata also make up a significant proportion. The formation is exposed mainly to the west of the Padas valley, where it forms the southern fringe of the Crocker Range and the northern end of the Maligan Range and there are small outcrops on Pulau Labuan and the Klias Peninsula.

The Labang Formation (Collenette, 1965b) consists mostly of fine sandstones interstratified with poorly bedded massive mudstones. The sandstone is occasionally feldspathic. Although generally subordinate to the sandstone, areas of generally soft grey mudstone sometimes intercalated with micaceous siltstone and sandstone occur. Crystalline limestone beds outcrop in a few places. The formation is found in the east of the Pensiangan District.

The Maligan Formation (Wilson and Wong, 1964) is composed mainly of massive sandstone strata with subordinate beds of shale. This formation makes up the central and southern parts of the Maligan Range. Outliers of the formation are found near the coast in the Sipitang and Beaufort Districts and near Rundum in the south of the Tenom District.

The Setap Shale Formation (Wilson and Wong, 1964) is confined to small areas of Pulau Labuan and the Klias Peninsula. It consists predominantly of soft mudstones and clay with minor intercalations of friable sandstone. It probably corresponds in age to the Maligan Formation.

The Belait Formation (Wilson and Wong, 1964) is similar to the Setap Shale Formation, but is composed of sandstone with minor intercalated beds of siltstone and shale. It is also restricted to Pulau Labuan and the Klias Peninsula.

The Liang Formation is poorly stratified and consists mainly of weakly consolidated conglomerates, sands and clays. It is restricted to small dissected terraces along the eastern shore of Brunei Bay and on Pulau Mengalum.

Pleistocene and Recent deposits are discussed below in the section on soil-forming materials.

Mud volcanoes occur on the Klias Peninsula, Pulau Labuan and on other adjacent islands, notably Pulau Tiga. The eruptions, which take place irregularly, are not the result of magmatic volcanism, but are due to the release of gas trapped at depth in unconsolidated argillaceous strata. The ejected material consists of a grey mud with pieces of shale, sandstone, limestone and occasionally chert (Wilson and Wong, 1964).

Structure

The tectonic history is complex and has been dominated by several phases of orogenic folding, which have given rise to an extremely contorted pattern. Folding is generally strong and beds dip steeply; this is particularly so in the Crocker, Sapulot and Trusmadi Formations. Two main trends in the regional strike pattern may be discerned (Collenette, 1965b). In the north-west and along the broad belt from the Sarawak border and the coast inland to the Witti Range, the strike is generally north to north-east (the Sarawak trend). From the Witti Range eastwards to Sapulut the strike changes and the structures reflect interaction between the Sarawak trend and a south-east trend (the Sulu trend). In the south of the Sipitang District and the east of the Pensiangan District there are large synclinal basins; they are 5-15 km (3-9 mi) wide and are bounded by steep scarps between 300-600 m (1 000-2 000 ft) high. Obvious signs of faulting are limited to the Tambunan, Keningau and Tenom Plains where there are clear fault line scarps.

Mineralogy and chemistry

The mineralogical composition of the sandstones and mudstones referred to in the section on geology is remarkably uniform and differences between them are most commonly due to differences in grain angularity and grain size distribution, rather than variations in composition of the mineral suites.

The rocks generally have high silica contents and few weatherable minerals. The massive sandstones of the Maligan Formation generally contain more than 90% silica. The massive sandstones of the Crocker Formation may contain more than 75% quartz and silica and have a high proportion of rock fragments (Raj, 1971). The greywackes (flysch-type sandstones) of the Crocker, Trusmadi and Temburong Formations contain between 60-85% quartz and silica by volume and between 5-45% matrix. A high proportion of the matrix of sandstones in the Crocker Formation is amorphous silica which is aggregated with sericite, chlorite and carbonate (Jacobson, 1970). Weatherable minerals are usually less than 7% by volume of the flysch-type sandstone, although feldspathic sandstones with contents of feldspars and micas as high as 25% may occur (Wilson and Wong, 1964). The siltstones and shales are also highly siliceous. Wilson and Wong (1964) note that a sample of Temburong siltstone was composed of 80% fine sand and silt-sized quartz, the remainder being indeterminate argillaceous material containing chlorite, calcite and iron ores. Raj (1971) found that the shales and mudstones of the Crocker Formation contained quartz and mica as the dominant minerals of the fine sand and silt-sized material, while quartz and illite were the dominant minerals in the clay-sized fraction.

Samples of shale and mudstone collected from the Temburong, Sapulot and Labang Formations during the present soil survey were found to have total silica contents of between 54% and 70% and less than 10% weatherable minerals; the dominant minerals of the clay-sized fraction were commonly illite and vermiculite (Table 4-11). The sandstones of both the Temburong and Maligan Formations contain quartz as the dominant mineral of the clay-size fraction, with trace amounts of vermiculite.

Partial chemical anlyses of some mudstone and sandstone samples are listed in Table 4-11. The mudstone samples all contain more aluminium, magnesium and phosphorus and generally more iron, calcium and potassium than the sandstone samples. Sandstones of the Maligan Formation generally have the lowest contents for all the elements analyses.

TABLE 4-11 Partial chemical and mineralogical analyses of rock samples

Formation	Lithology	Minerals of the clay-sized fraction				Chemical analyses (% by weight)					
		Quartz	Illite	Vermiculite	Kaolinite	Al_2O_3	Fe_2O_3†	CaO	MgO	K_2O	P_2O_5
Crocker	Sandstone*	n.d.	n.d.	n.d.	n.d.	n.d.	4.8	n.d.	n.d.	1.4	n.d.
	Sandstone*	n.d.	n.d.	n.d.	n.d.	n.d.	2.4	n.d.	n.d.	2.4	n.d.
Temburong	Siltstone*	n.d.	n.d.	n.d.	n.d.	n.d.	2.3	n.d.	n.d.	0.5	n.d.
	Siltstone*	n.d.	n.d.	n.d.	n.d.	n.d.	5.6	n.d.	n.d.	1.2	n.d.
	Ferruginous shale	—	—	dom.	—	19.0	6.5	0.3	1.6	5.5	0.02
	Shale	—	—	dom.	—	16.1	3.6	0.3	1.9	6.6	0.02
	Shale	—	dom.	tr.	tr.	n.d.	n.d.	0.1	1.3	1.9	0.09
	Carbonaceous shale	—	dom.	tr.	mod.	n.d.	n.d.	0.6	1.5	3.1	0.08
	Sandstone	dom.	—	tr.	—	8.6	0.6	0.3	0.4	2.6	0.01
	Sandstone	dom.	tr.	tr.	—	3.5	0.9	0.4	0.5	2.6	0.02
Maligan	Sandstone*	n.d.	n.d.	n.d.	n.d.	n.d.	1.8	n.d.	n.d.	0.5	n.d.
	Sandstone	dom.	—	tr.	—	1.7	0.1	0.01	0.02	1.7	0.01
	Sandstone	dom.	—	tr.	—	2.5	0.6	0.03	0.1	0.3	0.02
Sapulot	Grey shale	n.d.	n.d.	n.d.	n.d.	n.d.	4.9	1.5	2.0	1.7	0.12
Labang	Grey shale	—	dom.	dom.	—	11.8	5.7	1.8	2.7	2.3	0.12

* From Wilson and Wong, (1964)
† Fe_2O_3 represents total iron, both ferrous and ferric
dom. Dominant (>40%)
mod. Moderate (10-40%)
tr. Trace (<10%)
— Absent
n.d. Not determined

Parent materials of the soils

Nine parent material groups occur within the survey area: five are composed of rocks *in situ* or colluvium derived directly from them and four are comprised of alluvium and peat (Text Map 4-4). For the purpose of this volume of the report, one of the mudstone/sandstone group 'mudstone and sandstone' represents three groups in Text Map 4-4: 'Mudstone and minor sandstone; 'Sandstone and mudstone' and 'Sandstone and minor mudstone'.

Mudstone and sandstone

Mudstone and minor sandstone. Mudstones, shales and siltstones with minor sandstones are found mainly in the Sapulot and Labang Formations and locally in the Temburong, Setap and Belait Formations. The soils formed on these materials tend to be fine-textured and have slightly higher contents of calcium, magnesium, potassium and phosphorus than those derived from less argillaceous rocks.

Sandstone and mudstone. These rocks are dominant in the Crocker and Trusmadi Formations. The soils generally are coarser-textured and have lower levels of the main plant nutrients than the previous group.

TEXT MAP 4-4

SABAH

SOUTH-WESTERN DISTRICTS

Town, Village
Road
Railway
Trigonometrical Station (height in metres)
International Boundary
Inter-State Boundary
Soil Survey Boundary
Rivers

Alluvium
Sulphidic alluvium and sulphidic peat
Peat
Mudstone and minor sandstone
Sandstone and mudstone
Sandstone and minor mudstone
Sandstone, mudstone and miscellaneous rocks
Limestone

D.O.S. 3181X

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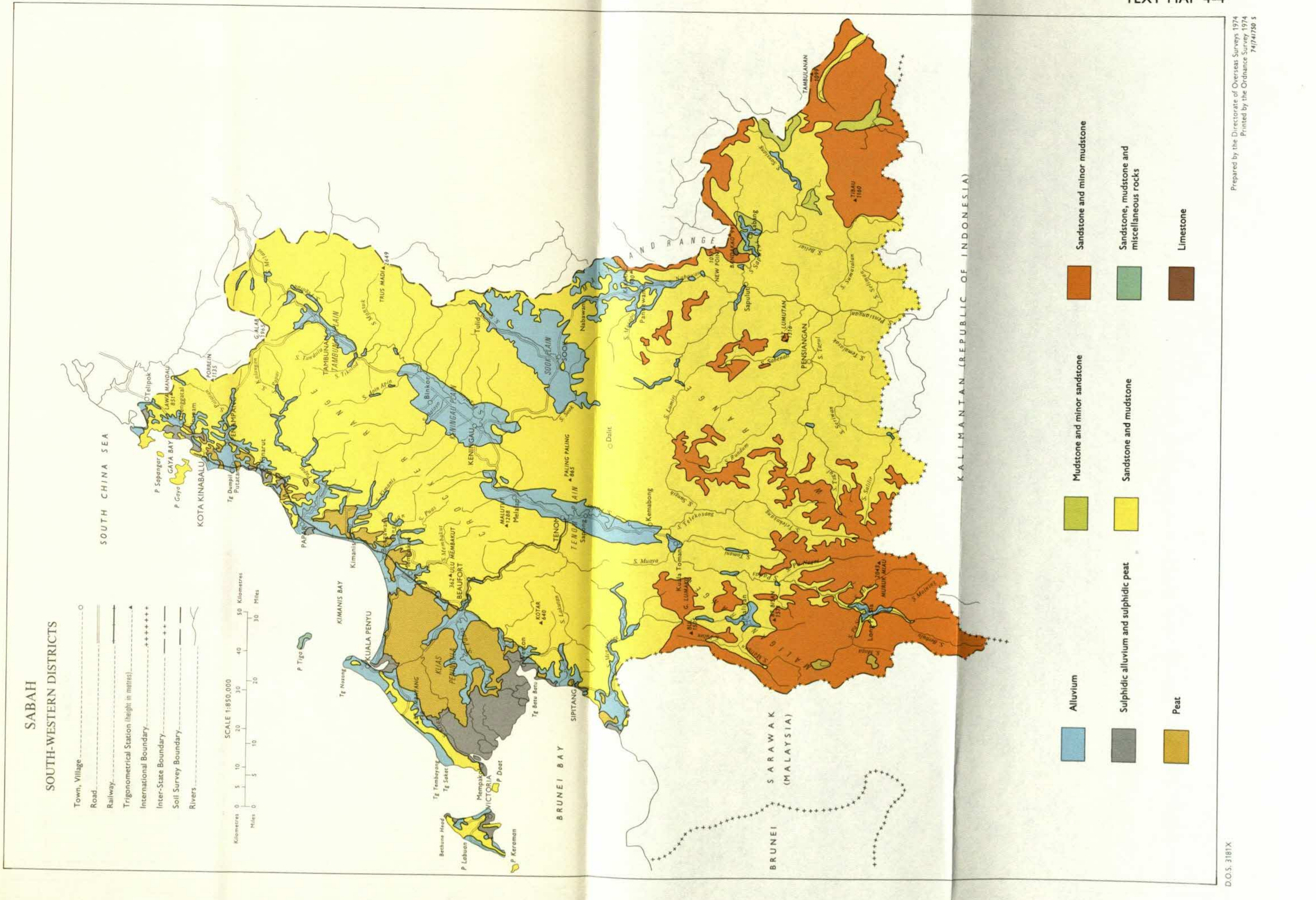
SABAH
SOUTH-WESTERN DISTRICTS
Town, Village
Road
Railway
Trigonometrical Station (height in metres)
International Boundary
Inter-State Boundary
Soil Survey Boundary
Rivers
SCALE 1:850,000
Kilometres
Miles
Alluvium
Sulphidic alluvium and sulphidic peat
Peat
Mudstone and minor sandstone
Sandstone and mudstone
Sandstone and minor mudstone
Sandstone, mudstone and miscellaneous rocks
Limestone
SOUTH CHINA SEA
BRUNEI BAY
KIMANIS BAY
SARAWAK (MALAYSIA)
BRUNEI
KALIMANTAN (REPUBLIC OF INDONESIA)
KOTA KINABALU
PAPAR
BEAUFORT
KENINGAU
TENOM
SIPITANG
KUALA PENYU
VICTORIA
TAMBUNAN
PENSIANGAN
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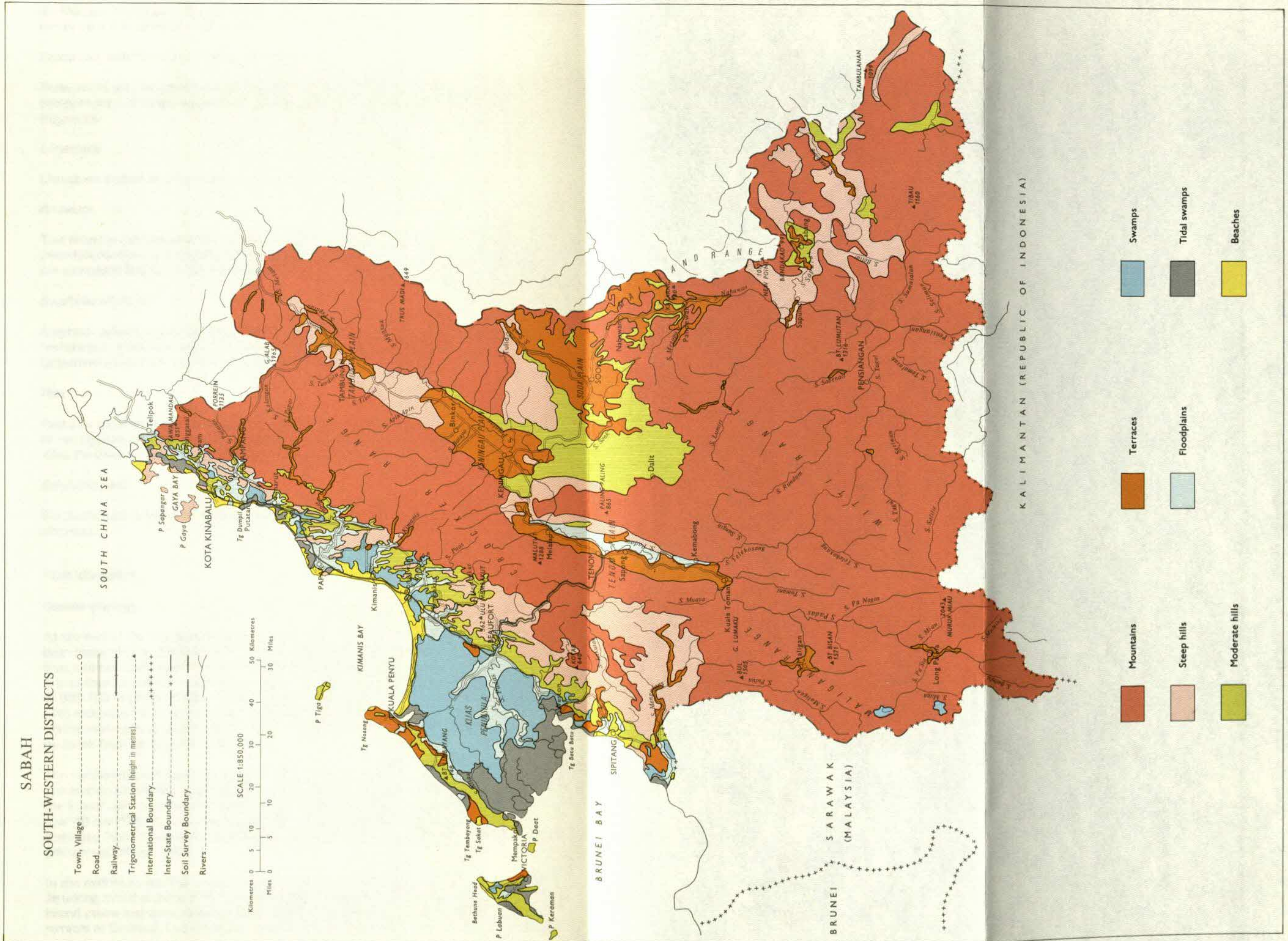
SABAH
SOUTH-WESTERN DISTRICTS
Town, Village
Road
Railway
Trigonometrical Station (height in metres)
International Boundary
Inter-State Boundary
Soil Survey Boundary
Rivers
SCALE 1:850,000
Kilometres
Miles
Mountains
Steep hills
Moderate hills
Terraces
Floodplains
Swamps
Tidal swamps
Beaches
SOUTH CHINA SEA
KOTA KINABALU
KIMANIS BAY
BRUNEI BAY
KUALA PENYU
BEAUFORT
SIPITANG
KENINGAU
TENOM
PENSIANGAN
Dalit
VICTORIA
BRUNEI
SARAWAK (MALAYSIA)
KALIMANTAN (REPUBLIC OF INDONESIA)
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Sandstone and minor mudstone. Sandstone and minor amounts of mudstone occur in the Maligan Formation. The sandstones usually contain more than 90% silica and have low or very low levels of all plant nutrients; the soils are mainly coarse-textured.

