Land Resource Study

20 The Soils of Sabah Volume 2 Sandakan and Kinabatangan Districts

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The Kinabatangan at Abai

Land Resources Division

The soils of Sabah

Volume 2

Sandakan and Kinabatangan Districts

B D Acres and C J Folland

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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ACKNOWLEDGEMENTS

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We wish to thank the Director of Agriculture and Staff of the Department of Agriculture, Sabah, for their interest and cooperation in the execution of this soil survey.

In particular we acknowledge the contribution of those working in the Soil Survey Office at Sandakan. Research Assistants Samuel Siambun, Fred Dunong, Joseph Voon and Aling bin Along worked throughout the survey and effectively organised field parties and undertook much preparatory work. We shall remember their willingness and industry together with the shared adventures of living in the forest. The draft report was typed and the draft maps were drawn by the clerical and cartographic sections and no praise is too high for the quality of their work and the spirit in which it was done. In particular we record the contributions made by Susan Tam, Christine Phan and Monica Lee.

Other colleagues have given their help and of these we thank those of the Soils Laboratory and Library at Tuaran, the Agricultural Office at Sandakan and the Oil Palm Research Station at Ulu Dusun.

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Finally we wish to record our appreciation for the help and hospitality received from the many timber companies and the friendliness of the people throughout the area.

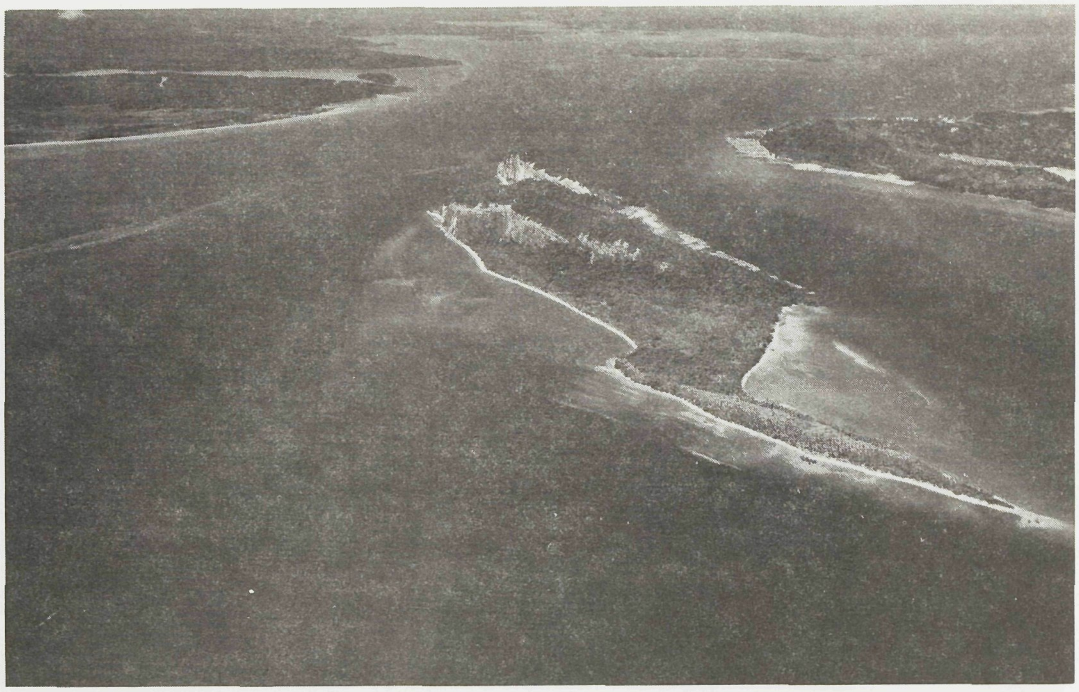
ABSTRACT

This volume describes the soils of the Sandakan and Kinabatangan Districts. These Districts cover an area of about 20 000 km^2 (8 000 mi^2) consisting largely of uninhabited forested land with extensive inland mountain ranges, broad zones of lowlands, floodplains and coastal swamps. Climate, vegetation, parent materials and landforms are summarised and 36 soil associations are described on alluvium, peat, mudstone, sandstone, limestone and igneous rocks. The physical and chemical characteristics of the soil families contained in the associations are described. In the final part the history of agriculture and present day agriculture are summarised and the soil associations discussed in terms of their suitability for agricultural development. About 13% of the land is found to be suitable for a variety of agricultural purposes, while 21% is marginal and 66% is unsuitable.

RÉSUMÉ

Ce volume traite des sols des Districts Sandakan et Kinabatangan. Ces Districts comprennent une superficie de 20 000 km^2 (8 000 mi^2) qui consiste pour une grande part de terres boisées inhabitées, où il se trouve des montagnes, des plaines, des aires d'inondation et des marais côtiers. Une résumé est donnée du climat, de la végétation, et des roches-mères.

On décrit '36 associations de sol dont les roches – mères sont l'alluvion, la tourbe, l'argilolithe, le grès, le calcaire, et les roches ignées. Les caractères physiques et chimiques des familles de sols appartenant à chaque association sont décrites. A la fin du volume on résume l'histoire agricole et l'agriculture actuelle des Districts et on discute l'utilisation potentielle de chaque association. On trouve qu'environ 13% de la superficie étudiée est utilisable pour plusieurs types de développement agricole, tandis que 21% pourrait utilisé avec difficulté et 66% est inutilisable.



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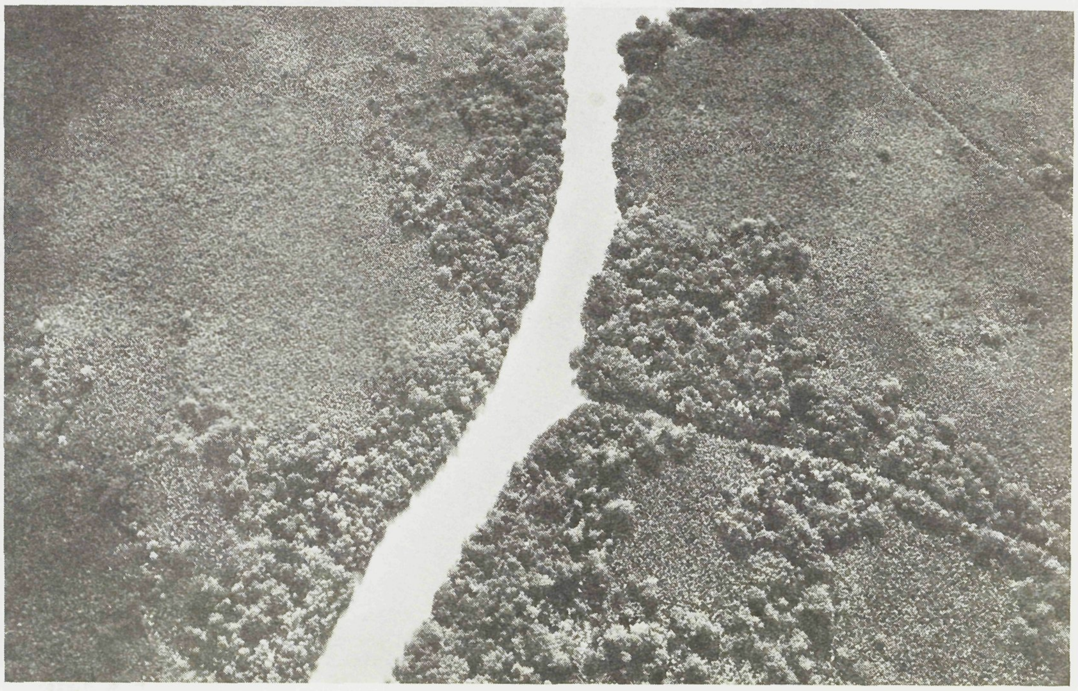

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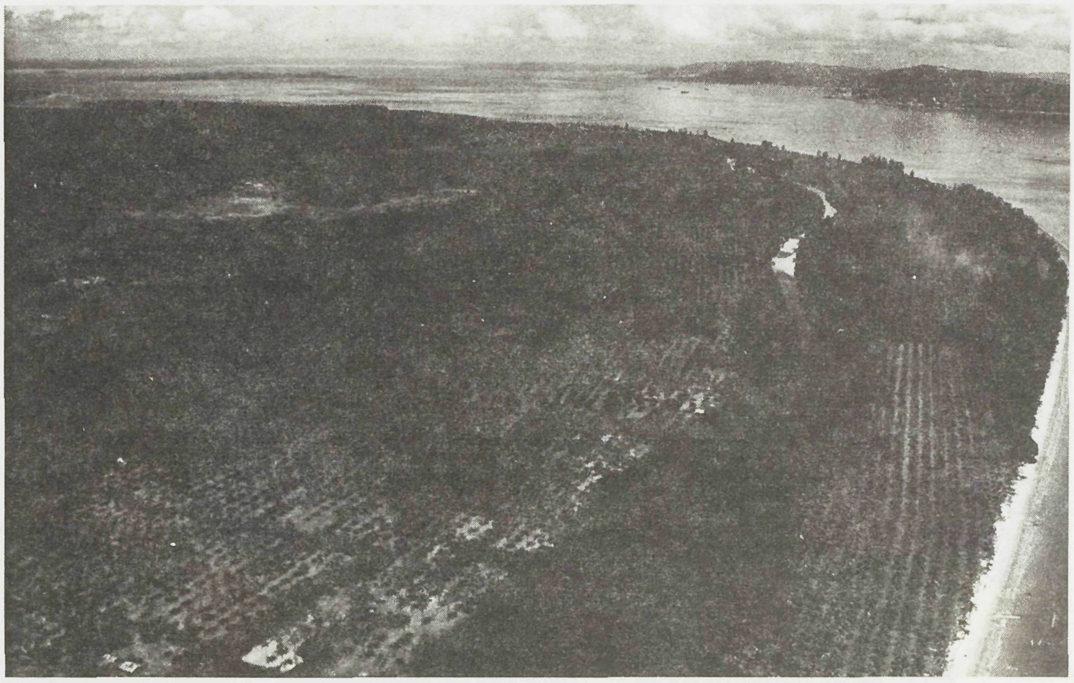

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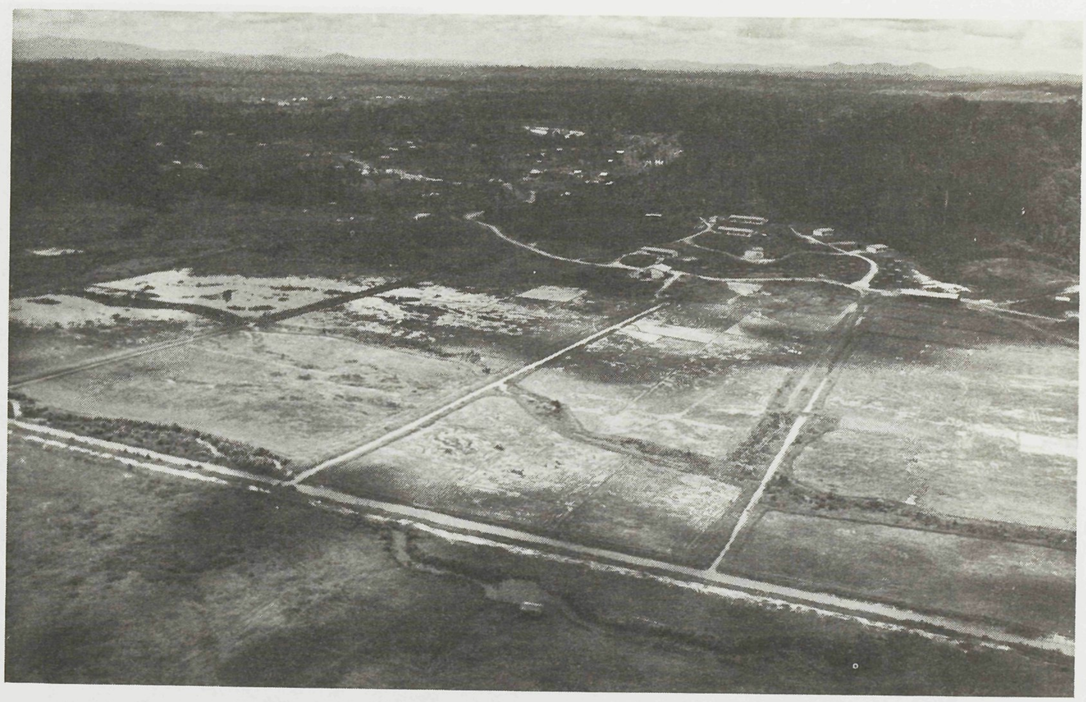

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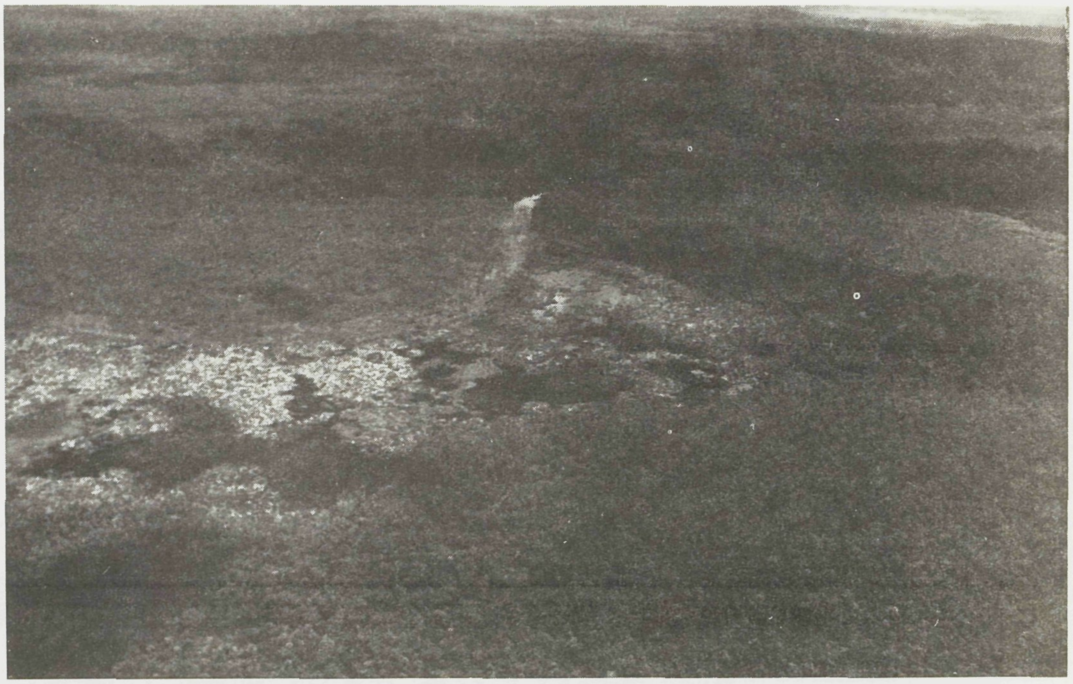

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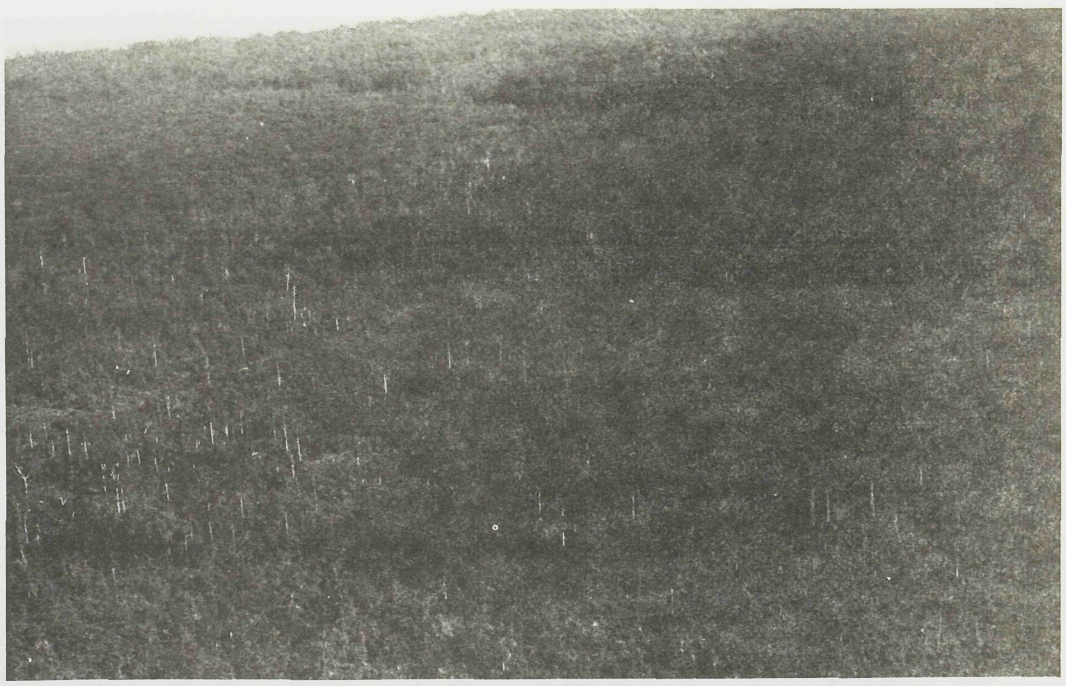

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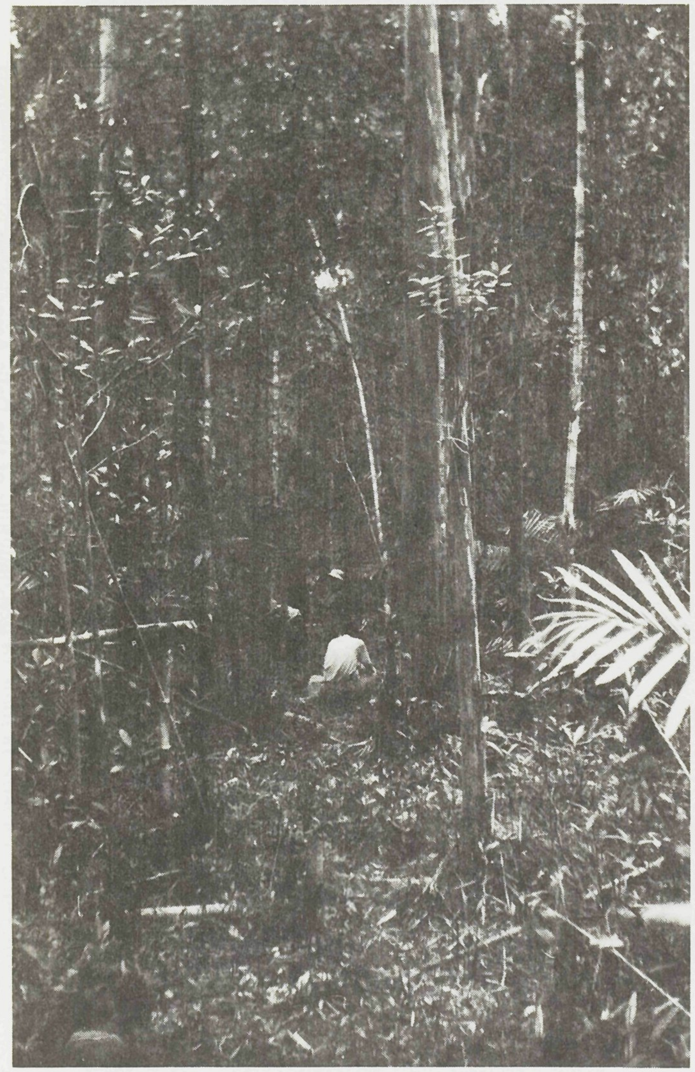

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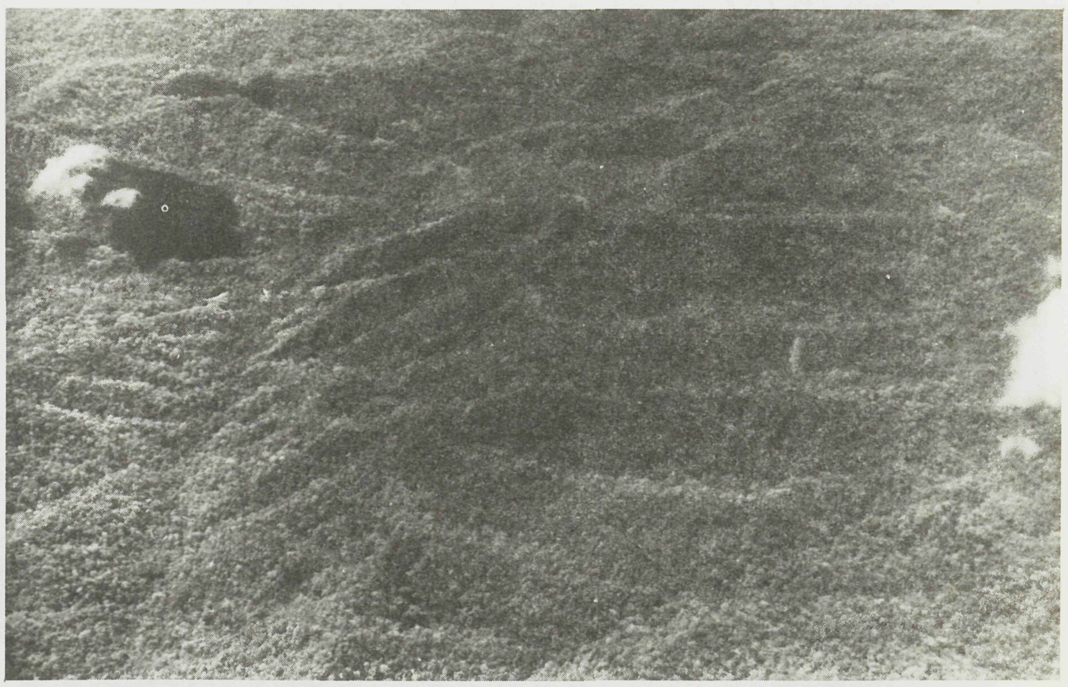

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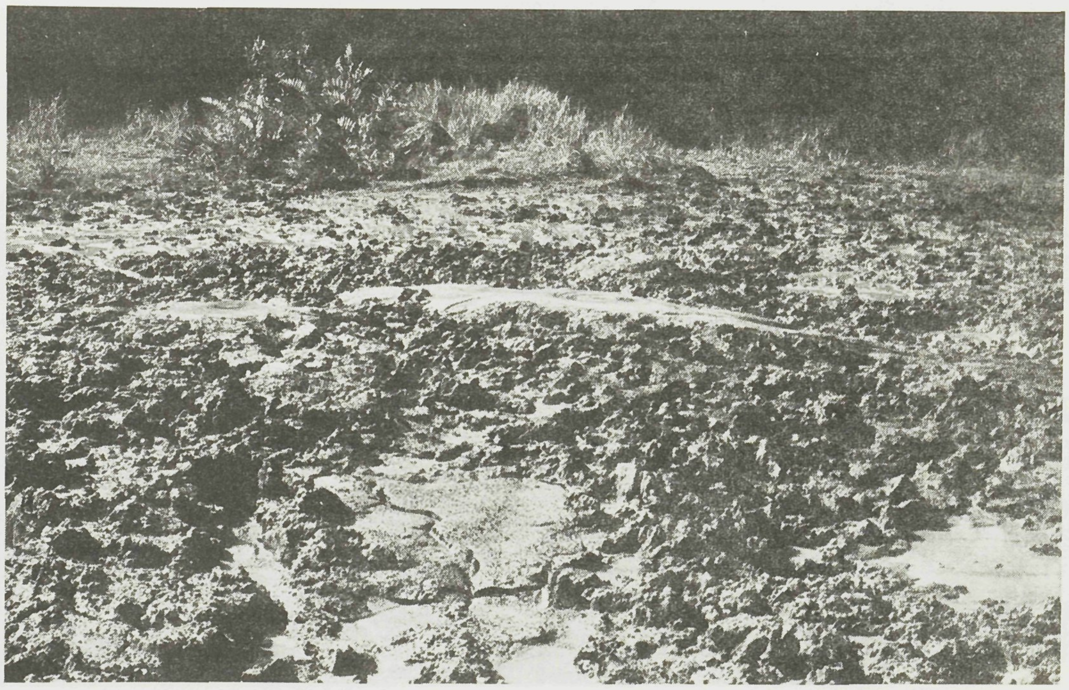

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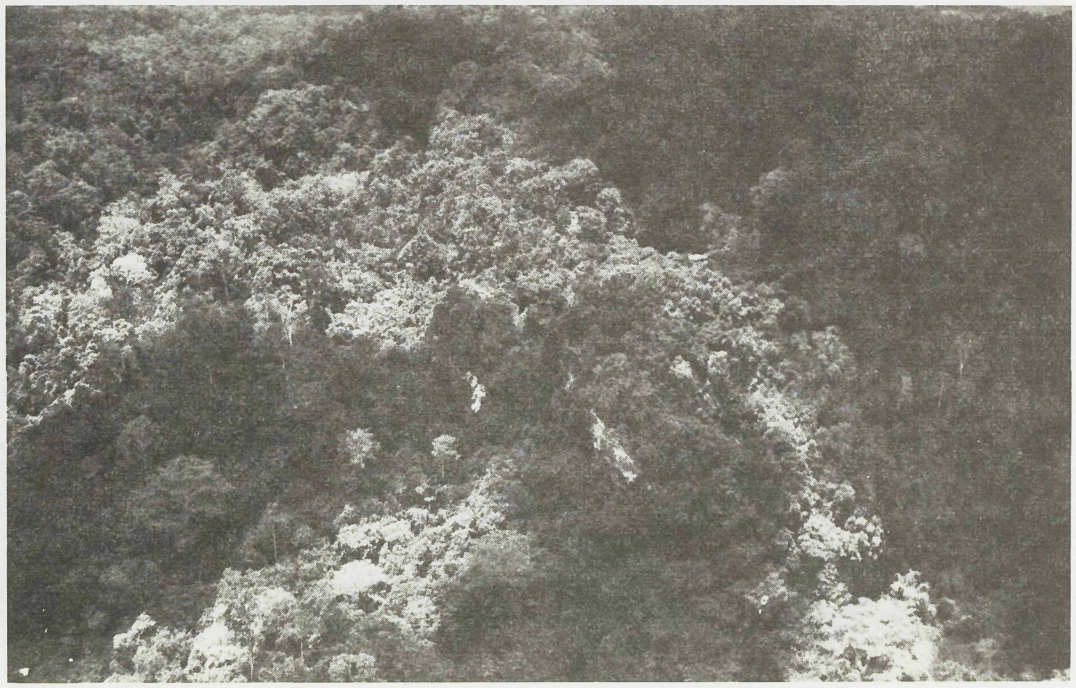