Sandstone, mudstone and miscellaneous rocks

These rocks are restricted to mud volcanoes. Mud and mudstone are the main components with lesser amounts of sandstone and occasional limestone and chert fragments.

Limestone

Limestone occurs in a few small areas, mostly in Pensiangan District.

Alluvium

This broad group includes river and marine deposits ranging from fine-textured materials containing some weatherable minerals to coarse-textured materials which are composed largely of silica; the deposits may contain pebbles, stones and boulders.

Sulphidic alluvium

Sulphidic alluvium is confined to the coasts and some river estuaries. It is variable in texture but contains at least 0.75% total sulphur and less than 3 times as much carbonate (as calcium carbonate equivalent) as sulphur (USDA, 1973).

Peat

Peat accumulates under waterlogged conditions, where temperatures are relatively low, or on deposits which are very low in nutrients. In some poorly drained areas of the Klias Peninsula, peat deposits are several metres thick.

Sulphidic peat

Sulphidic peat is confined to tidal areas, where it occurs in association with sulphidic alluvium.

TOPOGRAPHY

Geomorphology

At the end of the Pliocene or during the early Pleistocene most of the survey area had been reduced to a peneplain. The uplift of the Kinabalu pluton which began at this time also resulted in uplift of land to the south and south-west of Gunong Kinabalu; it is estimated that the uplift in the interior and Crocker Range area was of the order of 600-750 m (2 000-2 500 ft). Downwarping to the east of the Crocker axis coupled with extensive faulting produced the Patau, Tambunan, Keningau, Tenom and Maligan valleys and plains, while further uplift of the Trusmadi massif occured mainly by block faulting (Liechti *et al*, 1960).

The combination of rapid uplift and the high rainfall of the pluvial epoch led to rapid denudation of the new upland areas and the formation of deep alluvial deposits in the inland valleys and plains. The depths of these deposits have been estimated at over 40 cm (130 ft) in the Tambunan Plain (Raj, 1971), over 150 m (500 ft) in the Keningau Plain (Collenette, 1965b) and over 90 m (300 ft) in the Tenom Plain (Wilson and Wong, 1964).

In the middle to late Pleistocene a second major cycle of erosion and deposition (The Jerudong cycle) occurred, the main results of which were the broad terraces of the inland plains and the marine terraces along the coast (Liechti *et al*, 1960); the marine terraces at Sipitang, Labuan airport and the Klias Peninsula for example were probably formed during this period when world sea levels rose to between 30-45 m (100-150 ft) above the present level (Holmes, 1965). Coastal valleys, which were drowned by the rise in sea level, were also infilled with alluvium.

At this time there were many changes in the drainage pattern. The Sungai Pegalan, for example, initially flowed south from the Keningau Plain to the Sook Plain and thence eastwards into the upper Kinabatangan (Collenette, 1965b). The river which drained the Tenom Plain probably flowed northwards from Kemabong to Melalap and then, judging by the broad dry valley between Melalap and Keningau, joined the Sungai Pegalan at the southern end of the Keningau Plain. The Sungai Padas cut back eastwards from the coast capturing both the Tenom Plain drainage and the Sungai Pegalan; the terraces which flank the mature valley above the present Sungai Padas are evidence of this (Wilson and Wong, 1964). At about this time, some of the faults along the sides of the Keningau Plain were reactivated and the plain itself assumed a dip to the north-east; contrary to the general tilt of the country, the Baiayo and Apin Apin rivers are presently cutting into their northern banks. As a result of uplift to the south-west of Trusmadi, between Keningau and Sook, the Sungai Sook reversed its direction of flow to the north and cut a new gorge. When uplift temporarily exceeded the downcutting power of the rivers, lakes were formed on the terraces of the inland plains. The swamps which occur today on the second highest terraces in the inland plains and on the marine terraces are remnants of these former lakes.

A drop of sea level of about 75 m (250 ft) resulted in the carving out of coastal valleys, and the Padas and Tuaran rivers, for example, cut channels to a low base level through the offshore Quaternary sediments (Liechti *et al*, 1960). Inland, further downcutting in the major valleys and plains resulted in the formation of a third set of terraces which is clearly expressed in the Tambunan, Keningau and Tenom Plains and in the Maligan valley. Since the flow of the Sungai Pegalan from Keningau to Sook had been reversed prior to this period by its capture by the Sungai Padas, downcutting in the Sook Plain was minimised and the third-level terraces there are only weakly developed.

Some parts of the interior, notably the uplands between Maligan and Long Pa Sia and the mountains in the far east of the Pensiangan District, escaped dissection and denudation during the Quaternary owing to their distance from base level and to the hardness of their sandstone rocks: Wilford (1967a) cites the accordant summits of the sandstone mountains of the Sarawak border as remnants of the former Pliocene peneplain. Today these uplands consist of broad cuestas and hogsbacks and the large synclinal basins in the south of the Sipitang District are now swamps.

Towards the end of the glacial epoch the sea level rose again, resulting in the infilling of the coastal valleys. Material brought down from the interior by the Sungai Padas contributed to the building of the Klias Peninsula. At the end of the Pleistocene a marine terrace was formed about 3-4.5 m (10-15 ft) above present sea level.

Landforms

Eight classes of landform (Text Map 4-5) are described in the survey area and, with the groups of soil parent materials already discussed, form the basis of the soil associations described in Parts 4 and 5.

Beaches

Beaches and slightly raised beach ridges occur along the coast from Kota Kinabalu to Kuala Penyu, on Pulau Labuan and near Sipitang (Plate 4-1).

Tidal swamps

These occur around the estuaries of most of the rivers and are most extensive in the Padas delta (Plates 4-4 and 4-5).

Swamps

Freshwater swamps have developed either in abandoned river meanders or more commonly in lagoons behind beach ridges (Plate 4-2); they also occur in the synclinal basins of the Maligan Range above 1 200 m (4 000 ft) (Plate 4-18).

Floodplains

Floodplains are extensive along the west coast rivers (Plate 4-7) and along major rivers of the interior, such as the Padas (Plate 4-6); meander belts, levees and small areas of freshwater swamp are included.

Terraces

The terraces that occur in most river valleys are closely associated with minor floodplains of the valley floors. The terraces may be deeply incised to give the appearance of low hills with steep slopes as near Apin Apin in the Keningau Plain (Plate 4-19) or they may be wide and almost flat, as in the Sook Plain (Plate 4-12).

Moderate hills

Moderate hills are defined as hills with absolute amplitude of less than 150 m (500 ft) with slopes mostly between 10 and 25°. This landform class includes the lower foothills of the main mountain ranges and the smaller hills that occur along the coast.

Steep hills

Steep hills are defined as hills of up to 300 m (1 000 ft) absolute amplitude, with slopes generally more than 25°. The higher foothills of the various mountain ranges are included in this class.

Mountains

Mountains have an absolute amplitude greater than 300 m (1 000 ft). The slopes are very variable but are generally more than 25°. More than half of the survey area consists of mountains mostly in the form of mountain ranges with very steep ridges and occasional peaks. The other component of this landform class is the mountain cuesta, which consists of long, moderate dip slopes and very steep scarp faces (Plate 4-26).

EFFECTS OF AGRICULTURE ON SOIL FORMATION

The influence of man on soil development in this area is seen in the cultivation of wet rice and in shifting agriculture.

Wet rice

Cultivation of wet rice on fine-and medium-textured soils may lead to the formation of plough pans. These increase the water retention capabilities of the soil, but cause poor aeration of the subsoil; as a result of the reduction of iron and manganese compounds, the soil becomes gleyed. Soil structure deteriorates and the clay content of the plough layer may decrease either by dispersal in the irrigation waters or by translocation in the profile. The amounts of exchangeable bases however are sometimes increased, as nutrients may be brought in by irrigation water.

Shifting agriculture

There is very little information on how shifting agriculture affects soil formation and degradation in Sabah. In 1951 a committee was formed to look into the problems of shifting agriculture (Colony of North Borneo, 1951); it reported that if the rotation periods of cultivation and secondary forest were longer than 10 to 12 years there was no evidence of serious soil erosion taking place.

Immediately after clearing and burning, the surface soil has a strong baked-crumb structure, but the peds are very light and can be easily eroded because of the increased runoff. As the nutrients released by burning are absorbed by the soil the pH increases, but there is a reduction in the organic carbon and nitrogen levels.

However, when the secondary forest is re-established or if *lalang (Imperata cylindrica)* takes over after the hill rice, there is a slow build-up of organic carbon and nitrogen to levels similar to those found under primary forest. Analyses of data from 50 similar soil profiles in the survey area showed no significant differences in the levels of organic carbon or of total nitrogen between topsoils under primary forest, secondary forest or *lalang.*

In the survey area, *lalang* has taken over on sites where there has been over-cropping, particularly on relatively coarse-textured or deeply weathered soils in, or adjacent to, the plains and broad valleys of the interior, which often experience long dry periods.

Long-term cropping, buring or overgrazing produce complete soil degradation with very high loss of sediment and organic matter by erosion, because of very high runoff. The over cultivation of *lalang*-covered land in particular, can lead to very intense erosion and soil degradation.

Part 3

The soil associations

Introduction

The soils of the area have been mapped as soil associations at a scale of 1:250 000. A soil association is defined as a group of soil units that occurs together within a landscape unit, recognisable by a characteristic pattern of landform, soil parent material and vegetation. Each association has been named after the locality where it was first described.

Twenty-three soil associations were defined during the survey: of these 14 are described on alluvium, 8 on sandstone/mudstone and 1 on limestone.

Soils on alluvium are described in the following paragraphs in three sections:

1. Tidal swamps and beaches

2. Floodplains and associated terraces

3. Terraces

Soil associations on mudstone/sandstone and limestone are described in three sections:

1. Soils on mudstone and sandstone ('Mudstone and minor sandstone', 'Sandstone and mudstone' and 'Sandstone and minor mudstone' in Text Map 4-4).

2. Soils on Mudstone, sandstone and miscellaneous rocks.

3. Soils on limestone.

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

Soil associations on alluvium 1. Tidal swamps and beaches

The Weston, Tanjong Aru and Usukan Associations are mapped on tidal swamps and beaches (Table 4-12).

WESTON ASSOCIATION

The Weston Association consists of soils formed in estuaries and in tidal swamps. It occurs at the mouths of rivers and inlets along the coast (Plate 4-4) and covers 383 km^2 (148 mi^2); this is about 2% of the survey area. The soils are developed on alluvium which may be overlain by peat.

The vegetation nearest to the sea consists largely of mangrove (mainly *Rhizophora* spp., *Bruguiera* sp., and *Avicennia* sp.). Further away from the sea, nipah palm *(Nypa fruticans)*, and locally piah fern *(Acrostrichum aureum)* become increasingly frequent as the mangrove species decrease. Crab mounds are common.

TABLE 4-12. Soil associations on tidal swamps and beaches

Association	Landform	Parent materials	Main soil units	Soil families
Weston	Tidal swamps	Sulphidic alluvium	Thionic Fluvisol	Weston
		Alluvium		Kalibong
		Sulphidic peat	Dystric Histosol	Arang
Tanjong Aru	Beaches	Alluvium	Dystric Regosol	Tamanong
			Eutric Regosol	Tanjong Lita
			Gleyic Podzol	Baiayo
			Humic Podzol	Karamatoi
			Dystric Gleysol	Koyah
			Eutric Gleysol	Bangawat
			Humic Gleysol	Guan
Usukan	Beaches	Calcareous alluvium	Calcaric Regosol	Usukan
		Calcareous peat	Eutric Histosol	Mengalum

In some localities, notably near Inanam (Plate 4-5), the swamps are found surrounding islands with soils of the Dalit Association, but they are frequently too small to be separated at the 1:250 000 mapping scale.

Thionic Fluvisols are the dominant soils and Dystric Histosols occur sporadically; both soil units are potential acid sulphate soils. The salinity of these soils, as measured by conductivity, is extremely variable and reported values range from 0.3 - 22.1 mmho/cm^3; the value is related to the relative amounts of tidal and freshwater flooding that individual areas receive. Many of the soils are sodic with more than 15% of the exchange capacity taken up by exchangeable sodium. Soil drainage is poor or very poor.

Thionic Fluvisols: Weston and Kalibong Families

The soils of the Weston Family are developed on sulphidic alluvium that is generally medium to fine in texture. They are frequently flooded by high tides. Horizonation is generally absent, although A horizons with weak structures may occur; the C horizons are structureless. Soil hues are IOYR or yellower and chromas are usually low.

Organic carbon contents may be as high as 10% and total sulphur contents, which tend to increase with depth, may be as high as 3%. Cation exchange capacities generally range from 10-20 meq % and the exchange complex is usually saturated mainly by sodium; magnesium and calcium values are generally medium to high. (Profiles Jt 2 and 3).

The soils of the Kalibong Family are developed on mainly coarse-to medium-textured alluvium containing less than 0.75% total sulphur. Some of these soils have high organic carbon contents (>12%) and overlap with the Arang Family of Dystric Histosols (see below). Soil colours reflect the amount of organic matter present, being dark reddish brown where this is high and brownish grey or greyish brown where the organic matter content is low. Cation exchange capacities are also related to organic matter contents. The levels of exchangeable sodium and other cations tend to be lower than in the soils of the Weston Family, possibly because they are more frequently flooded by fresh water.

Dystric Histosols: Arang Family

These soils form a continuous sequence with those of the Kalibong Family as they contain variable and often appreciable amounts of fine - to medium - textured alluvium. The dark coloured Co horizons are composed largely of organic debris which may be fibrous or amorphous.

Reported total sulphur contents range from 1 to 6%. Cation exchange capacities are above 50 meq % and the soils are fully saturated with large amounts of exchangeable sodium and magnesium; calcium and potassium levels are also generally high. Easily soluble phosphorus levels are medium to low.

TANJONG ARU ASSOCIATION

The Tanjong Aru Association comprises soils formed on beaches of siliceous sand; it occurs at Karambunai, Tanjong Aru and along most of the Kimanis Bay coastline; small areas also occur on the Sipitang coast and on Pulau Labuan. It covers about 153 km^2 (59 mi^2) or 0.8% of the survey area.

The association includes present day beaches and beach ridges 1 - 3 m (3 - 9 ft) above mean sea level that are now some distance inland. They form characteristic parallel bands with a regular ridge and swale micro-relief (Plate 4-1). Soils in the swales are usually poorly drained and swampy due to fluctuations in groundwater level, but those on the ridges may be excessively drained.

Along the present shore line there is often a narrow belt of Casuarina forest in which *Casuarina equisetifolia* is dominant with *Glochidion* sp. Further inland the vegetation is dominantly poor healthy grassland with Straits Rhododendron (*Melastoma* sp.); it suffers frequent burning. Parts of this association are being used to grow coconuts with limited success.

Eutric and Dystric Regosols are the dominant soils on the well drained sites close to the sea and on some older beach ridges. Humic Podzols are also found on old beach ridges near Kuala Penyu, but generally these positions are occupied by imperfectly drained Gleyic Podzols. Poorly drained Gleyic Podzols, Dystric and Eutric Gleysols are found in the swales. Where the drainage is very poor, organic matter accumulates and Humic Gleysols occur.

Eutric and Dystric Regosols: Tanjong Lita and Tamanong Families

Eutric and Dystric Regosols occur on the better drained sites. The distinction between the soil units (base saturation above or below 50%) has little meaning as cation exchange capacities are mostly below 10 and may be less than 1 meq %. Soil textures are coarse throughout and structures are usually non-existent; they may be weakly developed in the surface horizons. Hues are generally 1OYR with chromas of 4 or less.

Organic carbon contents are mostly low although peat fragments may occur at depth. Soil pH values are mostly between 5 and 6. Levels of exchangeable cations are mostly negligible, but the amounts of easily soluble phosphorus vary from low to high (Profile Rc 1 is an example of a soil of the Tamanong Family).