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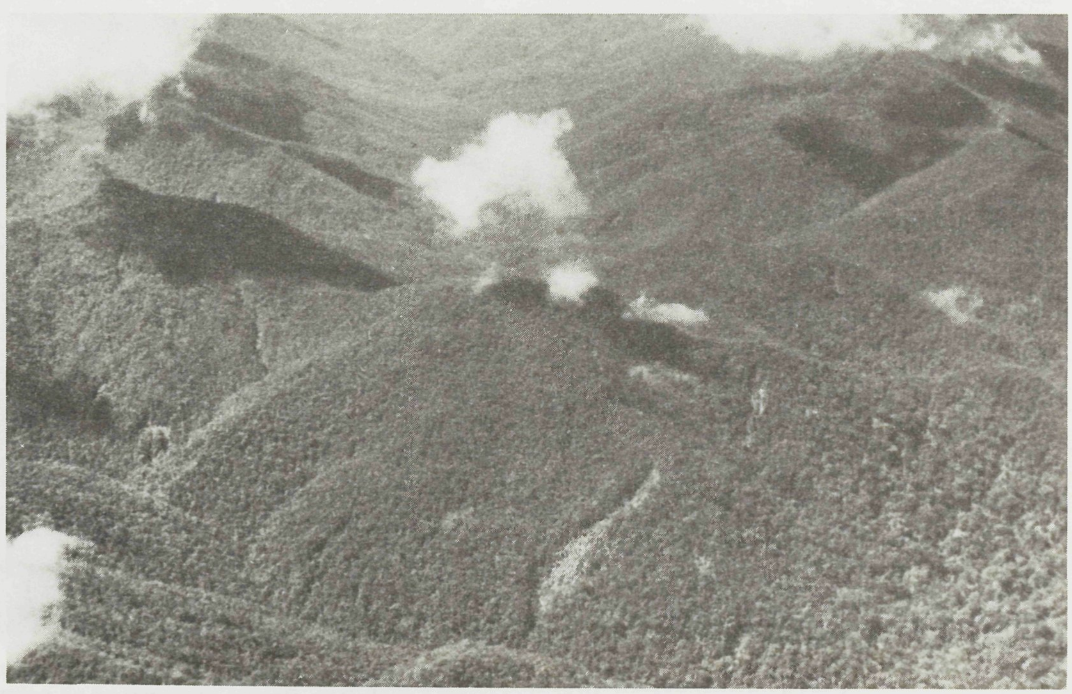

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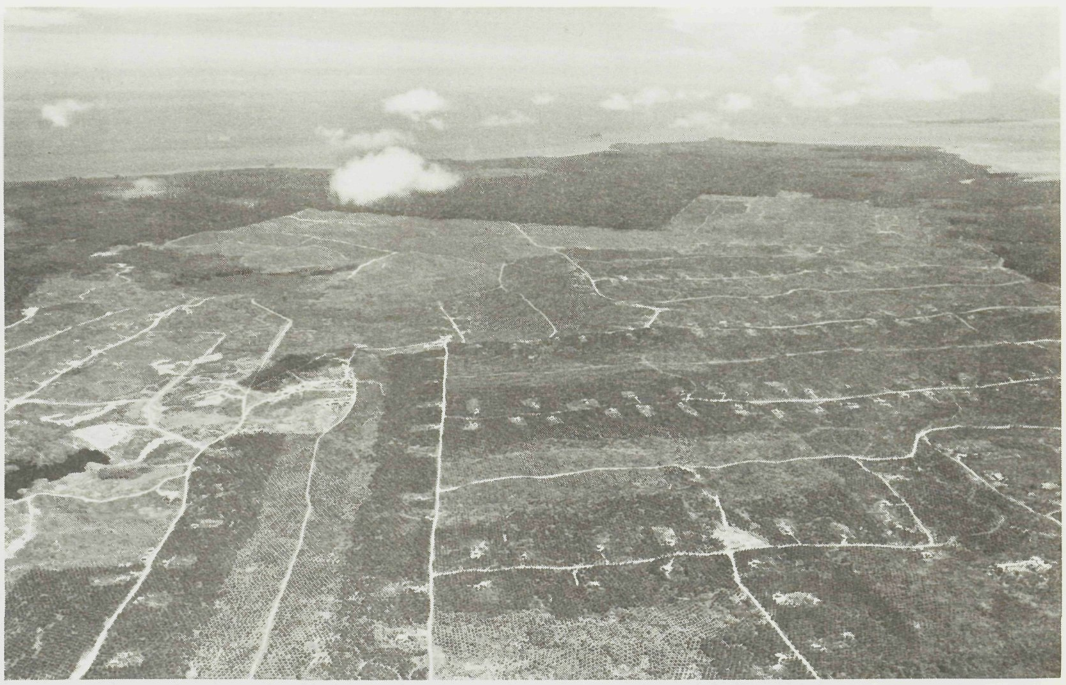

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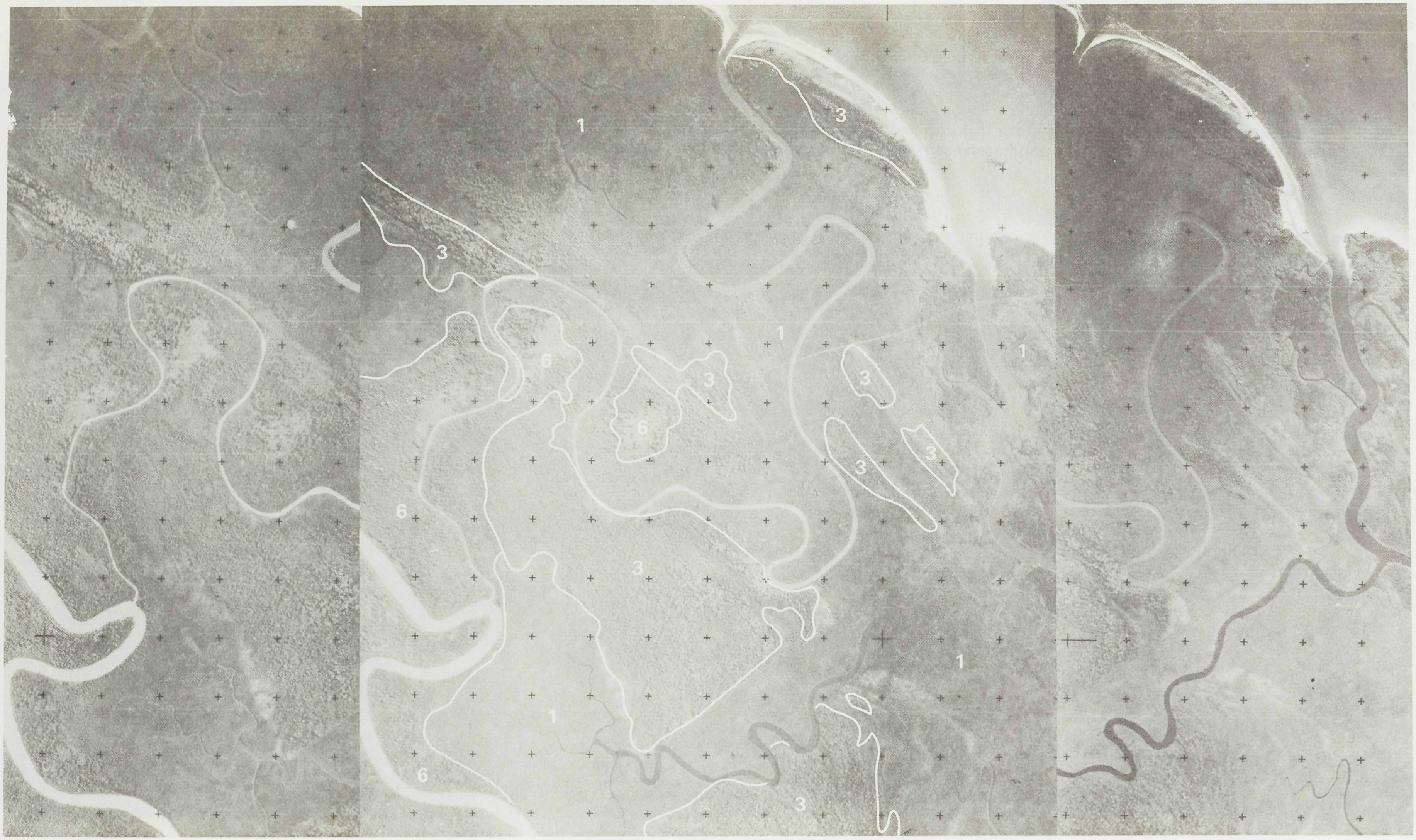

STEREOGRAM 2-1 The Kinabatangan delta east of Abai. Weston Association (1) in mangrove and nipah swamps; mangrove species are distinguished by dense, dark tones and light stippled patterns and nipah by even, light grey tones. The Tanjong Aru Association (3) occurs on old beaches and on coastal beaches. The Sapi Association (6) is also shown (Scale 1 : 56 000)

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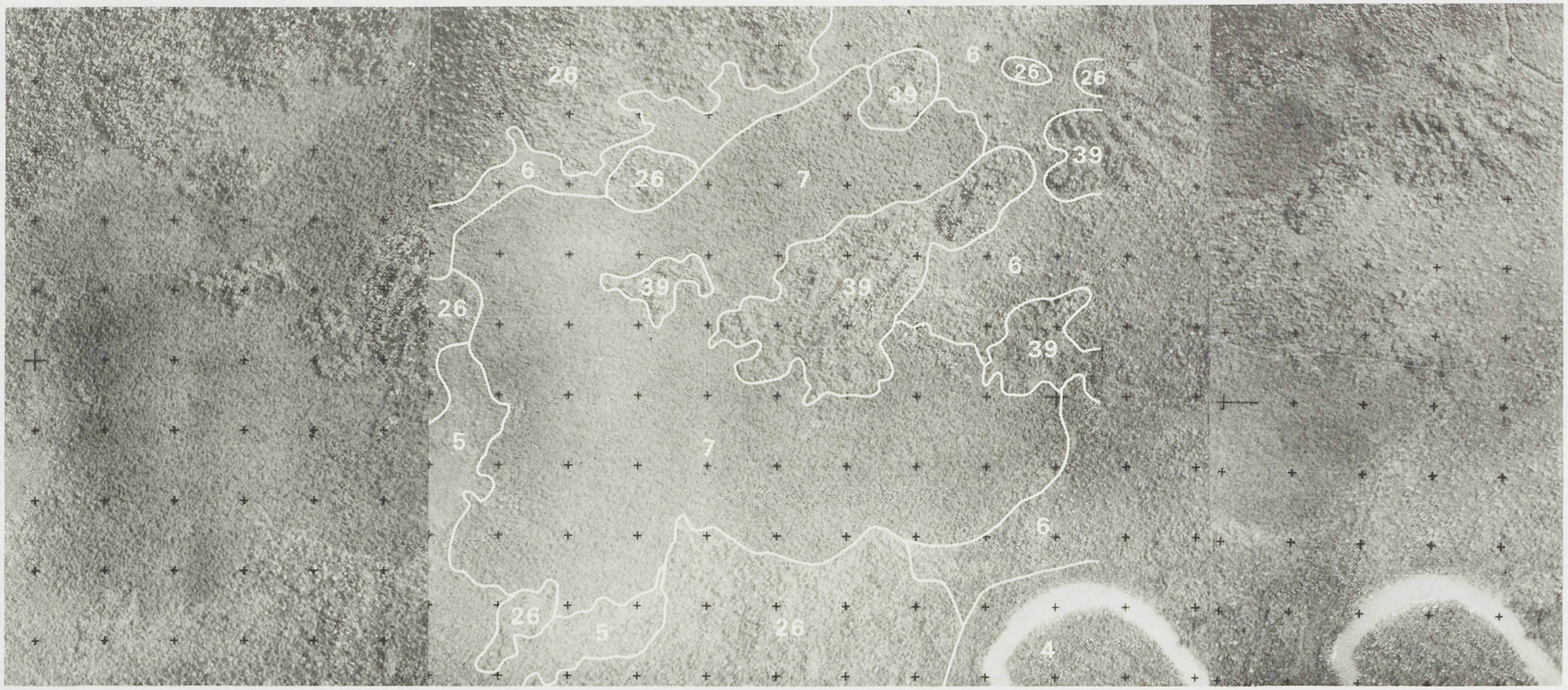

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STEREOGRAM 2-4 Headwaters of the Karamuak. The Mentapok Association (42) on mountains of basic igneous rocks and the Crocker Association (47) on mountains of sandstone and mudstone (Scale 1 : 48 000)