Humic and Gleyic Podzols: Karamatoi and Baiayo Families

The soil succession from well or excessively drained Humic Podzols on the ridges to imperfectly and poorly drained Gleyic Podzols in the swales is found in many localities; the distinction between Humic Podzols and imperfectly drained Gleyic Podzols is often very fine. The soils are all coarse in texture. Structure is generally lacking, although the lower spodic horizons of the Humic Podzols may show some small degree of cementation. The spodic horizons are generally rather diffuse and only weakly to moderately developed with some accumulation of organic carbon and a small accumulation of aluminium and iron. Soil pH values are below 5 and exchange capacities, which are all below 10 meq %, may be less than 1 meq %; amounts of exchangeable cations are low to negligible in all horizons.

Dystric and Eutric Gleysols: Koyah and Bangawat Families

These soils are arbitrarily separated on base saturation figures in the same way as Dystric and Eutric Regosols; as both often have very low cation exchange capacities there is again little significance in the distinction. Soil textures are mostly coarse. Structures are moderately or weakly developed in the upper parts above the gleyed horizions. These upper parts have IOYR colours with high chromas and they may also be mottled; in the gleyed horizons colours are mainly IOYR with low chromas. Plant nutrient levels are mostly low; pH values often rise from 4 at the surface to about 5 at depth.

Humic Gleysols: Guan Family

These soils are generally similar to the Eutric and Dystric Gelysols described above, except that they are all very poorly drained, have surface histic O horizons and have higher organic carbon contents in the subsurface horizons; reported values range from 2 to 10%. This organic carbon is in the form of only partly decomposed plant material and accounts for the higher cation exchange capacities and larger amounts of plant nutrients in these soils.

USUKAN ASSOCIATION

The Usukan Association occurs on parts of the coast of the Klias Peninsula, on Pulau Labuan and on Pulau Mengalum. It covers about 18 km^2 (7 mi^2) or 0.1% of the survey area. It consists of soils developed on beaches formed mainly of calcareous alluvium. On Pulau Labuan and on the Klias Peninsula coconuts have been planted but on Pulau Mengalum there is a low dense forest of *Pandanus* sp. with locally dominant *Casuarina equisetifolia.*

Calcaric Regosols developed on calcareous sand are the dominant soils; in some small parts, the calcareous material is overlain by non-calcareous alluvium and here the soils are Dystric Regosols. The soil drainage varies with the detailed topography; the ridge crests are well or excessively drained, but the swales are poorly or very poorly drained. Eutric Histosols, formed on calcareous peat and sand, have been described on Pulau Mengalum.

Calcaric Regosols: Usukan Family

Calcaric Regosols of the Usukan Family range from excessively to imperfectly drained soils. Textures are coarse with coral and shell fragments in all horizons. Structure may be moderately developed in the surface horizon but the other horizons are structureless. The colours in all horizons have IOYR hues with variable values and chromas.

Soil pH is between 7.0 and 8.5 and increases with depth. Cation exchange capacities are about 10 meq % in the surface horizon as a result of a small organic matter accumulation; below this, values are very low and are often below 1 meq %. Levels of exchangeable calcium are very high, but levels of other cations and easily soluble phosphorus are mostly low (Profile Rc 1).

Dystric Regosols: Tamanong Family

The Dystric Regosols in this association are similar to those described in the Tanjong Aru Association, except that below about 50 cm (20 in) the sand contains many shell and coral fragments. This causes a rise in the level of exchangeable calcium from less than 1 to more than 30 meq %.

Eutric Histosols: Mengalum Family

Eutric Histosols of the Mengalum Family occur on Pulau Mengalum. They are formed on peat which contains some shell and coral fragments and which result in high exchangeable calcium and magnesium values. The peat may be fibrous or amorphous; it is of variable thickness and overlies calcareous alluvium (Profile Oe 1).

Soil pH values range from 6 to 8. The peat horizons have high cation exchange capacities but values decrease in the mineral horizons. The exchange complex is fully saturated throughout.

Soil associations on alluvium 2. Floodplains and associated terraces

The soils of the river floodplains along the south-west coast have been grouped into 4 associations which reflect the deterioration of drainage with distance from the slightly raised levees and meander belts (Tuaran Association) across the true floodplains (Kinabatangan Association) to the backswamps (Sapi Association) and peatswamps (Klias Association). In the interior plains and valleys the soils formed on alluvium have been grouped in 3 associations; where valley bottoms are of sufficient size for meander belts to have formed, the soils are included in the Tuaran Association; on the river floodplains, which often have stony alluvium and which are subject to flash flooding, the soils are included in the Labau Association and soils on low river terraces comprise the Binkor Association (Table 4-13).

TUARAN ASSOCIATION

The soils of the levees, meander scrolls and cutoof lakes are included in the Tuaran Association which covers about 313 km^2 (121 mi^2) or 1.6% of the survey area. It occurrs mainly on the floodplains of the Sungai Pegalan and Sungai Padas in the Tenom Plain (Plate 4-6) and on the Padas floodplain west of Beaufort. In both localities, the true floodplains and back swamps are subordinate to the levees and meander scrolls; they are also included in this association.

Soil parent materials consist of alluvium, ranging in texture from coarse on the levees to fine in the abandoned cutoff lakes. Many sites are flooded periodically so that tiered deposits are common. The river banks are susceptible to erosion and during major floods, rivers often change their courses, abandoning former meanders for more direct channels.

Little primary vegetation remains and most of the area is used for agriculture and settlement. Wet rice and rubber are the major crops; cocoa, coffee and bananas, citrus and other fruits are also grown. The new Cocoa Research Station, near Tenom, is sited on land included in this association.

On the present day levees, the dominant soils are well drained Eutric Fluvisols of the Pegalan Family. In the Tenom Plain, the most extensive soils away from the rivers are moderately well or well drained Eutric Cambisols of the Bulanat Family; on the minor inclusions of floodplains, abandoned meanders, cutoffs and backswamps there are poorly or very poorly drained Humic, Dystric and Eutric Gleysols of the Guan, Koyah and Bangawat Families and poorly drained Gleyic Luvisols of the Buran Family. Gleyic Luvisols of the Buran Family also occur on low terraces, where they are imperfectly drained and rather coarser in texture. On the levees along the upper reaches of the west coast rivers, well drained Dystric Cambisols of the Kelawat Family and Eutric Fluvisols of the Pegalan Family are dominant; Orthic Acrisols of the Paliu Family cover large areas of the middle reaches of the Sungai Papar and there are minor inclusions of poorly drained Gleyic Acrisols of the Inanam Family. The Paliu Family is described in the Binkor Association.

TABLE 4-13 Soil associations on floodplains and associated terraces

Soil association	Landforms	Parent materials	Main soil units	Soil families
Tuaran	River meander belts, levees and abandoned cutoff lakes	Alluvium	Eutric Fluvisol	Pegalan
			Eutric Cambisol	Bulanat
			Dystric Cambisol	Kelawat
			Humic Gleysol	Guan
			Eutric Gleysol	Bangawat
			Dystric Gleysol	Koyah
			Gleyic Luvisol	Buran
Kinabatangan	River floodplains	Alluvium	Gleyic Acrisol	Inanam
			Dystric Gleysol	Koyah
			Eutric Gleysol	Bangawat
			Humic Gleysol	Guan
Sapi	Swamps	Alluvium	Humic Gleysol	Guan
			Dystric Gleysol	Koyah
			Eutric Gleysol	Bangawat
		Peat	Dystric Histosol	Klias
Klias	Swamps	Peat	Dystric Histosol	Klias
		Sulphidic peat		Arang
		Alluvium	Humic Gleysol	Guan
Labau	Valley floors and minor terraces	Alluvium	Dystric Fluvisol	Tenghilan
			Eutric Fluvisol	Pegalan
			Dystric Gleysol	Koyah
			Eutric Gleysol	Bangawat
			Gleyic Acrisol	Inanam
			Orthic Acrisol	Paliu
			Dystric Cambisol	Kelawat
			Eutric Cambisol	Bulanat
Binkor	Low river terraces	Alluvium	Dystric Gleysol	Koyah
			Eutric Gleysol	Bangawat
			Orthic Acrisol	Paliu
			Gleyic Luvisol	Buran
			Dystric Cambisol	Kelawat
			Eutric Cambisol	Bulanat

Eutric Fluvisols: Pegalan Family

Eutric Fluvisols of the Pegalan Family have strongly structured, medium-textured surface horizons overlying structureless, coarse-textured C horizons; evidence of sequential deposition is common. Soil colours are usually IOYR in hue throughout.

Organic carbon content is between 1 and 2% in the surface horizon giving a cation exchange capacity of about 10 meq %; values of both decrease sharply below this. Exchangeable cation levels follow the same pattern; calcium and magnesium levels may be high at the surface, but decrease to very low at depth. Easily soluble phosphorus contents show a similar decrease. Soil pH is generally between 5.0 and 6.5 (Profile Je 1).

Although all the reported profiles fall into the Eutric Fluvisol unit, it is probable that Dystric Fluvisols of the Tenghilan Family also occur.

Eutric Cambisols: Bulanat Family

The soils of the Bulanat Family have textures ranging from moderately fine to coarse; ranges of this nature can occur in individual profiles and are indicative of sequential deposition. Only moderately well drained profiles have been reported, but it is most probable that well drained soils also occur. Profile colours are IOYR in hue with values of 4 or 5 and chromas of 2 to 4. Profiles have A, B and C horizons; structures may be strongly or moderately developed in the A horizon, but only moderate structures have been described in the Cambic B horizons.

Soil pH values generally increase with depth from about 5.5 at the surface to 6.5 in the C horizon. Cation exchange capacity is medium to low (10-15 meq %) at the surface and decreases with depth, following the same pattern as organic carbon. Amounts of exchangeable calcium and magnesium are medium in the surface horizons, decreasing to low at depth; potassium and sodium are low throughout. Amounts of easily soluble phosphorus are medium at the surface and generally decrease to low with depth.

Dystric Cambisols: Kelawat Family

Dystric Cambisols of the Kelawat Family are well or moderately well drained and are generally coarse - to medium-textured; the lower horizons are sometimes stony. Soil structure deteriorates from moderate in the upper horizons to weak or structureless in the lower horizons.

Cation exchange capacities are generally between 5 and 10 meq % in all horizons and exchangeable cations are mostly low, so that the base saturation values of these soils are lower than those of the Bulanat Family.

Humic Gleysols: Guan Family

Poorly and very poorly drained Humic Gleysols of the Guan Family with fine or moderately fine textures occur in the backswamps and on meander scrolls. The alluvium may be underlain by peat and shallow histic horizons may occur at the surface. Soil colours are mostly IOYR and mottles of redder hues may occur in any horizon. Small, soft, iron concretions have been reported in the lower horizons of some profiles. Soil structure is generally only moderately developed in the upper horizions but some profiles with strong structures have also been described.

Soils examined in the Tenom Plain have higher levels of exchangeable cations, higher base saturation values and higher pH values than those along the west coast rivers. Cation exchange capacities are mainly between 10 and 20 meq %, but may be much higher in horizons rich in organic matter. Easily soluble phosphorus levels are generally medium ranging from 5-15 ppm (Profile Gh 2).

Dystric and Eutric Gleysols: Koyah and Bangawat Families

Poorly drained Dystric and Eutric Gleysols of the Koyah and Bangawat Families are found in similar sites to those where Humic Gleysols of the Guan Family occur. The Koyah Family has been described mainly along the west coast rivers; soils of the Bangawat Family are more frequent in the interior valleys.

Soils of the Koyah Family have fine-textured A and B horizons over coarse-textured C horizons. Structure changes from strong in the A to moderate or weak in the B horizons. Colours are IOYR with low chromas throughout.

Soil pH values are about 4.5 in all horizons. The A and B horizons contain up to 5% organic carbon and have medium cation exchange capacities; C horizon values are very low. Exchangeable cations are negligible except in the shallow A horizons.

The soils of the Bangawat Family described in the Tenom Plain have A, B and C horizons of variable textures. Structure is only moderate in both the A and B horizons. Soil colours are IOYR or yellower, generally with low chromas; mottles with redder hues may occur in any horizon.

Soil pH values are variable, values between 5 and 7 having been reported. Cation exchange capacities follow clay and organic carbon contents but are generally low. Exchangeable calcium levels are mostly medium, but other cations are low or very low.

Gleyic Luvisols: Buran Family

Moderately fine textured, poorly and imperfectly drained soils of the Buran Family have been described in the Tenom Plain. The soils have A, B and C horizons. The argillic B horizons are not srongly developed and have marginal increases in clay contents; clay cutans, however, are generally continuous. Some small concretions may occur in the lower argillic horizons. Soil colours are IOYR or yellower with chromas usually of 4 or less; all horizons may be mottled.

Soil pH values are in the 5 to 6 range and cation exchange capacities are usually between 10 and 20 meq %. Exchangeable calcium and magnesium values are generally medium to high in all horizons; other cations and easily soluble phosphorus levels are low.

KINABATANGAN ASSOCIATION

The Kinabatangan Association occurs on the floodplains of the west coast rivers and on Pulau Labuan. Many of these rivers have inextensive levees, meander belts and swamps which are too small to be separated as the Tuaran Association; they have been included in this association. West of the Klias Peninsula the association includes flat imperfectly to poorly drained areas between low hills and peat swamps. The association covers about 194 km^2 (75 mi^2) or 1% of the survey area (see Plates 4-7 and 4-8).

The land is used mainly for wet rice cultivation some of which is irrigated. Rubber is also an important crop, particularly where the land has been drained as in the Kimanis and Beaufort areas. Secondary forest and scrub occurs between Mesapol and Sipitang.

Medium - and fine-textured alluvium are the predominant soil parent materials; in places they overlie old beach sands and peat deposits.

Gleyic Acrisols and Dystric Gleysols are the most extensive soils. Gleyic Acrisols of the Inanam Family are formed on fine - or medium-textured alluvium and are poorly drained; nearer the coast they are formed on fine-textured alluvium over sand. Dystric Gleysols of the Koyah Family are mainly fine-textured, but nearer the coast they are also formed on fine-textured alluvium over sand; near Sipitang they occur on medium-textured alluvium. Eutric Gleysols of the Bangawat Family rarely occur. Humic

Gleysols of the Guan Family are found in small swamps where they are formed on fine-textured alluvium; coarser-textured soils of the same family occur on low wet sites in transition zones between floodplains and beaches. Apart from Gleyic Acrisols of the Inanam Family these soils are all described in the Tuaran Association.

Gleyic Acrisols: Inanam Family

Gleyic Acrisols of the Inanam Family are poorly drained and have variable textures; they are mainly medium to fine in texture, but coarse-textured deposits often form lower horizons. Most horizons have mottles super-imposed on a matrix colour that is usually 10YR or yellower in hue; several contain concretions. Cutans are generally present in the argillic horizons, but are not always well developed. Soil structures are mostly moderately developed, fine to medium, subangular blocky. Umbric surface horizons are common and large amounts of organic matter may occur in the lower horizons.

Soil pH is between 4.5 and 5.5 and tends to increase slightly with depth. Cation exchange capacities are mostly medium except in coarse-textured horizons. Base saturation figures are rarely below 20% and in some profiles the values are close to those required for Luvisols. Plant nutrient levels, with the exception of exchangeable magnesium, are mostly low.

SAPI ASSOCIATION

The Sapi Association is not extensive and covers only 18 km^2 (7 mi^2) or 0.1% of the survey area. It occurs in the backswamps of tributary valleys between the floodplains of the west coast rivers and hills and also between hills and tidal swamps, notably between Menggatal and Telipok.

Very little natural forest remains. Attempts to drain some areas for rice or rubber cultivation have failed and the cleared areas are now covered with sedges (*Rhynchospora* spp.) or moribund rubber trees. Sago palms, however, grow well; they usually grow on individual areas of less than 0.4 ha (1 acre).

The soils are formed on fine-textured alluvium and comprise Humic, Eutric and Dystric Gleysols of the Guan, Bangawat and Koyah Families respectively. Dystric Histosols of the Klias Family occur in the most poorly drained sites; they are formed on peat overlying fine-textured alluvium. The Gleysols are all described in the Tuaran Association, and the Dystric Histosols are discussed below in the Klias Association.

KLIAS ASSOCIATION

Peatswamps with very poorly drained Histosols comprise the Klias Association. The largest single area of the association is in the Klias Peninsula (Plate 4-9) and there are other significant areas inland from the beaches between Membakut and Papar (Plate 4-2), in narrow valleys along the west coast and in the broad delta at the mouths of the Mengalong, Merapok and Lawas rivers. The association covers about 738 km^2 (285 ml^2) or 3.8% of the survey area.

The primary swamp forest of the association consisted mainly of *Dactylocladus stenostachys, Gonystylus bancanus* and *Dryobalonops rappa* but most of this has now been logged. Sedges (*Rhynchospora* spp. and *Eleocharis* spp.) cover extensive areas north-west of Kota Klias in the Klias Peninsula. There are 800 ha (2 000 ac) of oil palm at the Klias Scheme; wet rice is also grown and there have been unsuccessful attempts to grow rubber on shallow peat.