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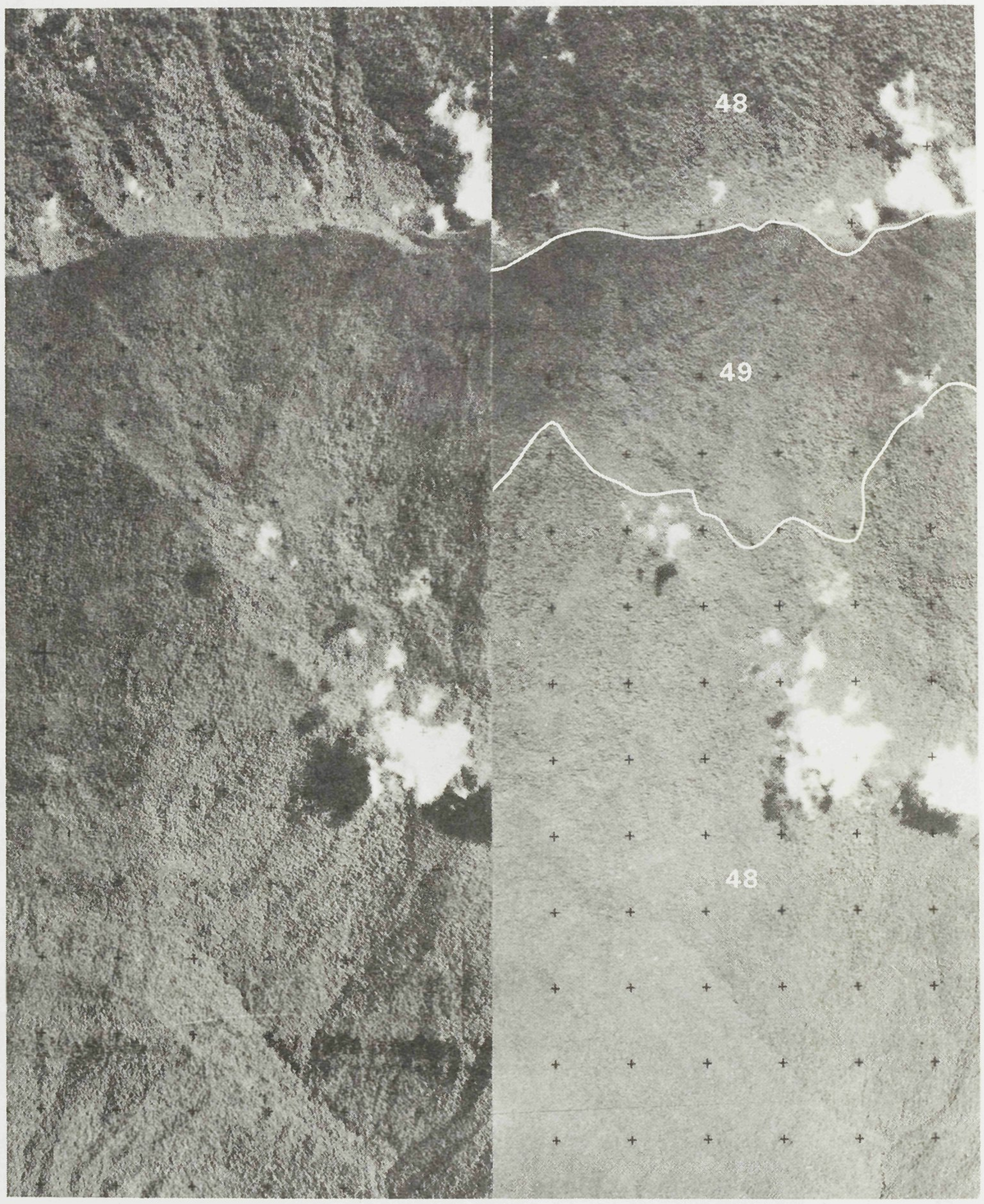

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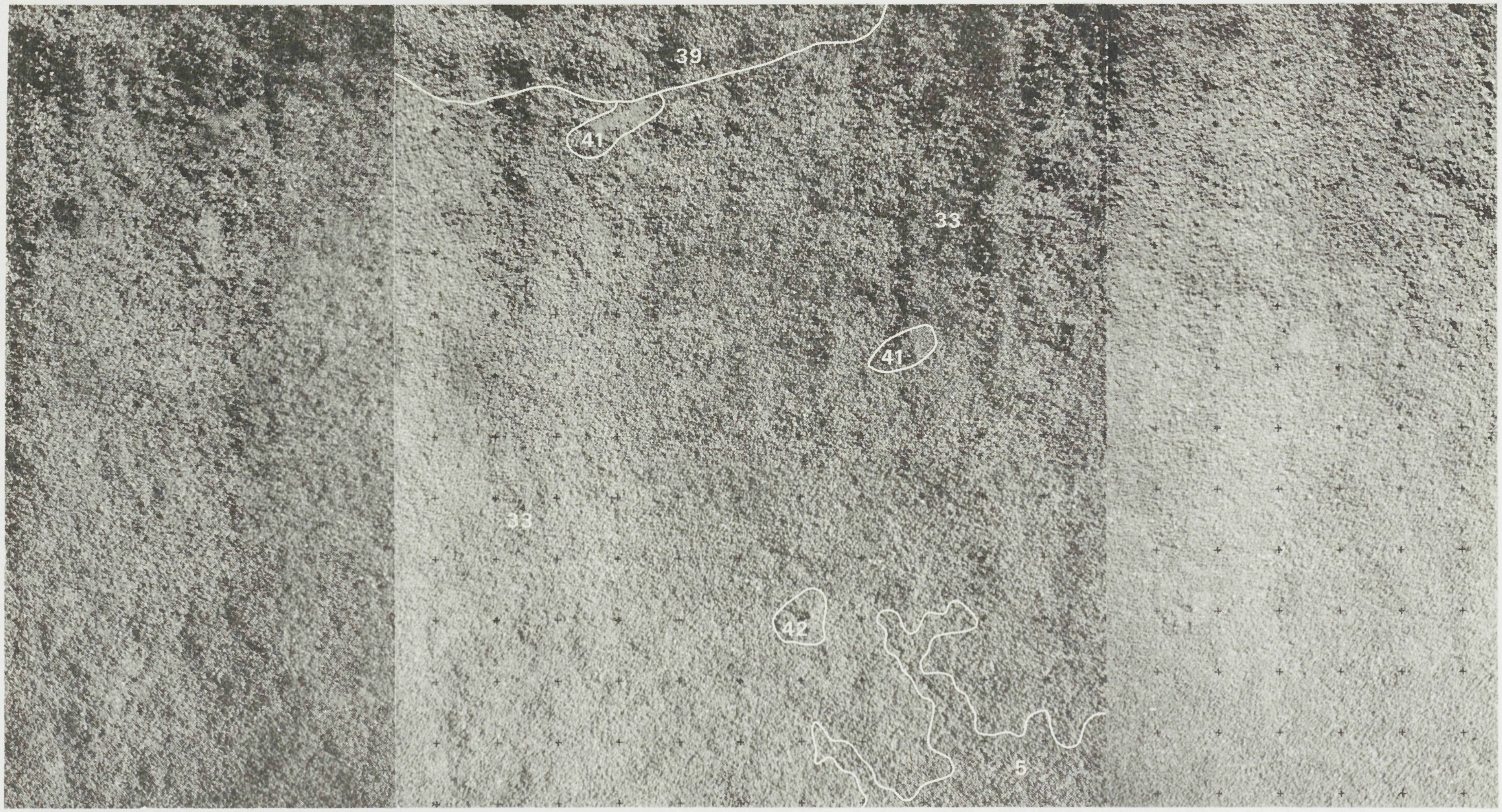

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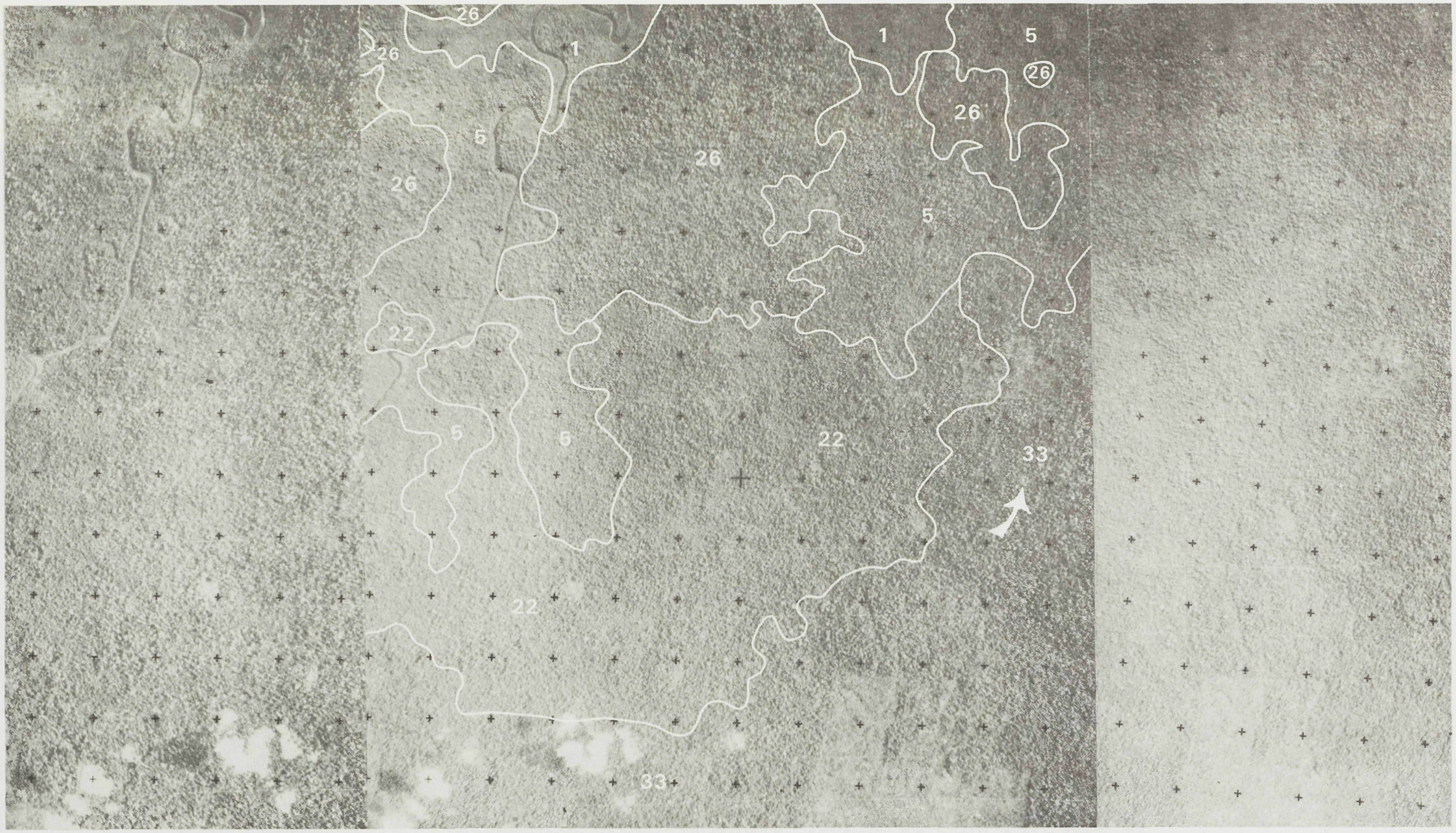

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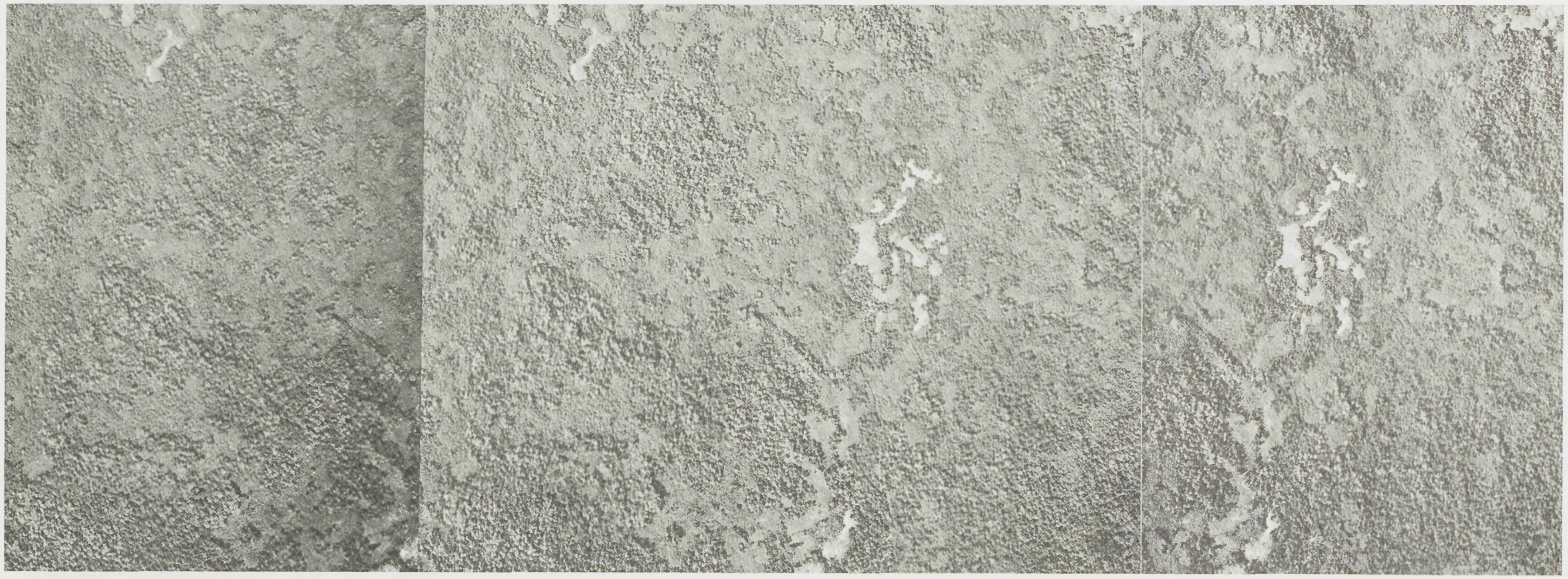