Parent materials are peat or mixtures of peat and fine-textured alluvium. Peat depth varies from less than 30 cm (12 in) to over 12 m (40 ft), and is generally greater at the swamp centres. On the Klias Peninsula there are extensive areas of peat deeper than 3 m (10 ft), notably north and east of Kota Klias and in the area between the Beaufort to Weston road and the Sungai Padas. The peat overlies fine - to medium-textured alluvium, except adjacent to beaches and west of the middle reaches of the Sungai Klias, where it overlies coarse-textured alluvium. At the peatswamp extremities, particularly those adjoining river flood plains, there are normally belts of alluvium overlying peat, or intercalated peat and alluvium, which result from successive stages of peat growth and alluvial incursion. The peat is predominantly fibrous and is composed of partly decomposed remains of trees and sedges.

The dominant soils are Dystric Histosols of the Klias Family; Dystric Histosols of The Arang Family occur sporadically and Humic Gleysols of the Guan Family occur on fine - to medium-textured alluvium in some backswamps and fringing the peat swamps.

Dystric Histosols: Klias Family

Dystric Histosols of the Klias Family are very poorly drained. They are generally formed on fibrous peat overlying alluvium. The alluvium, which is sometimes intercalcated with the peat varies from coarse to fine in texture.

Soil pH is generally between 4 and 5 but values as low as 3.0 have been reported in the deeper peat profiles. Cation exchange capacities are high or very high, but levels of exchangeable cations tend to be low except in a few areas where the groundwater is slightly saline; in such cases exchangeable cation levels are high. Easily soluble phosphorus contents are mostly high in the organic horizons; in mineral horizons they are low.

Dystric Histosols: Arang Family

Dystric Histosols of the Arang Family are formed on peat with total sulphur contents of more than 1.5%; generally, however, only one horizon in any one profile contains more than 1.5% sulphur (Profile Od 5). Compared with soils of the Arang Family described in the Weston Association, the exchangeable cation levels are usually lower; magnesium, with medium to high levels, is usually the dominant cation. Some surface horizons have extremely high amounts of easily soluble phosphorus (over 200 ppm), but these values decrease to low levels at depth.

Humic Gleysols: Guan Family

Soils of the Guan Family occur on the fringes of peat swamps and in some abandoned and infilled river meanders, they merge into Dystric Histosols of the Klias Family as the histic horizon increases in thickness. They have higher organic carbon contents in all horizons than in soils of the same family described in the Tuaran Association above.

LABAU ASSOCIATION

The soils of the floodplains of the main rivers of the interior, excluding the Sungai Pegalan and the Sungai Padas in the Tenom Plain, have been included in the Labau Association. In addition the association includes narrow valleys with floodplains and terraces, the latter being too small to be separated as the Brantian Association. The association covers about 179 km^2 (69 mi^2) or 0.9% of the survey area (see Plates 4-11 and 4-21; Stereogram 4-2).

The land is used extensively for shifting cultivation and around Tambunan wet rice is grown. The floodplains are subject to flash flooding. Parent materials are comprised of alluvium derived from sandstone and shale. In the Tambunan Plain, part of the Keningau Plain and most of the narrow mountain valleys the alluvium is dominantly coarse-textured and is often stony or bouldery. In the Sook Plain, the Labang Basin and in the south of the Keningau Plain, the parent material is predominantly moderately fine - to medium textured - alluvium.

Fluvisols and Cambisols are the dominant soils of the association. Dystric and Eutric Fluvisols of the Tenghilan and Pegalan Families are formed on stratified deposits of coarse-textured and pebbly alluvium levees and eyots. Further from the river banks there are well drained Dystric Cambisols of the Kelawat Family on coarse - or medium-textured alluvium with Eutric and occasionally Gleyic Cambisols of the Bulanat and Luba Families on medium-textured alluvium. Soils of the Bulanat Family occur particularly on fine - and medium-textured alluvium in the Labang Basin and in the east of the Pensiangan District. On small floodplains in the Sook Plain, Dystric Gleysols of the Koyah Family occur on fine-textured alluvium and in the Keningau and Tambunan Plains they occur on medium-textured stony alluvium with Eutric Gleysols of the Bangawat Family on medium-textured alluvium. Gleyic Acrisols of the Inanam Family and Orthic Acrisols of the Paliu Family occur on inextensive terraces in narrow valleys.

Eutric Fluvisols, Dystric and Eutric Cambisols and Dystric and Eutric Gleysols are all described in the Tuaran Association and there are no significant differences between these soils in the 2 associations; Gleyic Acrisols are described in the Kinabatangan Association and the Paliu Family of Orthic Acrisols is described in the Binkor Association.

Dystric Fluvisols: Tenghilan Family

Well drained soils of the Tenghilan Family are found in close association with the Eutric Fluvisols. The textures are usually coarse and structures are moderately or weakly developed in the surface horizons. Some profiles are shallow with C horizons dominated by pebbles or gravel. Soil colours are mostly 10YR but a few horizons have hues of 7.5 YR.

These soils have base saturation values below 50% but in other respects are identical to the Eutric Fluvisols of the Pegalan Family. In some profiles, soil pH decreases with depth.

BINKOR ASSOCIATION

In the Tambunan, Keningau and Tenom Plains river terraces have been included in the Binkor Association (Frontispiece and Plate 4-11; Stereogram 4-2). Further small areas occur at Long Pa Sia and near Mesapol, making a total of about 122 km^2 (47 mi^2) or 0.6% of the survey area. The river terraces are generally flat to gently sloping and are occasionally dissected by minor streams. In the Tambunan Plain near Sinsuron, however, dissected fans of colluvium emanating from the Crocker Range have been included. Much of the association is agricultural land and in the Tambunan and Keningau Plains wet rice is the major crop; some wet rice is grown in the Tenom Plain, but tree crops including rubber, coffee and cocoa are more common.

Soil parent materials are relatively recent deposits of alluvium derived from sandstone and shale. In the Tambunan Plain the alluvium is predominantely coarse to medium in texture and may be excessively stony. Coarse-textured and stony deposits also occur in the Keningau Plain, notably between Binkor and Bunsit; elsewhere and in the Tenom Plain the alluvium is predominantly medium in texture.

The association contains a wide range of soils. Dystric and Eutric Gleysols predominate and are most common in the Keningau and Tenom Plains; they are used for growing wet rice. Dystric Gleysols of the Koyah Family are usually formed on coarse-textured alluvium; in the Tambunan Plain they are commonly stony. Eutric Gleysols of the Bangawat Family occur on medium-textured alluvium.

Poorly and imperfectly drained Gleyic Luvisols of the Buran Family (Profile Lg 5) are formed on medium-textured alluvium in the Tenom Plain, where they are important agricultural soils. In the Tambunan Plain, near Sinsuron, these soils have developed as a result of wet rice cultivation; without such cultivation they would probably be Orthic Acrisols of the Paliu Family. Soils of the Paliu Family occur particularly in the

Tambunan and Keningau Plains. Adjacent to small streams, which cross the terraces, there are coarse-textured Eutric and Dystric Fluvisols of the Pegalan and Tenghilan Families and medium-textured Eutric and Dystric Cambisols of the Bulanat (Profile Be 1) and Kelawat Families (Profile Bd 1).

Dystric and Eutric Gleysols, Gleyic Luvisols, Eutric and Dystric Fluvisols and Eutric and Dystric Cambisols are described in the Tuaran Association; Dystric Fluvisols are described in the Labau Association and Orthic Acrisols are described in the Brantian Association.

Soil associations on alluvium 3. Terraces

Five soil associations have been mapped on terraces of alluvium (Table 4-14). The Brantian and Kepayan Associations occur along the west coast and in the interior valleys and plains; the Sipitang Association occurs both on the coast and in high altitude basins in the Maligan Range and the Sook and Sinarun Associations occur in the interior valleys and plains.

SINARUN ASSOCIATION

The Sinarun Association consists of the soils of the highest dissected river terraces flanking the Tambunan, Patau, Tenom, Dalit, Nabawan, Pandewan, Keningau and Sook valleys and plains. The terraces are in the form of low hills and alluvial flats with an amplitude of about 30 - 60 m (100 - 200 ft), convex or flat crests and short moderate to very steep slopes. This association covers about 235 km^2 (91 mi^2) or 1.2% of the survey area.

Secondary forest, scrub and *lalang* (*Imperata cylindrica*) are more common than undisturbed Dipterocarp forest; there are rubber plantations in the Tenom Plain and in the south-west of the Keningau Plain.

Parent materials comprise medium, occasionally coarse-textured and sometimes pebbly alluvium overlying sandstone and shale. On some hills the alluvium has been completely removed. Medium-textured stone-free alluvium is very similar to regolith derived from deeply weathered sandstone and shale (see the Dalit Association).

The dominant soils of the association are deep and well drained Orthic Acrisols of the Paliu Family; they are formed on medium-textured, sometimes stony, alluvium. Orthic Acrisols of the Tanjong Lipat Family occur particularly in the Sook Plain and in the Nabawan valley. In the north-east of the Keningau Plain and in the Tenom Plain Dystric Gleysols of the Koyah Family and Dystric Cambisols of the Kelawat Family occur on fans of stony alluvium at the foot of the dissected terraces. In the Patau valley Dystric Cambisols are probably the most common soils on terraces of coarse-textured alluvium.

Soils of the Paliu Family are described in the Brantian Association; Orthic Acrisols of the Tanjong Lipat Family are described in the Dalit Association and Dystric Cambisols of the Kelawat Family and Dystric Gleysols of the Koyah Family are described in the Tuaran Association.

Two small areas of river gravels at the northern ends of the Tenom and Keningau Plains (Plate 4-19) are also included in the Sinarun Association. These gravels have been upfaulted and strongly dissected into very steep, low to moderate hills.

On the crests and upper slopes severe erosion has occurred and extremely shallow (less than 25 cm (10 in) deep) Chromic Cambisols of the Mankawagu Family are the main soils on consolidated sandstone gravel. Regosols probably occur as well. In sites where erosion has been less severe, Orthic Acrisols of the Paliu and Tanjong Lipat Families are common.

TABLE 4-14 Soil associations on terraces

Soil association	Landforms	Parent materials	Main soil unit	Soil families
Sinarun	Dissected terraces	Alluvium with minor sandstone and shale	Orthic Acrisol	Paliu Tanjong Lipat
			Chromic Cambisol	Mankawagu
			Dystric Cambisol	Kelawat
			Dystric Gleysol	Koyah
Brantian	Terraces and terrace remnants	Alluvium	Orthic Acrisol	Paliu
			Ferric Acrisol	Lumisir
			Gleyic Acrisol	Inanam
			Gleyic Podzol	Baiayo
			Humic Podzol	Karamatoi
			Orthic Podzol	Silimpopon
			Orthic Ferralsol	Benuou
			Albic Arenosol	Serai
Kepayan	Terraces	Alluvium	Gleyic Podzol	Baiayo
			Gleyic Acrisol	Inanam
			Albic Arenosol	Serai
		Peat	Dystric Histosol	Klias
Sook	Terraces and minor swamps	Alluvium	Gleyic Acrisol	Inanam
			Gleyic Podzol	Baiayo
			Orthic Acrisol	Paliu
			Ferric Acrisol	Lumisir
			Dystric Cambisol	Kelawat
		Peat	Dystric Histosol	Klias
Sipitang	Swamps	Peat Alluvium	Dystric Histosol	Klias
			Gleyic Podzol	Baiayo
			Albic Arenosol	Serai

Chromic Cambisols: Mankawagu Family

Chromic Cambisols of the Mankawagu Family are excessively drained, shallow truncated soils with coarse textures and moderate angular blocky structures; the cambic horizons often occur at the surface. Colours range from 7.5 to 5YR with high chromas and values.

Soil pH values are usually below 5 and cation exchange capacities, plant nutrient levels and base saturation figures are all low.

BRANTIAN ASSOCIATION

This association covers 425 km^2 (164 mi^2) or 2.2% of the survey area. It is the most extensive association on terraces in the Keningau and Sook Plains and it also occurs in the Tenom Plain, on remanants of terraces along the coast from Sipitang to Kuala Penyu and on sets of terraces in small valleys on the western side of the Crocker Range.

In the interior valleys and plains the land is commonly flat to rolling with short gentle slopes of less than 10^o. The terrace surface may be cut by recent streams (Plate 4-12) and there are also shallow hollows and gullies which are remnants of former drainage systems.

In the Keningau and Tenom Plains the parent material is gravel, derived from sandstone and shale; gravel deposits, greater than 20 m (66 ft) deep, are exposed in river cliffs. Because there are no comparable exposures in the Sook Plain it is not easy to decide whether the terraces are formed from alluvium, or sandstone and shale which have undergone prolonged weathering. At Sipitang and on the north-west coast of the Klias Peninsula siliceous sand overlies alluvium, which is exposed in gullies cut through the terrace. Remnants of the same terrace near Salut Bay are included in the Dalit Association.

Most of the association has been affected by shifting agriculture and in the Sook, and Keningau and Tenom Plains, a savannah-like flora of *lalang,* bracken, rhododendron species and scrub occurs. At Sebrang Cattle Station near Keningau attempts have been made to establish pasture and at Sook there are plantations of *Pinus caribbea.* In the Tenom Plain, rubber is grown and cattle are also kept; rubber is also grown on the coast.

Well drained Orthic Acrisols of the Paliu Family are the dominant soils; these are generally medium-textured, but both fine-textured and stony soils have also been described. Gleyic Podzols and Gleyic Acrisols of the Baiayo and Inanam Families occur on medium - and coarse-textured alluvium in the poorly drained depressions. Ferric Acrisols of the Lumisir Family occur on well to moderately well drained sites bordering the depressions. On the coastal terraces the Gleyic Podzols are developed on sand, or on sand overlying finer-textured and stony subsoils. In certain sites in the interior, Humic Podzols of the Karamatoi Family have developed in hollows above the present groundwater level.

In the Sook Plain well drained Orthic Ferralsols of the Benuou Family occur on deeply weathered alluvium with Orthic Acrisols on the higher parts of the Plain and Gleyic Podzols in the gullies. Orthic Ferralsols have also been described on the remnants of terraces around Salut Bay, but as these are very small they have been mapped in the Dalit Association.

Gleyic and Humic Podzols and Albic Arenosols (Serai Family) occur on the tops of terraces around Brunei Bay; Ferric and Orthic Acrisols occur on the slopes with Gleyic Acrisols in the gullies. On the Klias Peninsula, north and west of Kuala Penyu and near Lamidan, Ferric and Orthic Acrisols are also common with Orthic Podzols and Albic Arenosols on the terrace tops.

Gleyic Podzols and Albic Arenosols are described in the Kepayan Association.

Orthic Acrisols: Paliu Family

These soils are moderately well or well drained; most have medium textures but some with moderately fine textures have also been described; they are rarely stony. Soil structures are typically moderately or strongly developed crumb or granular at the surface, changing to subangular blocky in the lower horizons. Colours are mostly 10YR but some profiles with 7.5YR hues have been described. Patchy or discontinuous cutans occur in most argillic horizons.

Soil pH is usually between 4.5 and 5.0. Cation exchange capacities are generally low and except in the surface horizons base saturation values and easily soluble phosphorus levels are also low (Profile Ao 2).

Ferric Acrisols: Lumisir Family

Soils of this family are well or moderately well drained. They are medium or fine in texture with marked clay increases and cutans in the argillic horizons; they are sometimes stony. Colours of the upper horizons are typically 10YR in hue changing to 7.5YR or redder with many coarse reddish mottles in the argillic horizons. Iron enriched concretions occur in many argillic horizons, which typically have moderate medium subangular blocky structures.

Soil pH values range from 4 to 5, lower values usually being at the surface. Cation exchange capacities are generally low (5-15 meq %), but the CEC per 100 g clay is only rarely below 25 meq %. The amounts of exchangeable cations and easily soluble phosphorus are generally very low particularly below the surface horizons.

Humic Podzols: Karamatoi Family

Humic Podzols of the Karamatoi Family generally have O, A, E, B1h and B2 horizon sequences. The O horizon is rarely more than 5 cm (2 in) thick and consists of fresh litter and raw humus. The A and E horizons tend to merge together; textures are coarse and colours range from dark grey and dark brown in the A horizons to light grey and white in the albic E horizons. The A horizons are loose and structureless but the albic E horizons are generally firm or compacted and massive. The boundary between the albic and the spodic horizons is clear and the latter are usually dark brown in colour, structureless and hard or compacted. The underlying horizons are generally paler in colour with weakly developed structures and firm to very firm consistency.

These soils are strongly acid; cation exchange capacities are medium in the O and some Bh horizons, but are otherwise low or very low; values below 1 meq % often occur in the E horizons. Exchangeable cation levels are negligible except in the O horizon. Total iron levels are below 0.2% in all horizons; total alluminium and organic carbon show an accumulation in the spodic horizons relative to the horizons above them (Profile Ph 1).

Orthic Podzols: Silimpopon Family

These soils are similar in many respects to those of the Karamatoi Family. In contrast, the spodic horizons may contain as much as 2% total iron and have redder colours and reddish mottles; iron concretions may also occur. Compacted E horizons are rarer than in the soils of the Karamatoi Family.

Orthic Ferralsols: Benuou Family

Orthic Ferralsols of the Benuou Family are medium - to coarse-textured with fine sand contents of about 60%. Structure is usually weak at the surface becoming moderate in the oxic horizons which usually occur below 50 cm (20 in); colours become redder in hue with depth and yellow to red mottles commonly occur.

Soil pH is usually close to 5. Cation exchange capacities are low or very low in all horizons; exchangeable cation levels decrease from medium or low at the surface to very low or nil in the subsurface horizons. Quartz and other resistant minerals are dominant in the oxic horizons (Profile Fo 4).

SOOK ASSOCIATION

The Sook Association occurs principally in the eastern half of the Sook Plain (Plate 4-13); it covers about 122 km^2 (47 mi^2) or 0.6% of the survey area. The soils are developed on broad terraces with small lakes and swamps.

Poorly developed dipterocarp forest is the primary vegetation, but much of the Sook Plain has been cut and burnt and has a secondary heath vegetation including *lalang*, bracken, *Baeckia frutescens* and rhododendron species. *Eugenia* swamp forest also occurs.

Parent materials comprise tiered deposits of coarse - to medium-textured alluvium overlying moderately fine-textured alluvium. Deposits of more recent alluvium border the major streams on the eastern edge of the Sook Plain.

The dominant soils of the association are poorly drained Gleyic Acrisols of the Inanam Family; they are closely associated with Gleyic Podzols of the Baiayo Family. On somewhat higher terraces there are well drained Orthic and Ferric Acrisols of the Paliu and Lumisir Families. Dystric Fluvisols of the Tenghilan Family occur on the levee sites and well drained Dystric Cambisols of the Kelawat Family occur on the narrow floodplains of the streams in the east of the Sook Plain. Dystric Histosols of the Klias Family are found in the swamps.

Gleyic Acrisols are described in the Kinabatangan Association, Gleyic Podzols in the Kepayan Association, Orthic and Ferric Acrisols in the Brantian Association, Dystric Fluvisols in the Labau Association, Dystric Cambisols in the Tuaran Association and Dystric Histosols in the Sipitang Association.

KEPAYAN ASSOCIATION

The Kepayan Association occurs on terraces in the interior valleys and plains (Stereogram 4-2) and along the south-west coast particularly near Sipitang (Stereogram 4-3) and on Pulau Labuan (Plate 4-14). It covers about 124 km^2 (48 mi^2) or about 0.6% of the survey area. The terraces are flat with shallow depressions and occasional small swamps and ponds (Plate 4-15). Where the swamps are extensive they are separated as the Sipitang Association.

Primary forest occurs on a few undisturbed sites in the Sook Plain and in the Pandewan valley where there is a mixed flora of *Dachrydium* spp. and *Tristania* spp. On small areas of swamp there are *Eugenia* spp. and sedges. The major part of the association has been burnt and cleared and is now under heath vegetation in which *Baeckia frutescens* is dominant; bracken (*Pteridium aquilinum*) and *lalang* grow in the better drained areas. Pitcher plants (*Nepenthes* spp.) grow in both primary forest and heath.

In the interior, parent materials consist mainly of tiered deposits of sand overlying medium - or fine-textured alluvium. On the coastal terraces, however, the parent materials are more commonly deep sand and pebble beds.

Poorly and imperfectly drained Gleyic Podzols of the Baiayo Family are the dominant soils of the association. Near Sipitang and on Pulau Labuan they merge into Albic Arenosols of the Serai Family, but in the Sook Plain they are closely associated with Gleyic Acrisols of the Inanam Family. Dystric Histosols of the Klias Family occur in the small swamps.

Gleyic Acrisols of the Inanam Family are described in the Kinabatangan Association, and Dystric Histosols of the Klias Family are described in the Sipitang Association.

Gleyic Podzols: Baiayo Family

Gleyic Podzols of the Baiayo Family have O, A, E and Bhfe horizons. Horizons of litter and raw humus occur at the surface and overlie A horizons which are sandy and usually dark brown or dark greyish brown in colour, with weakly developed structures. The albic E horizons are composed of white sand which is frequently hard and compacted; in some profiles the sand is loose and structureless. The boundary to the spodic B horizon is clear or abrupt and occurs at any depth from about 30 cm (12 in) to 125 cm (50 in). Where the spodic horizons occur below 125 cm the soils are classed as Albic Arenosols of the Serai Family (see below). The spodic horizons are usually dark brown or black in colour; structures, if present are weakly developed and the horizons are frequently firm or compacted. The B horizons which may underlie the spodic horizons are lighter coloured and often finer-textured; they may contain stones and are usually less compact.

Chemically these soils show the typical features of podzols with maximum pH and very low cation exchange capacities in the E horizons. Exchangeable cation levels are generally negligible and reflect the impoverished nature of the parent materials; quartz is the dominant mineral of the clay sized fraction in all horizons. Easily soluble phosphorus levels are low, except in the spodic horizons where high values have been reported (Profile Pg 3).

Albic Arenosols: Serai Family

Albic Arenosols of the Serai Family have O, A and E horizons comparable with those in Gleyic Podzols of the Baiayo Family; they can be regarded as 'Giant Podzols' (Andriesse, 1968) for spodic horizons have been described at varying depths below 125 cm (50 in). Soil drainage ranges from imperfect to excessive; soils with the latter tend to have loose or friable consistency, but the imperfectly drained soils are usually very firm or compacted.

Below the surface horizons cation exchange capacities are usually less than 1 meq % and the amounts of plant nutrients are negligible. Quartz is the dominant mineral of the clay sized fraction (Profiles Qa 1 and 2).

SIPITANG ASSOCIATION

The Sipitang Association occurs at low altitudes on coastal terraces near Sipitang (Plate 4-17; Stereogram 4-3) and above 1 200 m (4 000 ft) in basins in the Maligan Range (Plate 4-18); it covers about 23 km^2 (9 mi^2) or 0.1% of the survey area. At both low and high altitudes the landforms consist of poorly drained depressions with peatswamps.

The soil parent materials consist of peat and siliceous sand. Peat is at least 125 cm (50 in) deep at the centres of the swamps. The vegetation at both low and high altitudes is similar. At low altitudes swamp forest contains *Casuarina* and *Eugenia* spp., with *Tristania* spp. and *Nepenthes* spp. in heath forest on the swamp fringes; at high altitudes *Casuarina* spp. are dominant in the swamp forest and heath forest, with *Dachrydium* spp., *Podocarpus* spp., *Tristania* spp. and *Nepenthes* spp., occuring on slightly drier areas within the swamps. The trees of the swamp forest are usually taller than those of the heath forest. The high altitude flora resembles that found on Gunong Kinabalu at 3 000 m (9 900 ft) (Cockburn, 1972).

Dystric Histosols of the Klias Family are the dominant soils; they are very poorly drained, with water often standing on the surface. On the coastal terraces Gleyic Podzols and Albic Arenosols of the Baiayo and Serai Families occur under heath forest around the swamp fringes and, at high altitudes, Gleyic Podzols are associated with discrete patches of heath forest within the swamps (Profile Pg 2) (Plate 4-18).

Gleyic Podzols and Albic Arenosols are described in the Kepayan Association.

Dystric Histosols: Klias Family

Dystric Histosols of the Klias Family are formed on fibrous peat which contains variable amounts of very fine sand or coarse silt. The peat overlies mineral horizons which are mostly pale and occasionally white in colour. They consist of loose, structureless sand (Profile Od 2).

The pH values of the organic horizons are about 3.5 reaching 4.0 to 4.5 in the mineral horizons. Cation exchange capacities are very high in the organic horizons and very low in the mineral horizons. Plant nutrients are negligible in the mineral horizons, but in the organic horizons values are higher, and some very high values of easily soluble phosphorus have been recorded.

Soil associations on mudstone/sandstone and limestone

1. Mudstone and sandstone

'Mudstone and sandstone' includes three of the parent materials shown in Text Map 4-4: 'Mudstone and minor sandstone', 'Sandstone and mudstone' and 'Sandstone and minor mudstone'.

Seven soil associations have been defined on mudstone and sandstone and together they cover about 84% of the survey area (Table 4-15) of these, one, the Kabakan Association, is in an area where mudstone is the dominant parent material.

KALABAKAN ASSOCIATION

This association covers about 124 km^2 (48 mi^2) or 0.6% of the survey area and has only been mapped in the east of the Pensiangan District (Plate 4-24). It is formed on low hills with concordant summits, amplitudes of 0-75 m (0-250 ft) and with slopes between 0 and 20^o. The parent materials are mudstones of the Sapulot and Labang Formations and the primary vegetation is lowland dipterocarp forest.

The association is comprised of well drained Orthic Acrisols of the Kumansi Family and occasionally of the Tanjong Lipat Family and Dystric Cambisols of the Laab Family. The Laab and Tanjong Lipat Families are described in the Dalit and Lokan Associations.

Orthic Acrisols: Kumansi Family

Orthic Acrisols of the Kumansi Family are formed on mudstone with minor sandstone and, by definition, the upper argillic horizons contain 40% or more clay. They are mainly well drained and deep, although mudstone fragments often occur in the lower horizons. Soil colours range from 10YR to 2.5YR, the redder hues being more frequent at depth. The argillic horizons are often mottled and normally contain continuous cutans.

Soil pH values are between 4 and 5 and usually increase with depth. Cation exchange capacities are generally between 10 and 20 meq %. Base saturation is usually below 10% and exchangeable cation and easily soluble phosphorus levels are low or negligible except in the surface horizons. Illite is the dominant mineral of the clay sized fraction with minor amounts of vermiculite and kaolinite.

DALIT ASSOCIATION

The Dalit Association covers about 1 008 km^2 (389 mi^2) or 5.2% of the survey area. It occurs on hills with amplitudes of 0-75 m (0-250 ft); narrow valley bottoms and small areas of hills with amplitudes of up to 150 m (500 ft) are also included. Slopes are mainly between 0-20° and the modal slope is between 15-20°; slopes greater than 25° occur particularly on incised valley sides (see Plates 4-3, 8, 20, 21 and 22).

TABLE 4-15 Soil associations on mudstone and sandstone

Association	Landforms	Parent materials	Main soil units	Soil families
Kalabakan	Low hills: amplitudes 0-75 m (0-250 ft) with slopes 0-20°	Mudstone and minor sandstone	Orthic Acrisol	Kumansi Tanjong Lipat
			Dystric Cambisol	Laab
Dalit	Low hills: amplitudes 0-75 m (0-250 ft) with slopes 0-25°	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kumansi Kapilit
			Ferric Acrisol	Sipit
		Alluvium	Orthic Acrisol	Paliu
Lokan	Steep hills: amplitudes 0-300 m (0-1 000 ft) with slopes >25°	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kumansi Kapilit
			Dystric Cambisol	Laab
			Cambic Arenosol	Pangarangan
			Ferric Acrisol	Sipit
			Lithosol	
Crocker	Mountains up to 1 020 m (3 500 ft) a.m.s.l. with slopes >25°	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kapilit Kumansi
			Dystric Cambisol	Laab
			Chromic Cambisol	Luasong
			Lithosol	
Trusmadi	Mountains over 1 200 m (4 000 ft) a.m.s.l. with slopes >25°	Sandstone and mudstone	Gleyic Acrisol	Gunong Alab
			Orthic Acrisol	Tanjong Lipat Kumansi
			Humic Acrisol	Kiau
			Humic Gleysol	Kidukarok
			Gleyic Podzol	Pa Sia
			Dystric Histosol	Kaintano
			Lithosol	
Maliau	Mountains over 1 020 m (3 500 ft) a.m.s.l. with slopes >25°	Sandstone and minor mudstone	Gleyic Acrisol	Gunong Alab
			Gleyic Podzol	Pa Sia
			Orthic Podzol	Sibuga
			Dystric Cambisol	Antulai
			Humic Gleysol	Kidukarok
			Dystric Histosol	Kaintano
			Orthic Acrisol	Tanjong Lipat Kapilit
			Lithosol	
Serudong	Dipslopes of mountain cuestas with slopes 0-25°	Sandstone	Gleyic Podzol	Pa Sia
			Orthic Acrisol	Kapilit

The natural vegetation of the association is lowland Dipterocarp forest, but apart from the areas between the Keningau and Sook Plains it has been felled. Along the coastal hills there are many rubber plantations; inland the forest has been replaced by shifting agriculture and secondary regrowth.

Orthic Acrisols of the Kapilit and Tanjong Lipat Families are the dominant soils of the association; Orthic Acrisols of the Kumansi Family (Profile Ao 10) are found on shales, for example, in the Klias Peninsula (see the Kalabakan Association). Orthic Acrisols also occur on alluvium in parts of the association bordering the Keningau and Sook Plains and in minor valley bottoms (see the Paliu Family in the Brantian Association).

Ferric Acrisols of the Sipit Family occur on lower slopes along the south-west coast and Gleyic Acrisols of the Masaum Family occur on mudstones on Pulau Labuan.

Dystric and Chromic Cambisols and Cambic Arenosols of the Laab, Luasong (Profile Bc 7) and Pangarangan (Profile Qc 3) Families respectively have only been described between Sipitang and Beaufort (see the Lokan Association). On one small area of highly siliceous sandstone south of Membakut, Orthic Podzols of the Sibuga Family were found (see the Maliau Association).

Orthic Acrisols: Tanjong Lipat Family

Orthic Acrisols of the Tanjong Lipat Family are developed on sandstone and mudstone with argillic horizons containing 25-40% clay. They are well drained and deep, but are often stony in the lower horizons. Shallow litter and raw humus layers are described in about half the reported profiles. The colours of the A horizon are most frequently 10YR in hue with values and chromas of 3 or 4; colours in the lower horizons are usually 7.5YR or redder, with higher values and chromas than at the surface; mottles are only rarely described. E or EB horizons occur in about half the described profiles: in others A horizons rest directly on the argillic horizons. Soil structures are most commonly subangular blocky, but some A horizons have crumb structures and some argillic horizons have blocky structures. Patchy cutans are described in the argillic horizons of most profiles.

Soil pH values are generally about 4 at the surface rising to between 4.5 and 5.0 in the lowest horizons. Cation exchange capacities are between 5 and 15 meq % but in some surface horizons higher values have been reported. Exchangeable cation and easily soluble phosphorus levels are negligible below the surface. Vermiculite and kaolinite are the dominant minerals of the clay sized fraction; illite is rarely present in more than trace amounts.

Orthic Acrisols: Kapilit Family

Orthic Acrisols of the Kapilit Family are formed from sandstone with minor amounts of mudstone: their argillic horizons contain less than 25% clay. They are well drained, moderately deep to shallow and are often stony. Shallow litter layers often occur. Soil colours are usually of 10YR hue at the surface and change to 7.5YR, rarely 5YR, in the lowest horizons; mottling is not common. Soil structure is typically moderately developed, subangular blocky or crumb at the surface and blocky or subangular blocky in the lower horizons. Weakly developed cutans are described in most argillic horizons.

Soil pH ranges from 4 to 5 with the lower values at the surface. Cation exchange capacities are below 10 meq %, but in the surface horizons values are sometimes in the 10-15 meq % range. Levels of exchangeable cations, easily soluble phosphorus and total nitrogen are medium to low at the surface and low or very low in the subsurface horizons.

Ferric Acrisols: Sipit Family

Ferric Acrisols of the Sipit Family are well drained, deep and sometimes stony; textures are coarse to medium in the A horizons and medium to fine in the argillic horizons. Shallow litter layers are rare, but E horizons commonly occur. Soil colours are mostly of 10YR hue at the surface becoming 7.5YR or 5YR at depth; reddish yellow mottles and iron rich concretions are common in the argillic horizons. Structures are subangular blocky throughout, except in some surface horizons which have crumb structure. Patchy cutans occur in nearly all argillic horizons.

Soil pH values range from 4 to 5 with the lower values at the surface. Cation exchange capacities are between 10 and 15 meq %. Exchangeable cations, easily soluble phosphorus and total nitrogen levels are low to negligible except in the A horizons.

Gleyic Acrisols: Masaum Family

Imperfectly drained, moderately fine-textured Gleyic Acrisols of the Masaum Family occur on Pulau Labuan. Soil colours range from brown at the surface through brownish yellow to grey in the BCg horizons. Soil structure is generally moderate subangular blocky and cutans are often present in the argillic horizons. Fragments of rock and concretions occur in the lower B horizons.

Soil pH values rise from about 4.5 at the surface to about 5.0 in the BC horizons. Cation exchange capacities range from 10-20 meq %. Amounts of exchangeable magnesium are medium at the surface and increase with depth; levels of other cations and easily soluble phosphorus are low or very low in all horizons. Vermiculite and illite are the dominant clay minerals.

LOKAN ASSOCIATION

The Lokan Association covers about 2 193 km^2 (847 mi^2) or 11.3% of the survey area. It is mapped on hills with amplitudes of up to 300 m (1 000 ft); slopes commonly exceed 25^o. In the south-west it occurs on hills that run almost parallel to the coast between low hills of the Dalit Association and the mountains of the Crocker Range; in the interior it occurs on hills showing marked summit concordance with steeply incised valleys; in the east of the Pensiangan District the association occurs on steep hills which are parts of extensive synclinal basins.