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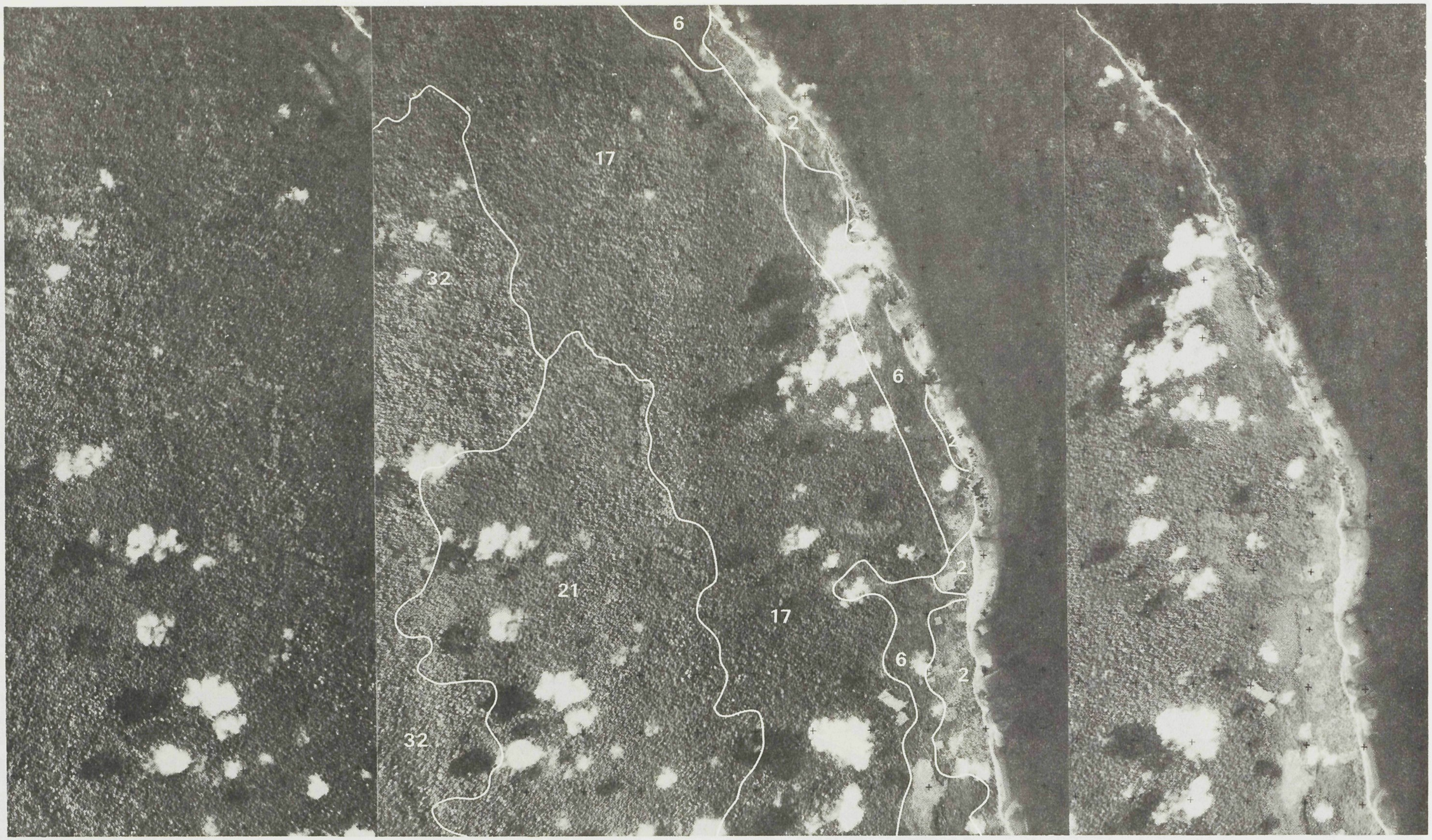

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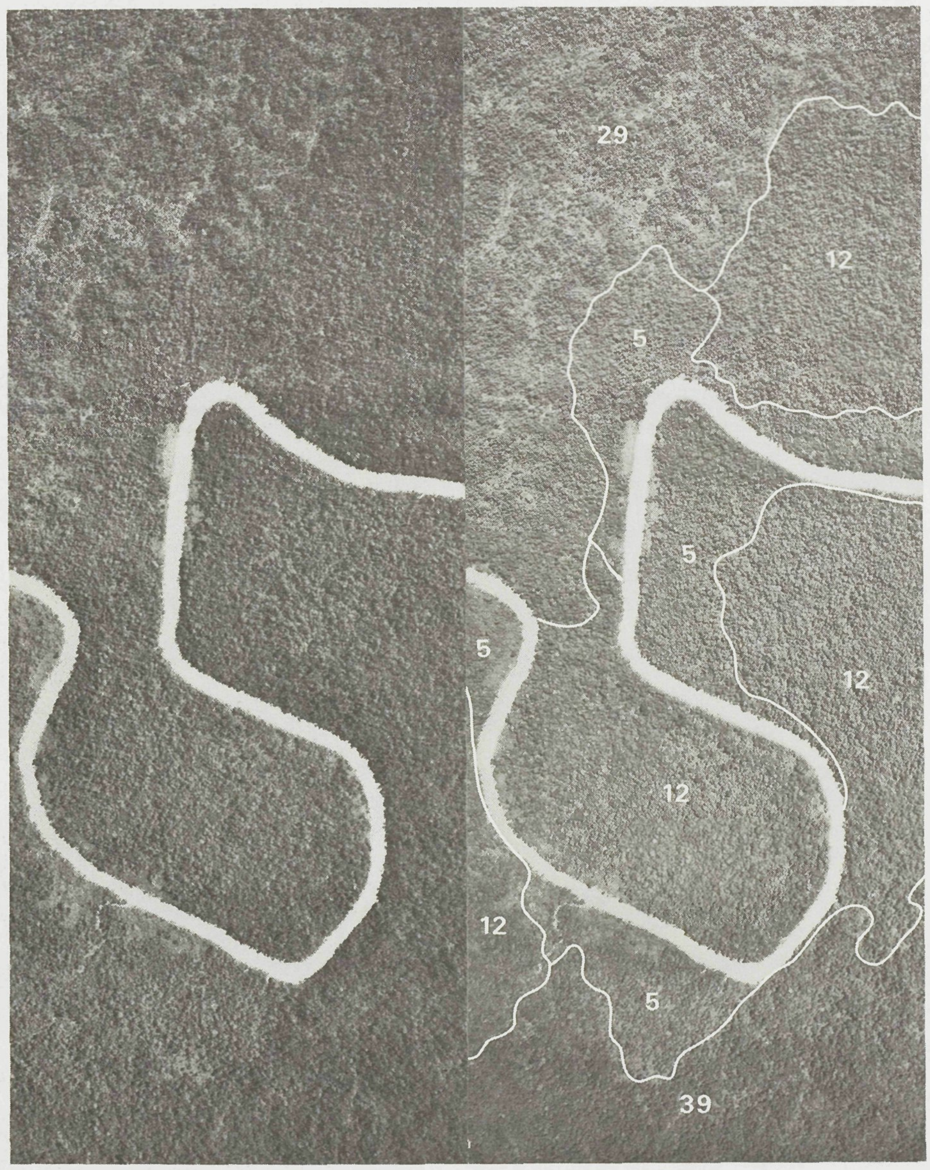
STEREOGRAM 2-12



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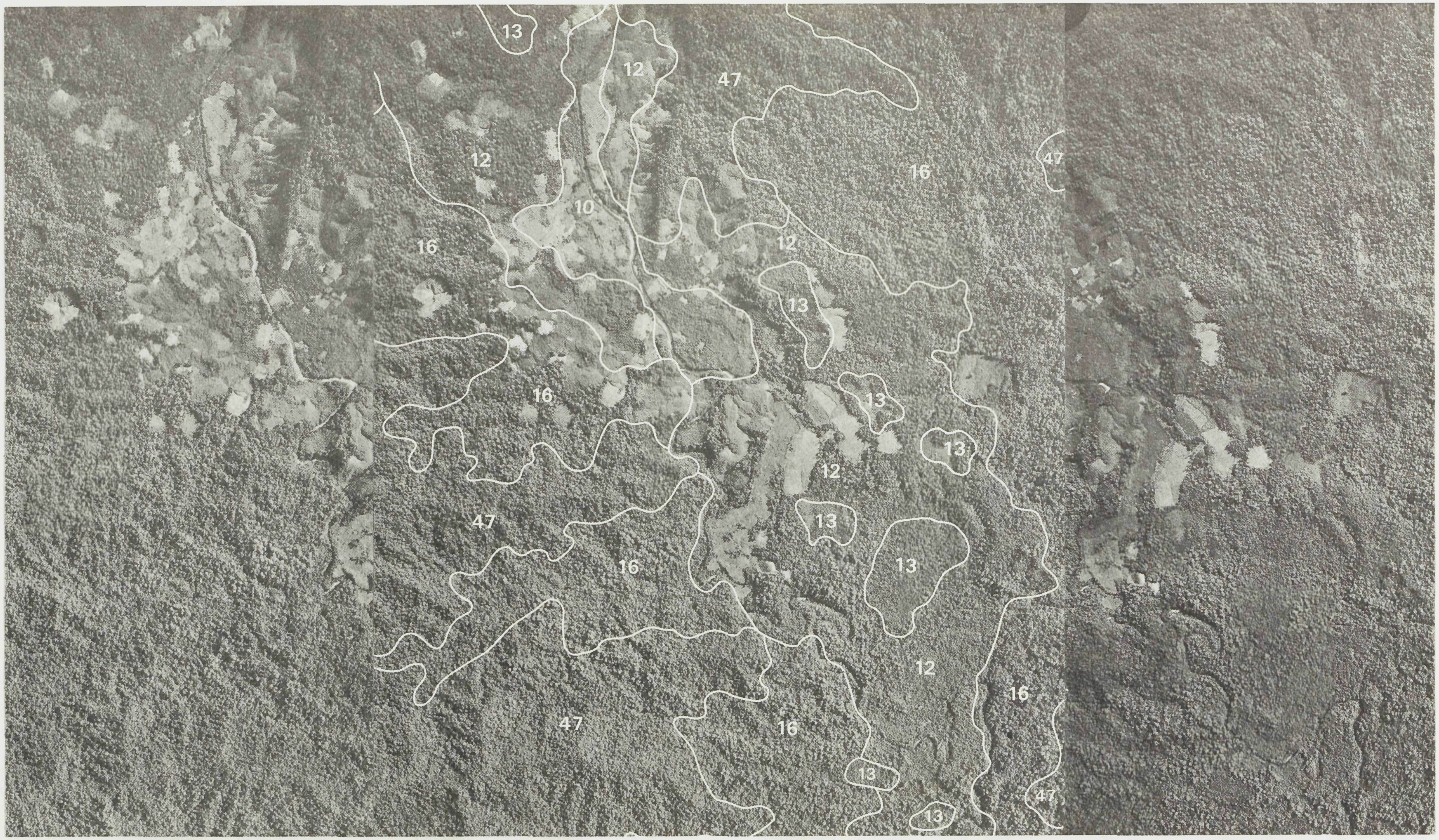