The natural vegetation of the Lokan Association is lowland dipterocarp forest, but this has largely been replaced by shifting agriculture and rubber plantations; the only large area of undisturbed forest is in the east of the Pensiangan District. Rubber plantations occur mainly on the coastal foothills of the Crocker Range. Around the Tambunan Plain, *lalang (Imperata cylindrica)*, bracken *(Pteridium aquilinium)*, Straits rhododendron *(Melastoma sp.)* and scrub are probably the result of excessive shifting agriculture.

The soils of the association are similar to those of the Dalit Association. In all areas to the north of Sapulut, Orthic Acrisols of the Tanjong Lipat Family, developed on sandstone and mudstone, are the dominant soils (Profile Ao 13). Soil depth and slope are not correlated, but on the summits and upper slopes the soils are generally deeply weathered; on the lower slopes the soils are usually shallower and less weathered.

Orthic Acrisols of the Kumansi Family are rare in the northern part of the survey area, but are dominant on mudstone to the south and east of Sapulut. Orthic Acrisols of the Kapilit Family are formed on sandstone near Sipitang (Profile Ao 16); Chromic Cambisols of the Luasong Family, Dystric Cambisols of the Laab Family and Cambic Arenosols of the Pangarangan Family also occur notably near Sipitang. Lithosols occur infrequently on steep slopes of both sandstone and mudstone. Ferric Acrisols of the Sipit Family are restricted to the footslopes of the hills bordering the coast.

Orthic Acrisols of the Tanjong Lipat and Kapilit Families and Ferric Acrisols of the Sipit Family are described in the Dalit Association; Orthic Acrisols of the Kumansi Family and Lithosols are described in the Kalabakan and Crocker Associations respectively.

Chromic Cambisols: Luasong Family

Chromic Cambisols of the Luasong Family are well drained and have medium - to moderately fine-textured cambic horizons which become increasingly stony with depth. Soil hues are 10YR to 7.5YR in the A horizons and 7.5YR or redder in the cambic horizons. Structure at the surface is usually crumb or granular; the cambic horizons have subangular blocky structures.

Soil pH is usually below 5 and does not vary appreciably with depth. Cation exchange capacities range from 10 to 20 meq %. Exchangeable cation and easily soluble phosphorus levels are normally very low except in the A horizon.

Dystric Cambisols: Laab Family

Both well drained, shallow soils and moderately well drained, deep soils of the Laab Family have been described; they are all stony within the top 25 cm (10 in). Textures are medium to moderately fine. Colours are usually 10YR in hue with higher chromas and values in the cambic horizons than at the surface.

Soil pH values are mostly between 4.5 and 5.0. Cation exchange capacities range from 10 to 20 meq %. The A horizons usually have medium levels of plant nutrients, but the cambic horizons have low to very low amounts.

Cambic Arenosols: Pangarangan Family

Cambic Arenosols of the Pangarangan Family are similar to the Dystric Cambisols of the Laab Family, but have coarse-textured B horizons containing less than 15% clay. They are well drained and generally moderately deep and stony. Surface layers of raw humus may occur. Soil hues are usually 10YR at the surface and become redder with depth; structures change from weak crumb at the surface to weak subangular blocky or structureless in the lower horizons.

Soil pH rises from below 4.0 at the surface to 4.5-5.0 at depth. Cation exchange capacities of the surface horizons may be very high, but they decrease to below 5 meq % in the B horizons. Exchangeable cation levels are low or very low in all horizons and easily soluble phosphorus levels, which are high at the surface, are negligible at depth.

CROCKER ASSOCIATION

The Crocker Association is the most widespread association; it covers about 9 360 km^2 (3 614 mi^2) or 48.1% of the survey area. It occurs on mountains with amplitudes greater than 300 m (1 000 ft) at altitudes not exceeding 1 200 m (4 000 ft) in the Crocker Range (Plate 4-23) or 1 050 m (3 500 ft) further inland (Stereogram 4-1); slopes often exceed 25^o. The association also includes many narrow valleys some of which contain inextensive terraces (Plate 4-10). The natural vegetation is lowland dipterocarp forest. In many places this has been destroyed by shifting agriculture and has been replaced by secondary regrowth.

Orthic Acrisols of the Tanjong Lipat Family are the most widespread soils on the Crocker Range. They are generally not very deeply weathered and are only moderately deep becoming shallower with increasing slope. Landslides are common, even under primary forest, and the soils are developed from colluvium rather than from solid rock. In the Pensiangan District, however, Orthic Acrisols of the Kumansi Family, formed on mudstone of the Sapulot and Labang Formations, are dominant, but there is no significant correlelation between soil depth and slope. Soils of the Kumansi Family (Profile Ao 9) also occur on occasional mudstone outcrops in the northern part of the survey area. Orthic Acrisols of the Kapilit Family occur on infrequent outcrops of massive sandstone and Lithosols occur sporadically throughout the area; Dystric and Chromic Cambisols of the Laab and Luasong Families occur on some steep slopes and ridges.

Orthic Acrisols of the Tanjong Lipat, Kapilit and Kumansi Families are described in the Dalit and Kalabakan Associations and Dystric and Chromic Cambisols of the Laab and Luasong Families are described in the Lokan Association. The soils of the minor valleys, which cannot be mapped at the 1:250 000 scale are similar to those described in the Labau Association.

Lithosols

By definition these soils are less than 10 cm (4 in) in thickness and overlie solid sandstone or mudstone. There may be up to 2.5 cm (1 in) of litter and raw humus at the surface; the underlying mineral horizon is usually dark greyish brown to brown in colour and varies from coarse to moderately fine in texture depending on the nature of the underlying rock. Soil structures are usually weak to moderate, subangular blocky.

Soil pH is generally about 4. The organic carbon content ranges from 2 to 6% and results in medium to high cation exchange capacities. Exchangeable cation levels are extremely variable, but there are medium amounts of total nitrogen and easily soluble phosphorus.

TRUSMADI ASSOCIATION

This association covers about 598 km^2 (231 mi^2) or 3.1% of the survey area; it has been mapped on steep mountainous land in the higher parts of the Crocker and Trusmadi Ranges (Plate 4-25). The boundary dividing this asosciation from the Crocker Association is between 1 200 and 1 350 m (4 000 - 4 500 ft) a.m.s.l.

The rocks of the Crocker Range are mudstone and sandstone, but in the higher parts of the Trusmadi Range the rocks have been subject to mild metamorphism; slates and sub-phyllites are common.

Dipterocarp forest occurs below about 1 350 m (4 500 ft); above this Oak/Conifer forest becomes dominant and at about 1 800 m (6 000 ft) the trees and shrubs are increasingly covered by mosses and epiphytic plants to form moss forest; on exposed ridges, moss forest occurs at slightly lower altitudes. The change from Dipterocarp forest to Oak/Conifer and moss forests is associated with a decrease in temperature and an increase in effective rainfall.

Gleyic and Humic Acrisols of the Gunong Alab and Kiau Families and Orthic Acrisols of the Tanjong Lipat and Kumansi Families are the common soils of the lower parts of this association. Above about 1 350 m (4 500 ft) these soils give way to Gleyic Podzols, Humic Gleysols and Dystric Histosols of the Pa Sia, Kidukarok and Kaintano Families. The Acrisols tend to reach higher altitudes in the valleys; Podzols, Gleysols and Histosols reach lower levels on exposed ridges. Lithosols occur on rock faces on steep slopes particularly on the Trusmadi massif.

The Tanjong Lipat and Kumansi Familise of Orthic Acrisols are described in the Dalit and Kalabakan Associations and Lithosols and Gleyic Podzols are described in the Crocker and Maliau Associations.

Gleyic Acrisols: Gunong Alab Family

Both very poorly and poorly drained Gleyic Aerisols of the Gunong Alab Family have been described; they are mainly deep and moderately deep with shallow litter layers, variable textures and few stones. Soil colours are of 10YR hue in the upper horizons and 10YR or 7.5YR in the lower horizons. Soil structures are normally weakly developed, subangular blocky. Broken cutans occur in most of the argillic horizons.

Soil pH values range between 4.5 and 5.0. Cation exchange capacities are usually below 15 meq %. Levels of exchangeable cations are low at the surface and decrease to very low amounts in the lower horizons. Easily soluble phosphorus levels are medium at the surface and decrease rapidly below.

Humic Acrisols: Kiau Family

Only one profile of the Kiau Family has been described (Profile Ah 1); it is moderately well drained, moderately deep, medium-textured and stony. The O horizon is 5 cm (2 in) thick and the organic carbon content of the upper B horizon exceeds 0.9% (see definition of Humic Acrisols in Volume 1); there are also large amounts of organic carbon in the A and E horizons. The argillic horizon is weakly expressed in terms of textural contrast, but there are continuous cutans. Hues range from 10YR in the A horizon to 7.5YR at depth and structures are moderately developed, subangular blocky.

This soil is chemically similar to those of the Gunong Alab Family of Gleyic Acrisols, but has higher cation exchange capacities; values range from 15-30 meq %.

Humic Gleysols: Kidukarok Family

Humic Gleysols of the Kidukarok Family are poorly drained with shallow histic and umbric horizons; they are moderately deep to shallow and have coarse textures. The A horizons are often dusky red, reflecting high organic carbon contents and, below this, 10YR hues with reddish mottles are commonly described. Soil structure is generally weak to very weak, subangular blocky.

Soil pH is less than 4 in the O and A horizons, but increases to 4.5-5.0 below. Cation exchange capacities, easily soluble phosphorus and total nitrogen levels are high in the humus-rich horizons, but are very low in the mineral soil; exchangeable cation values are low or very low in all horizons.

Dystric Histosols: Kaintano Family

Dystric Histosols of the Kaintano Family occur on slopes of up to 55° in the moss forest. They are formed on peat which varies from 40 to over 120 cm (16 - 48 in) in thickness. The peat becomes increasingly humified with depth. In some profiles histic horizons rest directly on rock, but in others, coarse-textured, variably coloured and weakly structured C horizons occur between the peat and the underlying rock (Profile Od 3).

The histic horizons generally have pH values below 4 and very high cation exchange capacities; in contrast the mineral horizons have pH values of about 4.5 and cation exchange capacities below 15 meq %. The levels of exchangeable cations are generally low; exchangeable potassium values of about 2 meq %, however, have been reported in the histic horizon. Total nitrogen and easily soluble phosphorus decrease from very high levels (about 1.4% and 40 ppm respectively) to medium or low levels below the histic horizons.

MALIAU ASSOCIATION

This is the second most extensive association in the survey area. It covers about 3 074 km^2 (1 187 mi^2) or 15.8% of the area and has been mapped on mountains in the southern parts of the Sipitang, Tenom and Pensiangan Districts. In the south of the Sipitang and Tenom Districts and in the centre of the Pensiangan District, the association occurs above about 1 020 m (3 500 ft); in the east of the Pensiangan District, however, the lower boundary of the association occurs at about 600 m (2 000 ft). It is formed on resistant sandstones, most commonly in the form of cuestas with very steep scarp slopes, often greater than 45°, and moderately steep (15-25°) dipslopes (Plate 4-26). In some localities, however, notably at Gunong Antulai in the centre of the Pensiangan District the sandstone strata have been tilted to angles greater than 30° to form hogsbacks (Stereogram 4-4) (Thornbury, 1954). Shales are interbedded with the sandstones notably in the east of the Pensiangan District. These landforms are in marked contrast to the highly dissected mountains in the Crocker Association.

Dipterocarp forest occurs on the lower slopes, but at higher altitudes this merges into montane forest. On exposed ridges moss forest occurs and many dipslopes have a high altitude form of heath forest.

On the lower dipslopes Orthic Acrisols, mainly of the Kapilit and Tanjong Lipat Families, are dominant (see the Dalit Association); soils of the Kumansi Family also occur locally (see the Kalabakan Association). At higher altitudes the Orthic Acrisols are replaced by Gleyic Acrisols, Humic Gleysols and Gleyic Podzols of the Gunong Alab, Kidukarok and Pa Sia Families respectively and on some better drained sites, usually on the upper slopes, Orthic Podzols of the Sibuga Family, have been found. Dystric Histosols of the Kaintano Family with occasional Lithosols occur on ridges under moss forest. Dystric Cambisols of the Antulai Family are the dominant soils of the steep scarp slopes; Dystric Cambisols of the Laab Family occur on shale outcrops and Chromic Cambisols and Cambic Arenosols of the Luasong and Pangarangan Families have also been described. In small swamps which occur at the foot of some dipslopes Dystric Histosols and Gleyic Podzols of the Klias and Baiayo Families are found; they are described in the Sipitang Association.

Cambisols, with the exception of the Antulai Family, and Arenosols are described in the Lokan Association; Lithosols are described in the Crocker Association and the Gleyic Acrisols, Gleysols and Histosols are discussed in the Trusmadi Association.

Dystric Cambisols: Antulai Family

Dystric Cambisols of the Antulai Family are well drained and typically have sandy loam textures; the lower cambic B horizons are sometimes stony. Both shallow and moderately deep profiles have been described. There is usually a thin O horizon of litter and humus at the surface overlying A horizons which are usually dark brown to dark reddish brown in colour owing to medium to high organic matter contents. The cambic horizons are typically brownish yellow or yellowish brown. Weak subangular blocky structures occur in both A and B horizons.

Soil pH values usually rise from about 3.5 at the surface to 4.5 at depth. Cation exchange capacities are high in the A horizons, but decrease to 10 meq % or lower in the B horizons. Exchangeable cation levels are mostly low; amounts of total nitrogen and easily soluble phosphorus decrease with organic carbon content and with depth (Profile Bd 7).

Gleyic Podzols: Pa Sia Family

Poorly and imperfectly drained, moderately deep and shallow soils with coarse to medium textures have been described; they are often stony in the B horizons. Surface O horizons up to 33 cm (13 in) in thickness have been reported. Soil colours are variable at the surface but the E horizons are usually light grey and the spodic horizons range from very dark greyish brown to pale brown with dusky red mottles; B horizons below the spodic horizons are generally paler in colour. Soil structure is weak subangular blocky in the A horizons; the E and spodic horizons are sometimes massive and extremely firm.

Soil pH values are generally below 4.0 at the surface and increase to about 5.0 in the lowest horizons. Cation exchange capacities are commonly very high in the O horizons, medium in the spodic horizons and low or very low in the other horizons. Plant nutrient levels are all very low, except in the O horizons. The spodic horizons usually show a marked accumulation of total and extractable aluminium and a smaller accumulation of total iron and organic carbon.

Orthic Podzols: Sibuga Family

Well or excessively drained, moderately deep or shallow coarse-textured soils, generally with O, A, E, B1h, B2fe and C horizon sequences have been described. The O horizons of litter and raw humus are seldom more than 5 cm (2 in) thick. The A horizons are dark grey or dark brown in colour and merge into light grey E horizons. The E horizons are sharply separated from the spodic B horizons; the B1h horizon is dark reddish brown in colour and the B2fe horizon is yellowish brown to dark grey with reddish coatings. The E and spodic horizons are often structureless and are sometimes slightly compacted.

Soil pH values are usually between 4 and 5; the lowest values are in the O and the highest are in the E horizons. Cation exchange capacities in the E horizons are often below 5 meq % and in the other mineral horizons are rearely more than 15 meq %. Plant nutrient levels, except total nitrogen and easily soluble phosphorus in the O horizons, are negligible. Organic carbon, total and extractable aluminium and iron show considerable increases in the spodic horizons. Quartz is the dominant mineral of the clay sized fraction in the A and E horizons; kaolinite is dominant in the spodic horizons (Profile Po 2).

SERUDONG ASSOCIATION

The Serudong Association occurs on the dipslopes of cuestas near the eastern boundary of the Pensiangan District; it covers about 62 km^2 (24 mi^2) or 0.3% of the survey area.

The soils are identical to those described on dipslopes in the Maliau Association and consist of Gleyic Podzols of the Pa Sia Family with Orthic Acrisols of the Kapilit Family on the lowest slopes.

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

The Kretam Association is the only association defined on mudstone, sandstone and miscellaneous rocks.

KRETAM ASSOCIATION

The Kretam Association covers 8 km^2 (3 mi^2) which is less than 0.1% of the survey area; it has been mapped on Pulau Tiga and on the mainland at Tanjong Nosong.

The landform of this association consists of low hills and is gently rolling with slopes ranging from 5-15^o. Mud volcanoes occur on Pulau Tiga and there are three cones on hills which are about 95 m (300 ft) high. On the mainland there is a single dome-shaped hill about 70 m (230 ft) high. The association includes soils formed on mud volcano deposits, which consist of clay containing angular fragments of shale, sand-stone and assorted rocks. On Pulau Tiga the slopes are strewn with sandstone boulders, some of which exceed 3 m (10 ft) in diameter.

Casuarina sp. have colonised the recent mudflows; elsewhere there are bushes and low trees.

Gleyic Acrisols of the Gunong Alab Family are the only soils which have been described.

Gleyic Acrisols: Gunong Alab Family

These soils are deep and imperfectly drained with moderately fine or fine textures; they are commonly stony below about 20 cm (8 in). Soil colours are usually of 10YR hue in all horizons.

Cation exchange capacities range from 10-20 meq %. Amounts of exchangeable magnesium and sodium are high at the surface and very high at depth.