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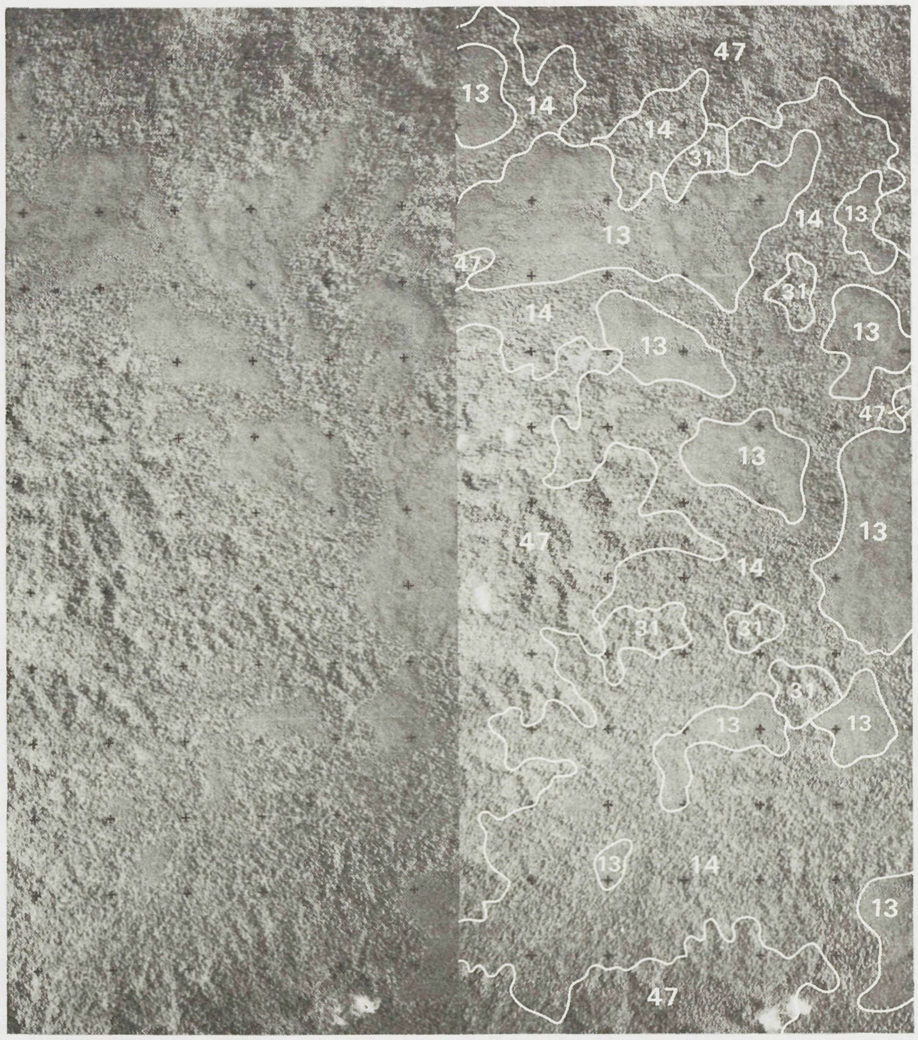
STEREOGRAM 2-14



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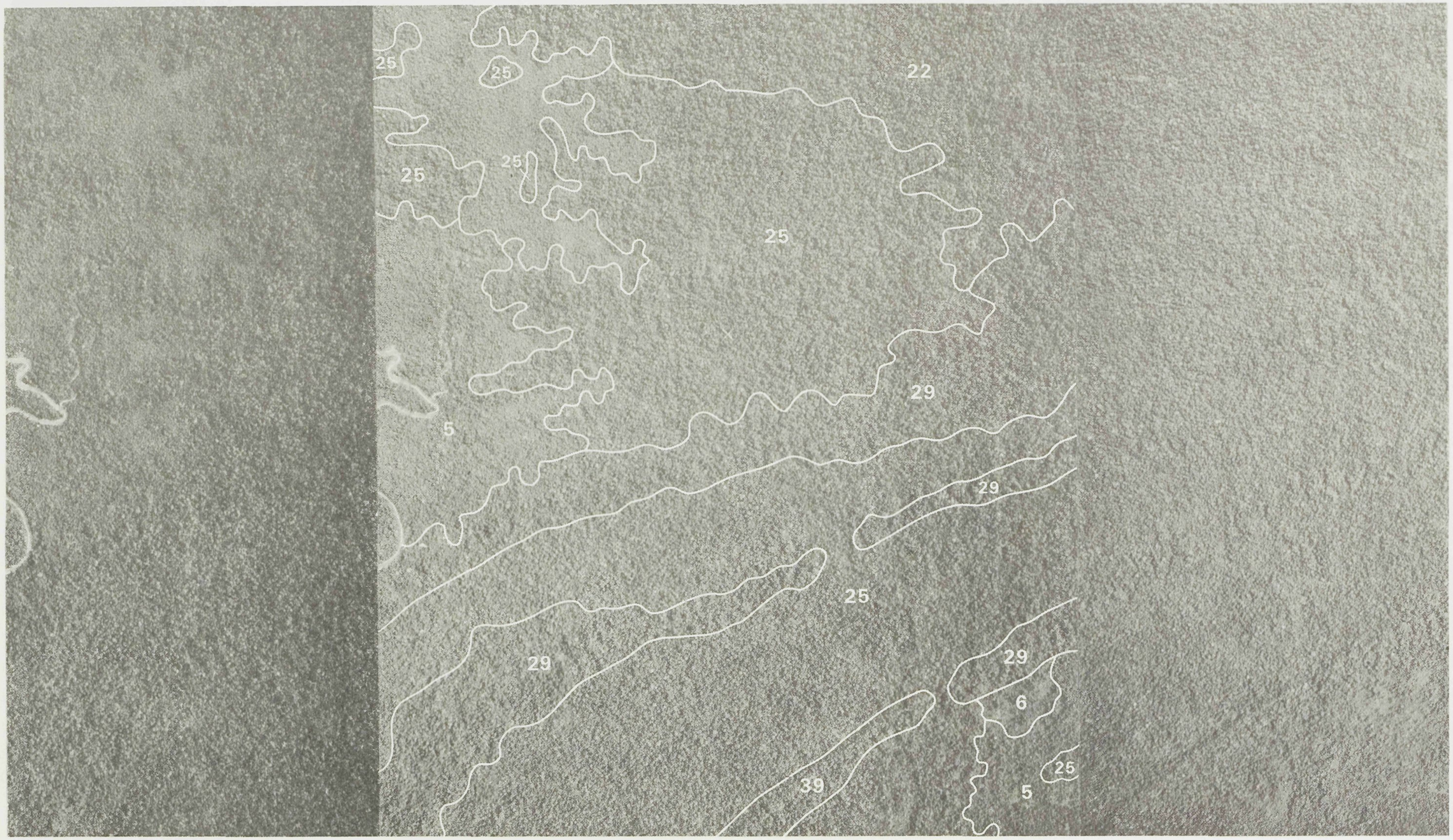

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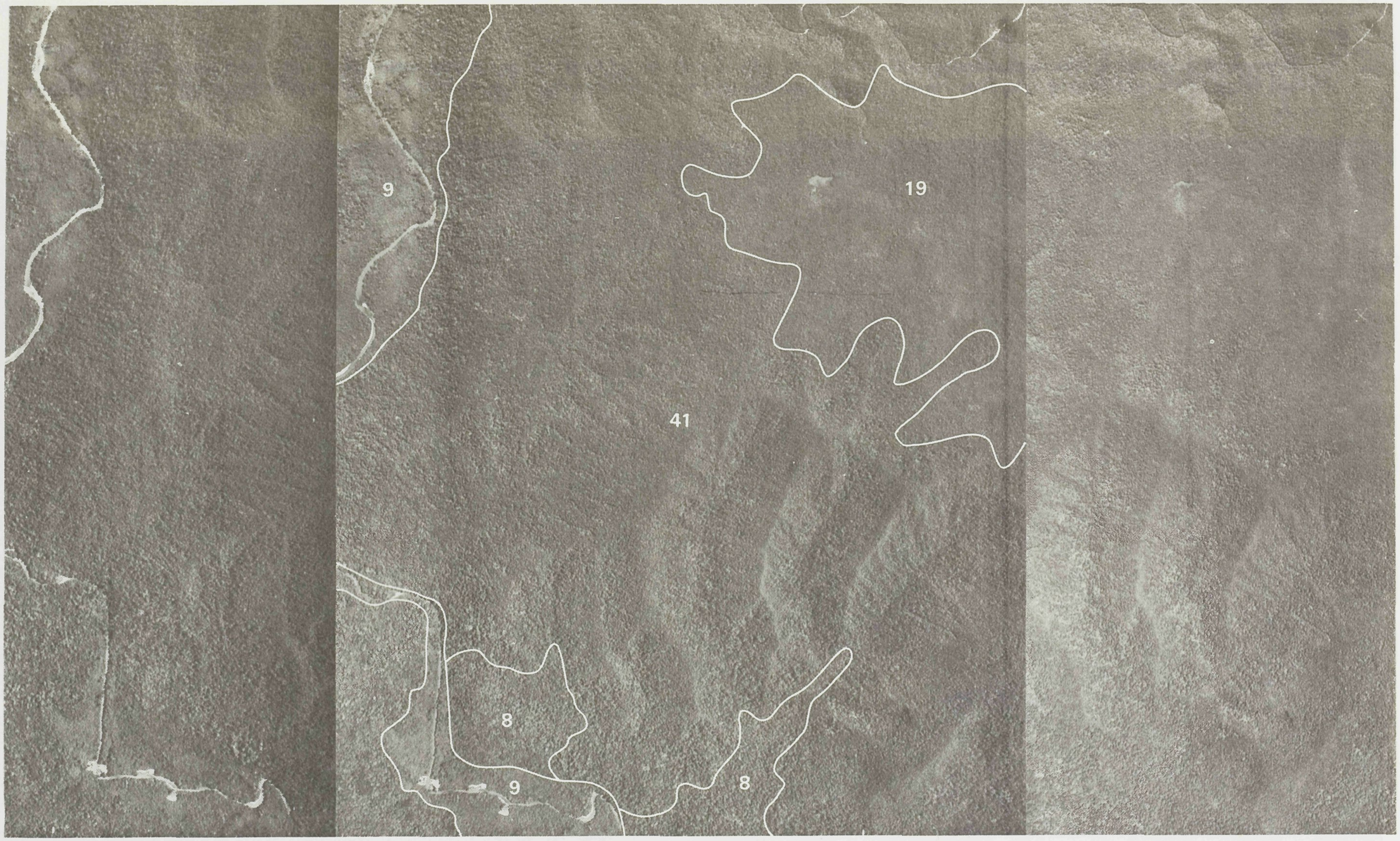

STEREOGRAM 2-17 The Karamuak valley, Tawai Range and Tawai Plateau. The Bidu Bidu Association (41) is on mountains of ultrabasic igneous rocks, the Tawai Association (19) on a plateau with ironstone capping and the Binalik Association (8) on fans of alluvium derived from the ultrabasic rocks; the Karamuak Association (9) is on the valley floor of the Karamuak (Scale 1 : 48 000)

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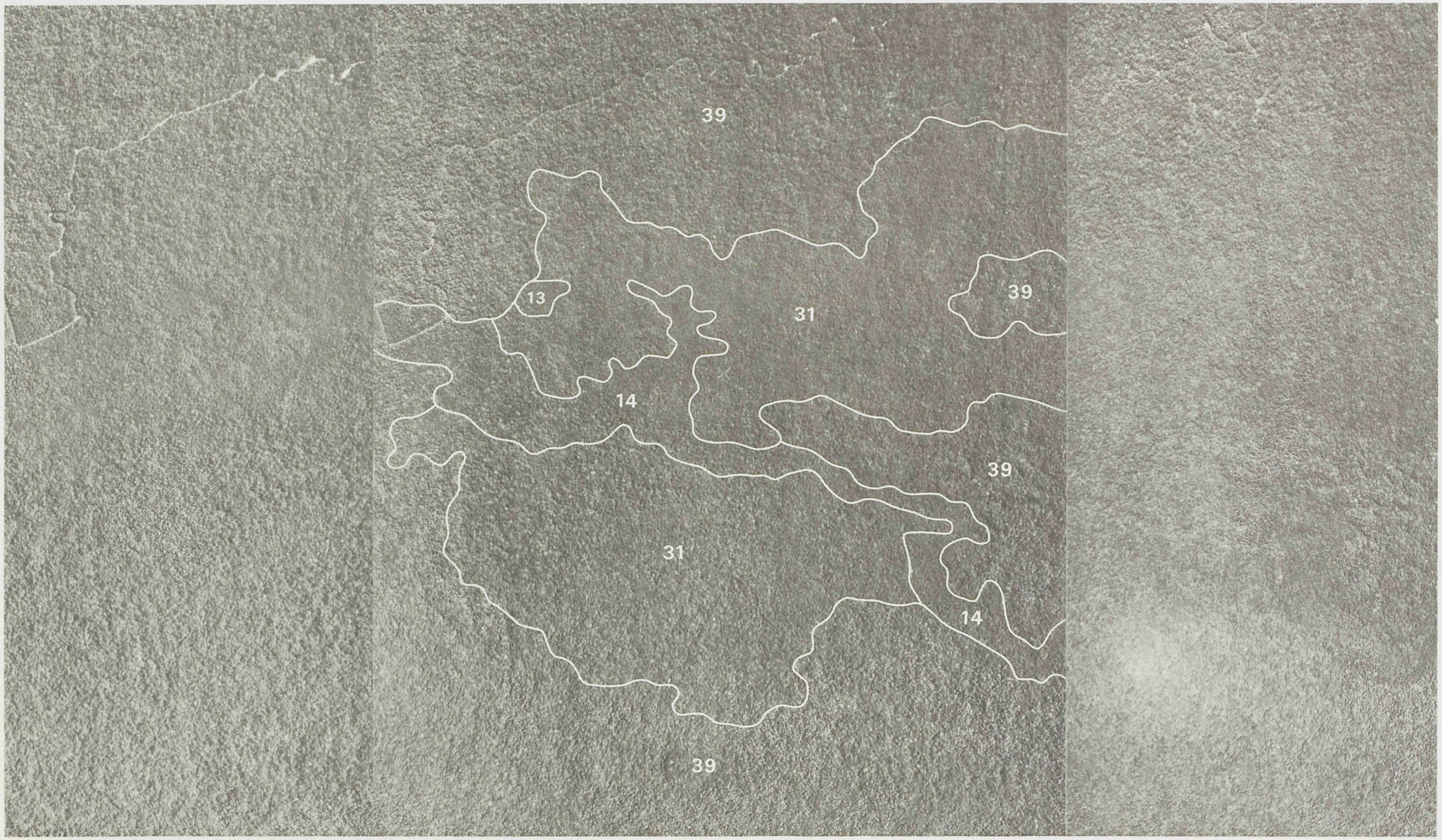

STEREOGRAM 2-18 The Sungai Lokan in the centre of the Lokan peneplain. The Sook Association (14) is on low terraces in a possible old course of the Lokan and the Kepayan Association (13) is on an isolated terrace flat. The Dalit (31) and Lokan (39) Associations are on moderate and steep sandstone hills and ridges (Scale 1 : 48 000)

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Part 2

Geographical background

LOCATION

The area surveyed covers the whole of the Sandakan and Kinabatangan Districts within the Sandakan Residency on the east coast of Sabah, East Malaysia (Text map 2-1). These districts lie between longtitudes 116°25′ and 119°15′E and latitudes 4°35′ and 6°N and cover an area of about 20 000 km^2 (8 000 mi^2). The boundaries of the districts are not always clearly defined owing to a lack of adequate maps in some parts. In general they follow watersheds, but in the west of the Sandakan District and the south-east of the Kinabatangan District they follow compass bearings. On the west of the Kinabatangan District the administrative boundary departs from the watershed, and villages such as Lanas within the Kinabatangan river catchment are administered from Keningau in the District of that name. In this area the watershed has been chosen in preference to the true administrative boundary. The location of of the survey area is shown in Text Map 2-1. Settlement and population, communications and the economy of the survey area are described briefly and then the major soil forming factors of climate, vegetation, parent materials and landforms are described in detail to provide the background to the soil associations in Parts 4, 5 and 6.