Soil associations on mudstone/sandstone and limestone
3. Limestone

The Gomantong Association is the only association described on limestone.

GOMANTONG ASSOCIATION

There are few outcrops of limestone in the survey area and of these, only three are sufficiently extensive to be included in the Gomantong Association. They occur in the Labang Basin, extending above the general level of the surrounding land; the most famous is Batu Punggul (Plate 4-16). The total area of the association is about 2 km^2 (1 mi^2) which is less than 0.1% of the survey area.

Rendzinas of the Loc Sambuang Family occur on limestone outcrops and also on stony limestone colluvium; Calcic Luvisols of the Semporna Family also occur on the colluvium.

Rendzinas: Loc Sambuang Family

Rendzinas of the Loc-Sambuang Family are well drained, fine-textured, shallow soils, less than 25 cm (10 in) deep, with mollic A horizons over limestone or limestone rubble. Soil colours are dark brown to reddish brown at the surface and dark brown to yellowish brown at depth. Soil structure is strongly developed crumb to subangular blocky.

Soil pH values are close to 7. Cation exchange capacities are high with base saturation figures between 90 and 100%; exchangeable calcium is dominant and magnesium is present in medium to high amounts. Vermiculite is the dominant clay mineral (Profile E 1).

Calcic Luvisols: Semporna Family

These soils merge into those of the Loc Sambuang Family. They are moderately deep and have umbric A horizons. Soil textures are medium at the surface and fine below; the lower horizons are often stony. Soil colours are paler than in the Rendzinas, being dark yellowish brown at the surface and yellowish brown below. Structures are subangular blocky in all horizons, being strongly developed at the surface and moderately developed below. Patchy cutans are described in some argillic horizons.

These soils are chemically similar to those of the Loc Sambuang Family, but organic carbon and exchangeable magnesium contents are lower. Vermiculite is also the dominant clay mineral.

Part 4

Agriculture and soil suitability

AGRICULTURE

Introduction

Rice, fruit and vegetables have been grown in parts of the area, mainly on a subsistence basis, for centuries. About a hundred years ago, Sabah attracted the attention of European business men and the Chartered Company of North Borneo was established with a view to developing estate agriculture. Reports by early travellers on the agricultural potential were varied. For example, in 1878, Dobree described the soil near Papar as 'fair, better than some districts in Ceylon, but by no means as rich or equal to the best districts in that island', and von Donop (1882) stated that the soil on the west coast was not so rich as on the east coast 'except for a fine piece of sago land between Kimanis and Papar'. Pavitt (1893), describing a journey from Ranau to Keningau, wrote: 'We arrived at Ranowan . . . . . and from there to Limbawan (Keningau) thence passing through splendid grassy plains . . . . . The whole valley from Limbawan up the Pegalan . . . . . is undoubtedly the best land I have seen in Borneo, having beautiful grassy plains well watered, with low rolling downs all fit for cultivation, and . . . . . could probably be leased to tobacco and other planting companies'.

In 1891 the first tobacco estate was established at Sapong on the Tenom Plain. This was not successful, however, and in 1898 the estate was converted to an experimental nursery with various crops including tea, coffee and cardamoms. Until 1909 the main agricultural export of the area was sago; about 9 000 tons were exported for example in 1898 (Chartered Company of North Borneo, 1899).

In 1900 rubber seeds from Ceylon were planted at Tenom and by 1920 rubber had become the main export crop of this part of Sabah. Rice was the only other extensive agricultural product of the area and was grown by the local people for their own use. The economy soon became dependent on rubber and rice and only since 1961 has there been any attempt to break this with the introduction of crops such as cocoa, coffee and oil palm; since 1954, the coconut acreage has also increased.

The land use by Districts in 1970 is shown in Table 4-16 and Text Map 4-6; the acreages of the main crops are shown in Table 4-17. The Annual Reports of the Sabah Department of Agriculture should be consulted for full details.

Agricultural stations have been set up in the populated parts of the survey area by the Department of Agriculture; they supply seeds and young plants and give advice on how to grow particular crops. In Keningau, the Sebrang Cattle Station is a 200 ha (500 ac) research farm devoted to cattle breeding and beef production, and in 1971 a new Cocoa Research Station was established near Melalap on the Tenom Plain to promote cocoa growing by smallholders.

Settlement schemes are managed by various Government departments. They were started by District and Agricultural Officers in the early 1950's and today there are two kinds, namely major and minor schemes.

Major schemes are resettlement projects involving the movement of large groups of people into new areas, where they learn to grow crops such as oil palm or rubber. The settlers are supplied with land, housing, and planting materials, and are paid a daily wage until crops begin to bear. Thereafter they must repay the cost of the planting materials and the wages paid. There are three major schemes in the survey area at Klias, Biah and Nabawan. The oil palm scheme at Klias is managed by the Sabah Land Development Board, and wet rice schemes at Biah and Nabawan are managed by the Sabah Padi Board.

Minor schemes are administered by the Department of Agriculture; grants are given for land clearing and maintenance, and planting materials, tools and fertilizers are supplied free of charge. In 1972 there were 52 minor schemes, of which 23 were in the Beaufort District, 10 were in the Papar District and 7 were in the Sipitang District. Of the total, 37 schemes were growing wet rice and 12 were growing coconuts.

Rubber

The development of the rubber industry at the beginning of this century coincided with the completion of the railway from Beaufort to Tenom. By 1907, 19 000 ha (46 000 ac) of land had been taken up by four estates near Tenom and Beaufort, although not all the land was planted (Chartered Company of North Borneo, 1907). Unitl about 1940 most rubber was grown in estates, but after 1946 many local people and some Chinese, who had settled in Sabah, became rubber smallholders. The high world demand for natural rubber in the 1950's and early 1960's, coupled with improved communications, led to a marked increase in the planted area worked by smallholders. Yields also increased with the introduction of high yielding clonal varieties. During the 1960's, world rubber prices fell considerably and so, although yields continued to increase, the revenue decreased. However, the world price of natural rubber has recently recovered and there are now prospects of increased prosperity for the rubber industry.

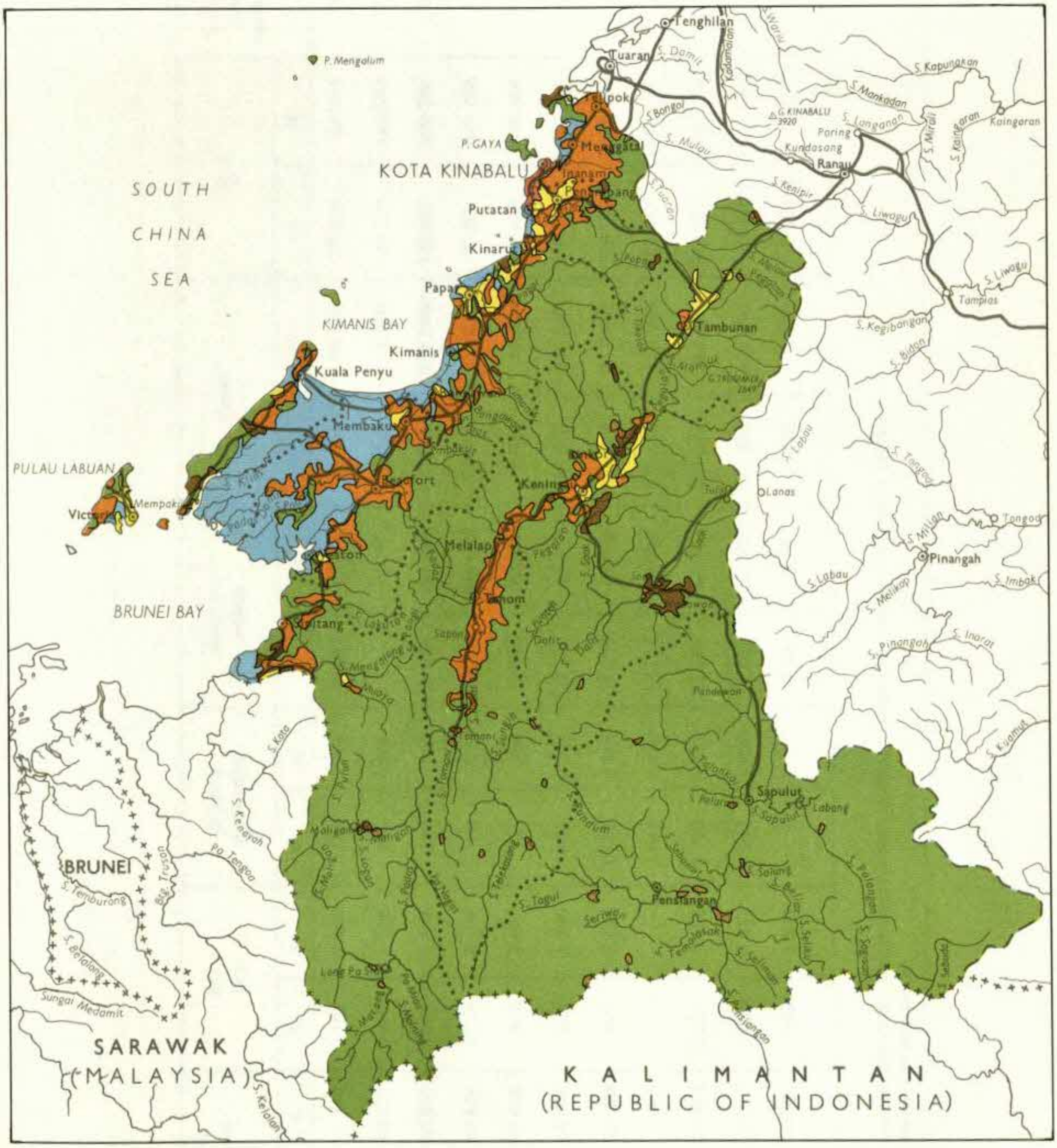
Rice

About 54% (18 146 ha (44 839 ac)) of the wet rice land of the State is in the survey area; this includes 1 287 ha (3 180 ac) that are double cropped (Table 4-17). Double cropping was introduced to the west coast in 1966, but is slow in spreading due partly to the lack of year-long irrigation and partly due to the conservative attitude of many farmers.

Hill rice continues to be grown in all the Districts of the survey area and the average amount of land used for each year from 1966 to 1971 is estimated to be about 2 830 ha (7 000 ac). Most commonly the land used for hill rice is under secondary forest and each family clears about 0.4 ha (about 1 ac) per head. For example in 1971 at Rundum in the south of the Tenom District (Rundum population about 150) about 53 ha (132 ac) were cleared to grow hill rice. Besides hill rice, tapioca, maize, yams, sugar cane, bananas and cucumbers are also grown. Each plot is usually worked for 1 year only, but sometimes tapioca may be grown in a second year. The total area around Rundum, which has been used for shifting agriculture, is about 665 ha (1 640 ac), so that about 8% of the total land used for shifting agriculture is farmed at any one time; this implies a rotation of about 12 years. Growing hill rice, however, is not encouraged by the government, and the establishment of settlement schemes, with land suitable for wet rice and other crops, will eventually reduce the amount of hill rice grown.

LAND USE 1970

TEXT MAP 4-6



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Prepared by the Directorate of Overseas Surveys 1974
Printed by the Ordnance Survey 1974
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SCALE 1:1,425,000

Miles 10 0 10 20 30 40 50 Miles

Kilometres 10 0 20 40 60 80 Kilometres

International Boundary	+ + + + + + +
State Boundary	—+ +—
District Boundary	••••••••••
Soil Survey Boundary	— — — —
Motorable Road	———
Railway	—+—+—+—
Trigonometrical Station (ht. in metres)	▲

Arable crops	
Tree crops	
Shifting cultivation	
Grassland	
Forest	
Swamp forest including mangrove and nipah	
Urban and associated areas	

TABLE 4-16 Land use by Districts in 1970

District	Urban areas		Tree and permanent crops		Wet rice		Shifting agriculture		Scrub and swamp		Forest		Total		% District under agriculture
	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	
Kota Kinabalu	825	2 038	12 593	31 118	1 166	2 880	147	364	9 687	23 936	9 431	23 304	35 009	86 505	39.7
Penampang	220	544	7 903	19 527	3 058	7 556	257	636	6 762	16 709	31 247	77 210	49 775	122 992	22.5
Papar	149	368	16 420	40 573	4 724	11 674	311	768	21 953	54 245	77 562	191 653	122 925	303 744	17.5
Beaufort	276	682	20 008	49 439	2 774	6 854	70	173	74 641	184 436	71 888	177 632	173 901	429 703	13.2
Kuala Penyu	38	95	5 431	13 419	988	2 441	125	310	32 546	80 420	5 635	13 924	47 093	116 364	13.9
Sipitang	110	273	4 212	10 408	914	2 259	960	2 373	17 557	43 383	250 516	619 017	276 273	682 661	2.2
Tenom	181	448	14 189	35 060	980	2 422	1 677	4 144	21 723	53 677	193 087	477 112	234 748	580 055	7.2
Pensiangan	27	66	403	995	–	–	2 542	6 282	19 543	48 289	578 464	1 429 365	603 413	1 491 013	0.5
Keningau	467	1 153	7 059	17 442	3 851	9 516	1 725	4 262	33 662	83 178	277 367	685 365	326 565	806 930	4.0
Tambunan	108	267	2 030	5 017	3 080	7 611	1 347	3 329	15 571	38 476	177 361	289 994	139 656	345 085	4.6
Labuan	362	895	2 157	5 329	538	1 329	6	14	3 540	8 747	1 222	3 020	9 348	23 099	28.8

Source: Malaysia, Department of Agriculture, 1972

Notes: Tree and permanent crops includes rubber, oil palm, coconuts, sago, orchards, cocoa, coffee, bananas and improved permanent pasture

Shifting agriculture includes hill rice and other subsistence dry land crops

TABLE 4-17 Areas of main crops

Year	Wet rice		Rubber		Coconuts		Cocoa		Oil palm		Sago		Coffee		Bananas	
	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac	ha	ac
1934	11 515	28 452	33 733	83 352	3 148	7 779	–	–	–	–	5 625	13 899	12	30	182	450
1954	11 333	28 004	30 671	75 785	1 167	2 883	–	–	–	–	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1961	14 593	36 060	50 575	124 968	3 589	8 869	–	–	–	–	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1971	18 146*	44 839	63 028	155 740	5 749	14 206	440	1 087	1 037	2 562	n.a.	n.a.	618	1 527	1 229	3 037

n.a. Data not available
* Includes area double cropped
Source: Sabah, Department of Agriculture Annual Reports for 1934, 1954, 1961 and 1972

Other crops

The greatest diversity of crops in any one district is on the Tenom Plain where, to a limited extent, rubber is being replaced by coffee, cocoa and bananas. Bananas are also grown in the Sipitang District and there is a small export trade with Brunei. A small area of cocoa has also been planted in the Beaufort District.

Oil palm is being grown on the Klias Peninsula on the 800 ha (2 000 ac) Sabah Land Development Board Settlement Scheme. There is a processing factory at the scheme and for this reason oil palm is being encouraged as a smallholder crop in the area near Beaufort. There are 20 ha (50 ac) of oil palm on the Tenom Plain and although it could be grown in other parts of the area it is not practical at present owing to the lack of processing facilities.

Coconuts are grown in all Districts of the survey area and notably in Labuan, Kuala Penyu and Papar. In 1971 these Districts grew 2 432 ha (6 010 ac), 1 775 ha (4 410 ac) and 628 ha (1 552 ac) respectively.

Citrus and other fruits together with a wide range of vegetables are grown in small gardens in many parts of the area.

A total of 3 221 ha (7 960 ac) of sago was grown, mainly on the west coast, during 1970.

SOIL SUITABILITY

The soil associations have been classified in terms of the suitability of their soils for agriculture; 3 broad suitability classes are recognised (Text Map 4-7).

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

2. 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.

Suitable land corresponds broadly with Groups 1 and 2, marginal land with Group 3 and unsuitable land with Groups 4 and 5 of the soil suitability classification used in Sabah (Sabah, State Development Planning Committee, 1973).