SETTLEMENT AND POPULATION

The total population of the area is about 90,000 (Chander, 1972), (Table 2-1). Sandakan, with a population of 42 249 is the main centre, situated at the entrance to Sandakan Harbour, one of the finest natural harbours in Borneo (Plates 2-1 and 2-4). It first developed as a trading station supplying guns to the Sultan of Sulu. The Chartered Company selected it as the main administrative centre for the east coast and the town was moved to its present site in 1879 (Plate 2-3). As the state capital it grew rapidly and became the main commercial centre. It is still the largest town in Sabah, but has relinquished its position as State Capital to Kota Kinabalu on the west coast.

Apart from Sandakan, settlements comprise small villages, timber camps, estates and smallholdings. About 17 500 people live along or near roads in the Sandakan peninsula. Of these the majority are smallholders, but about 5000 live on settlement schemes and agricultural estates which have been established during the last 10 years. They include the Settlement Schemes at Sungai Manila and Ulu Dusun and the Oil Palm Research Station, also at Ulu Dusun.

Coastal villages include Tambisan, Tundun Buangin, Mumiang, Bungon, Tanjong Aru, Nunuyan Laut (Plate 2-2), Libaran, Dandulit, Gum Gum and Samawang and others around Sandakan Bay. The people of these villages are basically fishermen and gardeners and number about 10 300.

TABLE 2-1. The population of the Sandakan and Kinabatangan Districts

Location				Population
Sandakan Town				42 249
Sandakan suburbs and smallholders				12 421
Sandakan Peninsula estates and populations				5 039
Man Woo Loong	109	Mile 36	352	
Sandac	128	Sungai Manila Settlement Scheme	2 662	
Sandala	247	Ulu Dusun Settlement Scheme	307	
Manjang	137	Oil Palm Research Station	355	
Coastal villages and populations				10 329
Tambisan	553	Tonglit	248	
Tundun Buangin	187	Segaliud	332	
Mumiang	317	Libaran	264	
		Nunuyan Laut	546	
Sepinong	238	Berhala	198	
Bungon	195	Lamut	577	
Tanjong Aru	503	Others	6 171	
Middle and Lower Kinabatangan: villages and populations				4 476
Abai	273	Sebangan	202	
Sukau	678	Pintasan	594	
Bilit	322	Kulu Kulu	402	
Batu Puteh	219	Kara Kara	431	
Bukit Garam	417	Kuamut	309	
Lamag	188	Others	441	
Middle and Lower Kinabatangan: timber camps				6 558
Middle and Lower Kinabatangan: estates				1 406
Upper Kinabatangan (including villages and populations in the Labau Valley administered by the Keningau District)				6 623
Nandagan	328	Mensiad	262	
Karamuak	307	Lulumiab	361	
Titimbang	326	Tanjong Kapok	202	
Lalampas	233	Inarat	300	
Tongod	304	Bunkulan	235	
Tampasak	156	Others	3 609	
Total				89 101

In the middle and lower reaches of the Kinabatangan and in the lower Segama settlements include timber camps, estates and villages. About 6 500 people, including immigrants from the Philippines and Indonesia, live on timber camps on the Kinabatangan. Where about 4 500 people are considered indigenous and are known locally as Orang Sungai, 'riverfolk'; they are in fact a mixture of the Suluk and Buludupi groups (Guillemard, 1886). They are grouped in large river bank villages with populations up to about 500 in individual villages; examples include Abai, Sukau, Bilit (Plate 2-6), Batu Puteh, Lamag, Bukit Garam, Sebangan, Pintasan, Kulu Kulu, Kuamut and Kara Kara. Lamag, with government offices, is the main administrative centre. Although these villages are well established, groups of villagers periodically move to new sites along the river banks so that the traditional pattern of shifting cultivation is maintained. Tapioca and rice are the main crops; these are supplemented by fruits such as bananas, papayas and mangoes. Fish is the main source of protein.

In the upper Kinabatangan about 6 600 people live in small villages along the Milian and its tributaries in the Labau valley and in the Mananam Plain. These are predominantly Kadazan communities but there are Muruts in the Ulu Pinangah (Woolley, 1938). The main centres are at Karamuak, Tongod, Pinangah, Lalampas,

	Population
	42 249
	12 421
	5 039
352	
2 662	
307	
355	
	10 329
248	
332	
264	
546	
198	
577	
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	4 476
202	
594	
402	
431	
309	
441	
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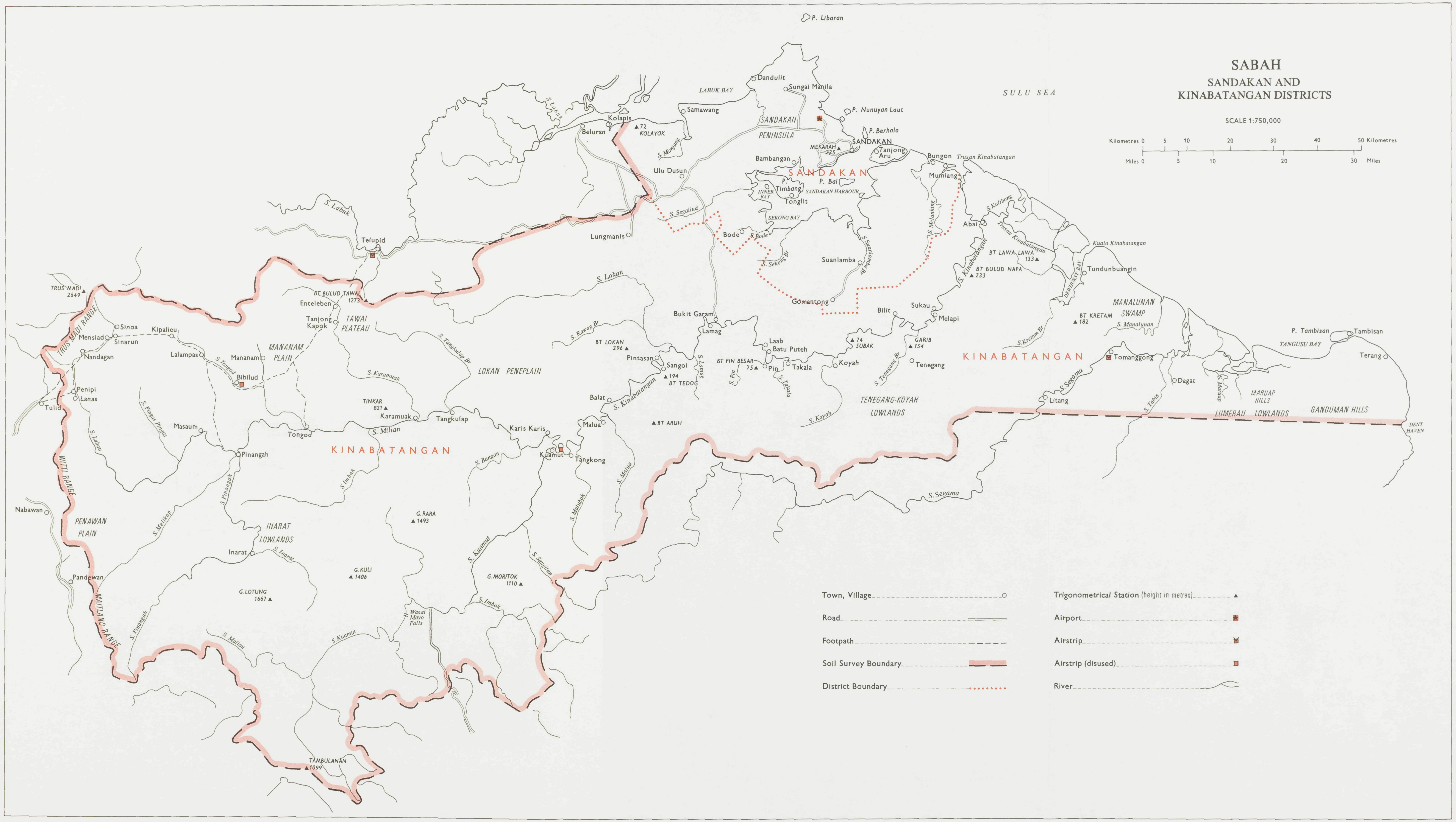
SETTLEMENT AND COMMUNICATIONS

TEXT MAP 2-1



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Menusu, Longkabong, Inarat, Lulumiab, Mensiad, Sinarun, Sinoa (Plate 2-5) and Lanas. Pinangah was a government outstation as early as 1882. Settlement is becoming increasingly more permanent, but periodically entire villages move to new sites, the most recent being moves from Bibilud to Tanjong Kapok and from Nandagan to the Sook Plain.

COMMUNICATIONS

There are regular steamship services to Sandakan from Singapore, Kota Kinabalu and Tawau and many ships sail directly between Sandakan and Japan carrying timber exports. The introduction of air services in the early 1960's revolutionised travel and changed Sandakan from an isolated settlement to one within 24 hours travel of the world's capitals. There are daily flights to and from Tawau, Lahad Datu and Kota Kinabalu, the latter with a daily link to Singapore, and weekly rural services to Tomanggong, Kudat and Telupid.

Roads have been the main means of opening up the interior to settlement and development. At present there are 80 km (50 mi) of sealed road and about 200 km (125 mi) of gravel roads giving access to estates, settlement schemes and timber camps in the Sandakan District. Motorable roads were confined to the immediate vicinity of Sandakan until the Labuk Road and its spur to Sungai Manila were constructed during the inter-war years. The Labuk Road was intended as a link to the Labuk District with its administrative centre at Beluran, but it has now been extended and forms the eastern part of the highway linking Sandakan with the west coast. Bukit Garam, on the Kinabatangan has recently been linked with the main east-west highway, but apart from this, roads in the Kinabatangan District are confined to timber camps and in general lead from logging areas to the camps on the Kinabatangan and Segama. An exception is the road leading from a logging area in the Kuamut catchment to Kalabakan west of Tawau. Access to logging areas is also provided by temporary narrow gauge railways. Communications in this District are mainly dependent on rivers. Small launches can reach Litang on the Segama and when river levels are high, Karamuak on the Kinabatangan. In general, however, small launches rarely travel above Kuamut and at low river levels cannot proceed beyond Pintasan. Travel above these places is by canoes powered by outboard motors or by paddles in the very remote stretches. Many people still travel by foot. Frequently-used main footpaths (see Text Map 2-1) include those from Sinoa along the Labau valley to Lanas and then to the Keningau road system; from Sinarun in the Labau valley to Lalampas; down the Mankawagu and Tongod valleys to Tongod and Pinangah; from Tongod northwards through the Mananam Plain to Enteleben and Telupid; from Pinangah along the Pinangah river to Inarat, and from Inarat westwards to Sapulot and Nabawan.

The areas traversed during the survey are shown in Text Map 2-2.

ECONOMY

Timber extraction, agriculture and fishing are the basis of the present day economy. Large scale timber extraction is centred on the Sandakan Peninsula, the Lower Segama, the Middle Kinabatangan, the Lokan Peneplain and the Middle Kuamut (Plate 2-7). The majority of timber is exported in log form through Sandakan and of this 65% is bound for Japan and 20% for Korea. Exports have increased by more than half and values have more than doubled since 1965, the Sandakan and Kinabatangan Districts having contributed a major share of this. (Sabah, Department of Statistics, 1971). Some logs are processed into sawn timber, plywood and veneers in Sandakan where there are also several large commercial firms concerned with the sales and servicing of heavy machinery for the timber industry.

In the mountainous interior and along the main rivers shifting agriculture is practiced and is supplemented by hunting and fishing (Plate 2-8). On the coast coconuts have long been the staple crop and copra is exported through Sandakan. In the Sandakan Peninsula smallholders produce pigs, poultry, fruit and vegetables largely for the

Sandakan market and rubber and oil palm are grown on estates. The majority of rubber estates are now neglected but the acreage of oil palm has grown rapidly in the last decade. Oil palm estates have also been established at Suan Lamba and on the Segama.