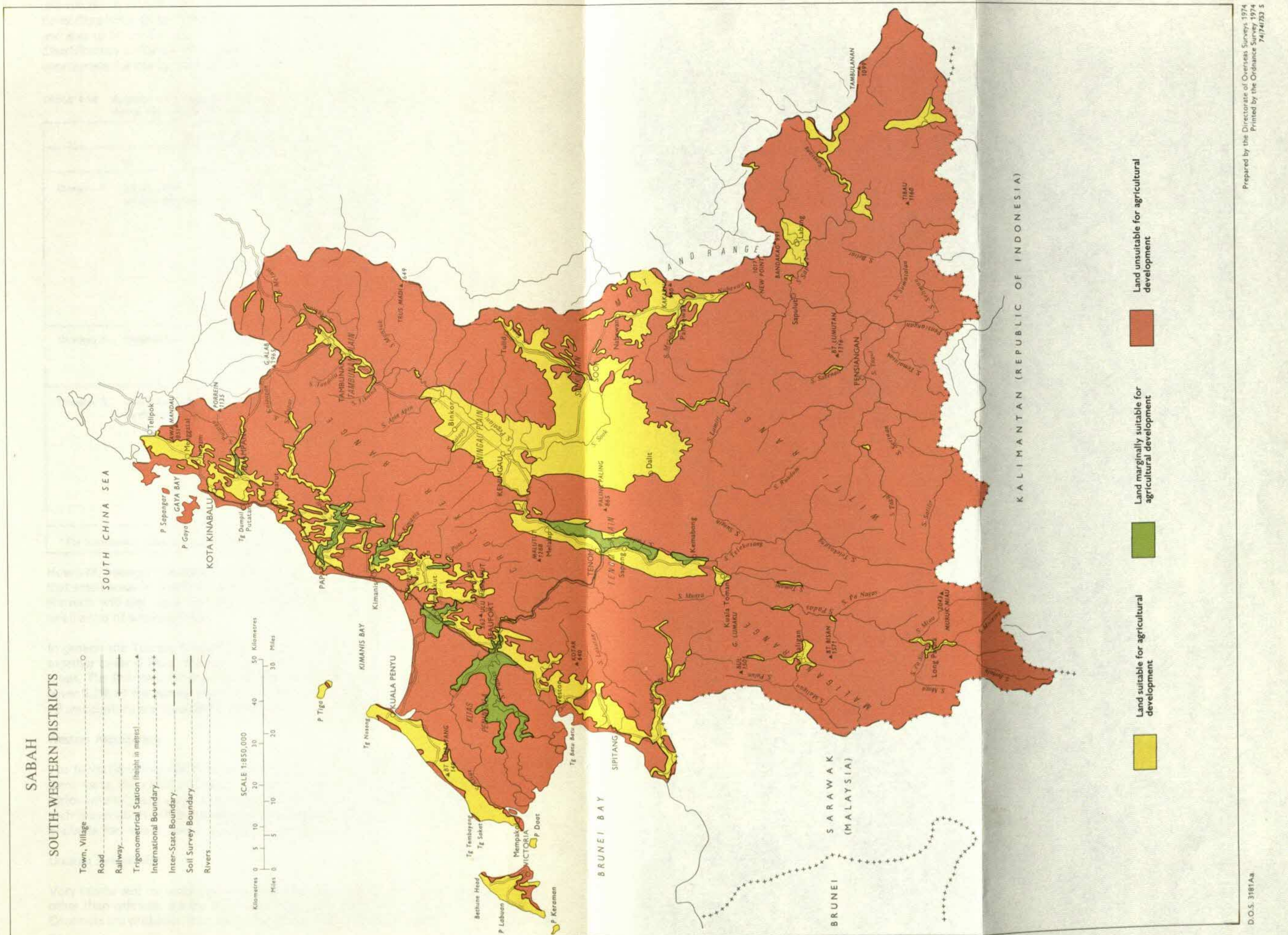
SABAH
SOUTH-WESTERN DISTRICTS
Town, Village
Road
Railway
Trigonometrical Station (height in metres)
International Boundary
Inter-State Boundary
Soil Survey Boundary
Rivers
SCALE 1:850,000
Kilometres
Miles
Land suitable for agricultural development
Land marginally suitable for agricultural development
Land unsuitable for agricultural development
SOUTH CHINA SEA
KOTA KINABALU
GAYA BAY
KIMANIS BAY
BRUNEI BAY
KUALA PENYU
BEAUFORT
SIPITANG
KENINGAU
TENOM
PENSIANGAN
KALIMANTAN (REPUBLIC OF INDONESIA)
SARAWAK (MALAYSIA)
BRUNEI
VICTORIA
P Labuan
Prepared by the Directorate of Overseas Surveys 1974
Printed by the Ordnance Survey 1974
D.O.S. 3181Aa

Table 4-18 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 4-18 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*			

However, because this classification is based on a reconnaissance survey it is inevitable that small areas in 'suitable' associations will be marginal or even unsuitable. The converse will also occur and it will be found that 'unsuitable' associations will contain small areas of suitable land.

In general the Tuaran, Kinabatangan, Labau, Binkor and Usukan Associations, which together cover 4.2% of the survey area, are considered to be suited to a wide range of crops. The Brantian, Sinarun, Dalit, Kalabakan and Kretam Associations together cover 9.2% of the survey area and are marginally suited to agriculture. The remaining 13 associations are considered to be unsuited to agriculture.

Weston Association

The limitations imposed by sulphur toxicity, very poor drainage, tidal flooding and, in some parts, deep peat and saline conditions preclude the use of this association for agriculture without very expensive and large-scale improvements. It is unlikely that such reclamation will be necessary in the foreseable future as there are better areas available for development elsewhere in the State.

Usukan Association

Very coarse soil textures, low exchange capacities and minimal plant nutrient levels, other than calcium, are the main limitations of the soils of the Usukan Association. Coconuts are probably the most suitable crop; intensive horticulture would be suitable if organic fertilisers were used and it would be particularly appropriate close to population centres such as Labuan. The largest single area of the Usukan Association is on Pulau Mengalum where the State Livestock Quarantine Station is being set up; for this the establishment of pasture is necessary and it is suggested that appropriate trials are carried out.

Tanjong Aru Association

The soils of this association have coarse textures, negligible amounts of plant nutrients and very low exchange capacities; in addition they are often poorly drained. No crops can be recommended but small-scale horticulture might be feasible on better drained soils close to markets such as Kota Kinabalu and Papar. Large amounts of organic matter and fertilisers will be required to counterbalance the infertility of these soils.

Tuaran Association

The soils of this association are potentially the most productive in the survey area. A wide range of crops could be grown providing that soil drainage is improved and the flood hazards are reduced. In order to reduce erosion of river banks it is recommended that river banks and levees should only be used for tree crops and areas that are still under forest should be constituted riparian reserves. The provision of irrigation in the Tenom Plain would make the double cropping of wet rice a practical proposition.

Kinabatangan Association

The soils of this association have less potential than those of the Tuaran Association, because they are more poorly drained and the risk of flooding is greater; once these limitations are overcome, however, a wide range of arable and tree crops could be grown. Irrigation would be desirable for double cropping of rice and also in areas, for example to the north of Papar, where long dry periods occur in 5 years out of 10.

Sapi Association

The major limitation of the Sapi Association is poor or very poor drainage caused by high groundwater levels in low topographical situations; it will therefore be difficult to improve the soil drainage without pumping. Apart from small areas where wet rice, sago or yams can be grown, the agricultural potential of this association is limited.

Klias Association

Poor to very poor drainage, deep peat and flood hazards are the serious limitations of this association. In some parts high sulphur contents will cause toxicity problems if the soils are drained. Normal drainage techniques result in slight improvements only and pumped drainage schemes will be required to achieve major and lasting improvements. In view of these limitations, no crops can be generally recommended. Oil palm, however, is being grown on the Klias Peninsula and is reported to be giving satisfactory yields, although there are problems of poor rooting which cause the palms to fall over. Maize and pineapples grow well on drained peat soils in West Malaysia, but it is recommended that thorough trials be undertaken before these or any other crops are planted.

Labau Association

Many areas included in the Labau Association are extremely inaccessible. The soils are poorly drained and they are coarse-textured and often stony. In all localities there is a danger of flash floods. If the poor drainage can be remedied and the flood hazard controlled, then some parts of the association could be used for coffee, oil palm and fruit trees, for example. Wet rice and some dry land crops are currently grown.

Binkor Association

Soil drainage is the main limitation of this association especially in the Keningau and Tambunan Plains, but this can generally be rectified. Nutrient levels tend to be low, but these can be controlled by appropriate fertilisers. Stoniness is a minor limitation. A wide range of crops including coffee, rubber, wet rice, maize and fruit trees is already being grown and there is scope for intensification.

Sinarun Association

Soil nutrient deficiencies, steep slopes and in some areas shallow soils make this association suitable for a limited range of crops. The steep slopes will require terracing before being used. Rubber is currently grown on some of these soils and other crops such as fruit, cashew nuts and coffee could also be grown.

Brantian Association

Low levels of plant nutrients and topography are the two main limitations to the agricultural use of this association. Soil drainage is seldom more than a minor limitation. Terracing of steep slopes will be necessary in some areas for tree crops such as rubber, fruit and coffee. In the interior valleys and plains, tree crops and pasture could possibly be established. Reafforestation with quick growing soft woods has been started on a small scale near Sook and could prove to be a suitable use of large parts of this association.

Sook Association

The soils of the Sook Association have very low levels of plant nutrients and are poorly or very poorly drained. The lack of nutrients can be overcome by the use of fertilisers, but major schemes would be necessary to improve the drainage. On the whole the association is not suitable for agriculture. Should the limitations be overcome, the range of suitable crops would be limited to the less demanding tree crops, such as cashew nut, some fruit species and possibly rubber.

Kepayan Association

Poor drainage, lack of nutrients, coarse soil textures and shallow rooting depths preclude the use of this land for any form of agriculture. Attempts have been made to grow pasture and forage crops on these soils, but even under experimental conditions they have not been successful.

Sipitang Association

Very poor drainage and deep peat deposits associated with very low levels of plant nutrients make this association unsuitable for agriculture.

Kretam Association

With erosion control measures on steep slopes the soils of the association would be suited to most tree crops. The nutrient status of the soils is generally satisfactory. However, the greater part of this association occurs on Pulau Tiga, which is both inaccessible and has limited supplies of drinking water; agricultural development is not recommended.

Kalabakan Association

Steep slopes are the major restriction to the use of this land and for tree crops terracing would be necessary. Inaccessibility is also a further restriction on the use of this association.

Dalit Association

The main limitations of the Dalit Association are steep slopes and low plant nutrient levels. Extensive terracing will be necessary and with fertilisers, tree crops such as rubber, coffee, cashew nut, and some fruit species could be grown. It is also suggested that those parts of the association now under secondary forest or *lalang,* should be reafforested.

Associations on steep hills and mountains

The Lokan, Crocker, Trusmadi, Maliau, Serudong and Gomantong Associations together comprise 76% of the survey area. They have the general limitation of steep to very steep slopes and the soils are often shallow and low in plant nutrients. Although some of the less severe slopes on the west of the Crocker Range are planted with rubber, no general agricultural use for any of these associations is recommended. The cultivation of temperate zone vegetables as currently practised around Kundasang, to the north of the survey area, however, might be practical in accessible areas at high altitudes; a possible area would be along the Kota Kinabalu to Tambunan road to the east of the Crocker Range. It is strongly recommended that agriculture should be discouraged, as erosion and greatly increased runoff with associated flooding would result. By extending the present boundaries of the Crocker Range, Gunong Lamaku, Trusmadi and Mandalom Forest Reserves large areas could be preserved for future recreational use and would ensure conservation of soil and water resources.

RECOMMENDATIONS

In the following paragraphs the development potential of each administrative District is discussed and suggestions are made for agricultural or other uses.

Kota Kinabalu and Penampang Districts

There are about 20 ha (50 ac) of land suitable for most agricultural crops and about 1 187 ha (2 932 ac) of land with potential that are unalienated. This land occurs sporadically throughout the Districts, and as a result no large-scale agricultural development is feasible. An expansion in horticultural crops would, however, be practicable assuming the continued growth of Kota Kinabalu. Irrigation in the rice-growing areas, especially Penampang, would allow more double cropping to be undertaken.

Papar District

Very little land that is suitable for agriculture remains unalienated. There are a few small areas that could be used for a limited range of tree crops such as rubber, fruit trees and cashew nuts; drainage schemes would permit the greater choice of crops and result in greater productivity. The District is liable to suffer periods of water stress; for this reason and also to allow double cropping of wet rice, irrigation is necessary.

Beaufort District

There are about 93 km^2 (36 mi^2) of undeveloped land with agricultural potential in the Beaufort District. Of this the land included in the Tuaran and Klias Associations will need effective drainage before it can be fully utilised; drainage will be difficult in low lying positions with high regional watertables and in such areas rice is the only suitable crop. Areas of the Dalit Association will need terracing, after which tree crops could be grown.

Kuala Penyu

About 93 km^2 (36 mi^2) (18% of the District) is considered suitable for agricultural development; most of this is in the southern part of the District around Bukit Nuri and there are about 445 ha (1 100 ac) on Pulau Tiga. Tree crops and pasture could be grown on areas of the Dalit Association and, with drainage, areas of the Kinabatangan Association would be suitable for wet rice. Access throughout the District is good.

Sipitang District

About 4% of the District, which is at present unused, is suitable for a limited range of tree crops; much of this land, however, is remote. The area around Long Pa Sia and Long Miau, included in the Binkor Association, is capable of greater production than at present and the possibility of growing temperate fruit and vegetables could be investigated.

Parts of the accessible coastal strip are under-used, despite considerable assistance from the Government. For instance, to the south of Mesapol a large irrigation system has been built, but its full potential has yet to be realised; areas under semi-derelict rubber trees could be cleared and replanted with fruit trees, coffee or cocoa.

Tenom District

The only land in the District which is suitable for agricultural development is between Melalap and Tomani. The floodplains and the first terrace above the Sungai Padas and Sungai Pegalan are suited to a wide range of crops and they are nearly all used at present by estate owners, smallholders and the Cocoa Research Station; drainage improvements and flood controls could, however, increase productivity.

Parts of the upper terraces in the Tenom Plain are deeply dissected and the soils are low in plant nutrients so that they are only suited to a limited range of crops; re-afforestation and possibly pasture are the suggested uses. In the northern part of the plain much of the land is under rubber and to the south there is shifting agriculture.

Pensiangan District

This is a District of hills and mountains with only a few valleys containing flat land. Access is limited and the only road is the track from Nabawan to Sapulut; Pensiangan itself can only be reached by river or on foot. At Pandewan there are about 800 - 1 200 ha (2 000 - 3 000 ac) of flat land, but the soils have low reserves of plant nutrients and are, in some parts, podzolised. Hence the potential of these areas is restricted to tree crops such as rubber, cashew nut and fruit trees or to reafforestation with such species as *Pinus caribbea.* There are also about 52 km^2 (20 mi^2) of land with agricultural potential in the Labang Basin; the area includes a part of the Sapulut floodplain which is suited to a wide range of crops. Access to the area, however, is a major problem.

Keningau District

The Keningau and Sook Plains, and the Nabawan valley are the major areas of the District which are suited to some form of agriculture. The Keningau Plain covers about 311 km^2 (120 mi^2) of which about one third is suitable for most crops and the remainder for a more limited range of crops. Most of this land however, is alienated. Individual holdings are mostly small and fragmented so that the use of modern techniques and machinery are difficult. Extension of the irrigation scheme could make parts of the lowest terraces suitable for wet rice and between Binkor and Apin Apin the land might be suitable for pasture; water would be necessary for stock.

The Sook Plain covers about 404 km^2 (156 mi^2), but is of limited potential. Afforestation with *Pinus caribbea* is in progress at Sook and could be extended to some other parts of the plain. Generally the drainage, low nutrient levels and periodic droughts preclude agriculture and the only area that is recommended for use is near Tiulan, where the soils are derived from recent alluvium and there is a small river to supply irrigation needs. This area is 1 600 - 2 400 ha (4 000 - 6 000 ac) in extent and could be used for a range of dry land crops and with irrigation rice could be grown. A government sponsored agricultural youth scheme is planned for part of this area.

Most of the suitable land in the Nabawan valley is being used by the settlement scheme, but near Dalit, land could be used for tree crops such as rubber, cashew nut and fruit trees; terracing, however, would be needed.

Tambunan District

The only land suitable for agriculture in the District is contained in the Patau Valley and Tambunan Plain and this is mostly already in use. Much of the land is under wet rice, but one possible way to increase productivity here is to encourage the growth of dry land crops such as maize or peanuts after the rice harvest.

Labuan District

About two thirds of the island is suitable for agriculture and except for about 98 ha (241 ac) the land is already in use; thus the only possible recommendation is to intensify the cropping.

CONCLUSIONS

About 13% of the survey area is suitable for agriculture and most of this land is already in agricultural use; there are no large tracts of virgin land that are suitable for agricultural development.

The only general recommendation that can be made is to intensify the present agricultural systems, for although much of the suitable land is already fully used some areas could be more productive.

In the survey area as a whole there are four main areas with potential for agricultural development. They are summarised in Table 4-19.

TABLE 4-19 Areas with potential for agricultural development

Location	Area		Altitude		Access	Recommended crops
	ha	ac	m	ft		
Dalit (Keningau District)	40 500	100 000	300 - 450	1 000 - 1 500	Area astride track from Keningau to Dalit.	Rubber, cashew nut, some fruit, coffee.
Sook (Keningau District)	12 000	29 600	300 - 450	1 000 - 1 500	Area bordered in west by Sook to Tulid road and in south by Sook to Nabawan road.	Pasture, softwoods.
Labang Basin (Pensiangan District)	5 000	12 400	240 - 300	800 - 1 000	6 hours by boat from Sapulut.	Tree crops, fruit, rubber, citrus, cashew nut.
Bukit Nuri (Kuala Penyu District)	3 600	8 900	0 - 75	0 - 250	Centre of area about 16 km (10 mi) by road from Kuala Penyu	Tree crops, rubber, citrus, cashew nut, pasture.

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