Sandakan is the centre of the prawn fishing industry in Sabah having 80% of the registered prawn trawlers. Prawns are deep-frozen and packed in Sandakan for export, the quantity and value having more than doubled since 1965. Other forms of fishing are locally important, the main market for fresh fish being at Sandakan.

Sandakan is the focus of all economic activity in the area and the chief port for export of logs, palm oil, copra, rubber and prawns. Small scale ancillary industries consist of brickmaking, bottling, printing, engineering, tailoring and jewellery manufacture. It is essentially a market town relying on the import of consumer goods and machinery and the export of primary products.

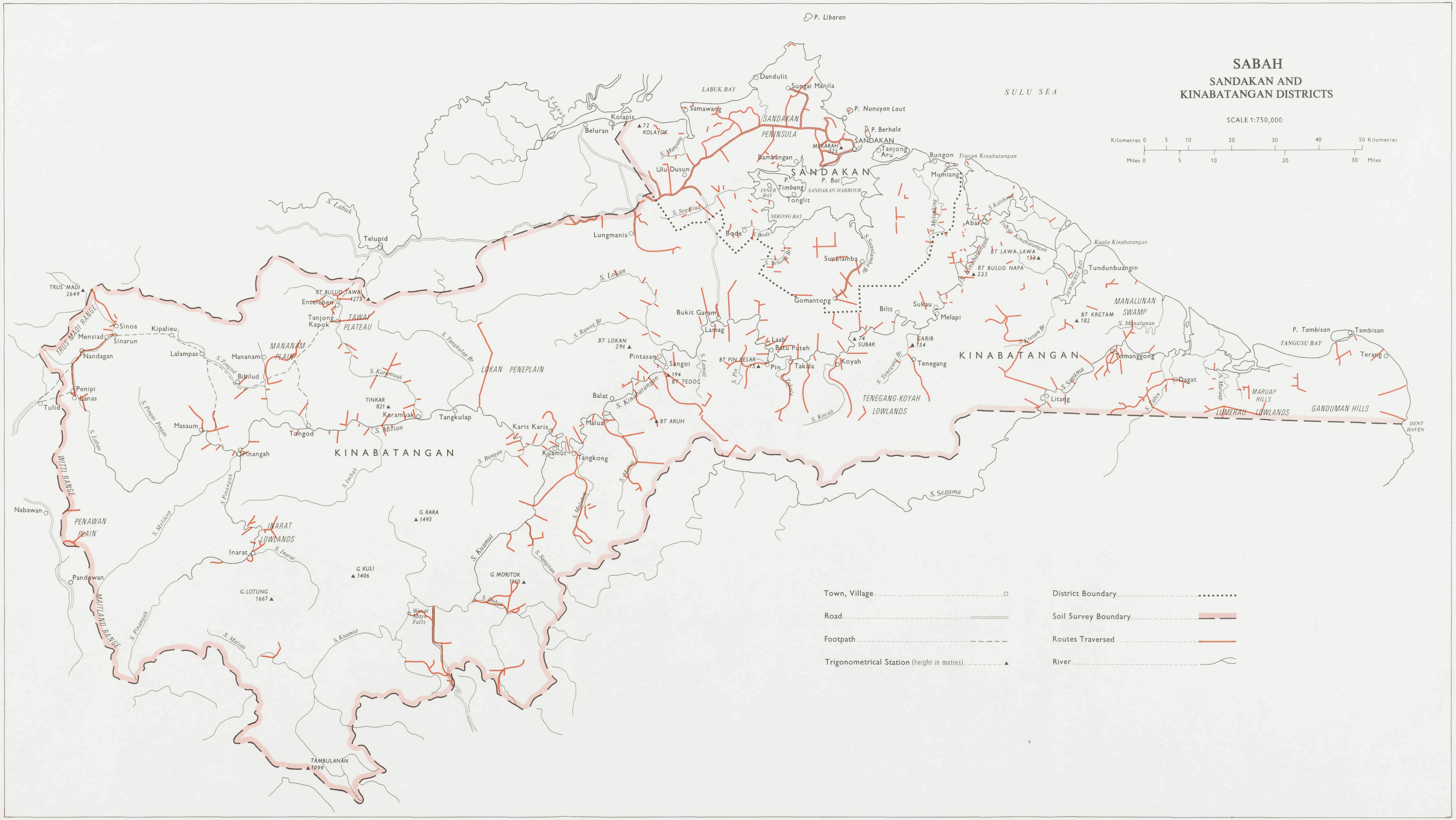
CLIMATE

Climate controls and classification

The climate of Sabah is ultimately controlled by the Inter-Tropical Convergence Zone, which is the zone of convergence between the north-east and south-east trade winds; It is a monsoonal climate with a seasonal reversal of the dominant winds and it is these winds with their associated air masses which determine the seasons. Between October and February, when the Inter-Tropical Front is furthest south, the north-east trade winds are dominant, bringing warm, moist air from their passage over the South China Sea. From May to August when the Front is furthest north, the weather is controlled by the warm moist south-east trade winds which change to south-west winds north of the equator. These trade winds are not smoothly flowing air currents, but contain weak pressure systems, bringing considerable cloudiness and often widespread rain. The salient features of the climate resulting from this air circulation are high mean annual temperatures and a high mean annual rainfall e.g. Sandakan, at sea level, 27°C (80°F); 2 976 mm (124 in). Regional differences are caused by relief and altitude, by position relative to the dominant winds and by local effects of land and sea breezes. The central mountain ranges in Sabah reach over 1 500 m (5 000 ft) and act as an effective barrier to both north-east and south-west winds giving a rain shadow on their lee and in the interior valleys. The survey area lies mostly to the east of these ranges and thereby receives the full force of the north-east winds in their season, but only the overspill from the south-west winds, which have travelled overland. Temperatures decrease with altitude and those parts of the survey area above about 1 200 m (4 000 ft) experience a different temperature regime.

Two main types of climate, namely the Tropical Rainy Climate and the Warm Temperate Rainy Climate, Highland Type (Trewartha, 1954) occur within the survey area. The Tropical Rainy Climate affects the majority of land below 1 200 m (4 000 ft); the mean temperature of its coolest month is above 18°C (64.4°F) and its driest month has a mean rainfall greater than 60 mm (2.4 in). The Warm Temperate Rainy Climate affects land above about 1 200 m (400 ft); its coolest month has a mean temperature of less than 18°C (64.4°F); it has no dry season. There are no stations at high altitudes within the survey area, but Kundasang lies just to the north at a height of 1 350 m (4 500 ft); its records are considered to be suitable for purposes of comparison.

These two very broad categories of climate do not convey the considerable daily and seasonal variation that can occur in the climatic elements. The two most significant elements are radiation and rainfall. Insolation as a result of the equatorial position, is both high and constant; it is reflected in constantly high air and soil temperatures and rates of evaporation. Rainfall is the most variable of the elements and the fluctuations in daily and monthly amounts largely determine the day-to-day weather and the seasonal patterns of climate.



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Climatic data are published monthly by the Department of Meteorological Services, Malaysia. In Sabah records have been published by the Drainage and Irrigation Department (1970), by the Department of Civil Aviation, (1961) and by McCredie (1970b). Sandakan Airport is a First Order meteorological station and has been in operation since 1953. The stations at Telupid, lying just outside the northern boundary on the Labuk River, and Kuamut are recording stations of the Drainage and Irrigation Department and have been functioning since 1964 and 1969 respectively. The Agriculture Department started recordings at Ulu Dusun Oil Palm Research Station in 1967. Rainfall data are available from these stations and also from estates, timber camps, schools and government stations; these are of variable reliability. Statistical analyses of available data have been made by Wycherly (1963) with particular reference to rubber production and Billington (1969) with regard to water supply in Sandakan.

Insolation

Measurement of insolation by direct means has only recently begun at Ulu Dusun and Sandakan. At present hours of sunshine are the only available indicators of insolation. Records are available from Sandakan (1953-71), Telupid (1969-71) and Kuamut (1969-71) (Table 2-2). In Sandakan the average hours of sunshine are 7 hr/day between March and September with peaks in May and August; December and January have only 5 hr/day with some years when an average of only 2 hr/day was recorded in January (e.g. 1962 and 1963).

TABLE 2-2 Insolation (monthly and annual mean hours of sunshine per day).

Station	Years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Sandakan	1953-71	5.0	5.6	6.9	8.1	7.6	6.8	7.0	7.0	6.6	6.3	5.7	5.0	6.5
Telupid	1969-71	4.0	4.5	6.5	7.0	7.0	6.0	6.0	6.0	6.0	5.6	5.0	4.5	5.7
Kuamut	1969-71	4.1	4.0	5.8	6.2	6.3	5.6	5.9	5.5	5.6	5.4	5.1	3.8	5.3

Air temperature

Mean monthly and annual temperatures recorded at Ulu Dusun, Telupid and Sandakan are very similar, while those for Kundasang are about 8°C (14-15°F) lower (Table 2-3). The temperature regimes at Sandakan and Kundasang are typical of the two extremes within the survey area (Table 2-4). In Sandakan the minimum mean monthly temperatures show a seasonal variation from 26°C (79°F) in January to 28°C (82°F) in May. The mean monthly range is only 2°C (4°F). The mean diurnal range is 8°C (15°F), daily variations being accentuated by storms and cloudiness; in the rainy season temperatures may fall to 19°C (66°F). There is a gradual fall of temperature with altitude so that at Kundasang at 1 350 m (4 500 ft) the mean annual temperature is 19°C (67°F). The minimum mean monthly temperatures show a seasonal variation from 18°C (64°F) in January to 20°C (68°F) in May. The mean diurnal range of 6°C (10°F) is less than at Sandakan, but the absolute range that can occur is considerably greater. Minimum temperatures of 10°C (50°F) and maximum temperatures of 32°C (89°F) have been recorded giving a range of 22°C (39°F). Corresponding values for Sandakan are 19°C (66°F) and 36°C (96°F), a range of 17°C (30°F). These indicate a more extreme climate at higher altitudes.

Humidity

Relative humidity values recorded at Sandakan and Ulu Dusun are shown in Table 2-5. At Sandakan the mean values at 0800 h and 1400 h are 91% and 70% respectively; these values are related to the daily changes in air temperature.

TABLE 2-3 Mean monthly and annual temperature (°C and °F)

Station	Years of record	Jan. °C	Jan. °F	Feb. °C	Feb. °F	Mar. °C	Mar. °F	April °C	April °F	May °C	May °F	June °C	June °F	July °C	July °F	Aug. °C	Aug. °F	Sept. °C	Sept. °F	Oct. °C	Oct. °F	Nov. °C	Nov. °F	Dec. °C	Dec. °F	Mean °C	Mean °F
Sandakan	1951-71	26	79	26	79	27	80	27	81	28	82	27	81	27	81	27	81	27	81	27	81	27	80	26	79	27	80
Telupid	1964-71	26	79	26	79	27	80	28	83	28	82	27	81	27	81	27	81	27	81	27	81	27	81	27	80	27	81
Ulu Dusun	1968-72	26	78	26	78	26	79	27	81	27	81	27	81	27	81	27	80	27	80	27	81	27	80	26	79	27	80
Kundasang	1967-71	18	64	18	64	19	66	19	67	20	68	20	68	20	68	20	68	19	67	19	66	19	67	18	65	19	67

TABLE 2-4 Mean monthly temperatures at Sandakan and Kundasang (°C and °F)

Sandakan (1951-71)	Jan. °C	Jan. °F	Feb. °C	Feb. °F	Mar. °C	Mar. °F	April °C	April °F	May °C	May °F	June °C	June °F	July °C	July °F	Aug. °C	Aug. °F	Sept. °C	Sept. °F	Oct. °C	Oct. °F	Nov. °C	Nov. °F	Dec. °C	Dec. °F	Mean °C	Mean °F
Mean maximum	29	85	29	85	31	87	32	89	32	90	32	90	32	89	32	89	32	89	32	89	31	87	30	86	31	88
Mean minimum	23	73	23	73	23	74	28	74	23	74	23	73	23	73	23	73	23	73	23	73	23	73	23	73	23	73
Absolute maximum	31	88	32	90	33	91	34	93	36	96	35	95	34	94	34	93	34	94	35	95	33	92	33	91	36	96
Absolute minimum	19	66	19	67	20	68	21	70	21	70	21	69	21	69	21	69	21	69	21	70	20	68	21	69	19	66
Mean diurnal range	7	12	7	12	7	13	8	15	9	16	9	17	9	16	9	16	9	16	9	16	8	14	7	13	8	15

Kundasang (1967-71)	Jan. °C	Jan. °F	Feb. °C	Feb. °F	Mar. °C	Mar. °F	April °C	April °F	May °C	May °F	June °C	June °F	July °C	July °F	Aug. °C	Aug. °F	Sept. °C	Sept. °F	Oct. °C	Oct. °F	Nov. °C	Nov. °F	Dec. °C	Dec. °F	Mean °C	Mean °F
Mean maximum	19	67	21	70	22	71	23	73	23	73	23	73	23	73	23	73	23	73	22	71	22	71	21	70	22	72
Mean minimum	17	62	15	59	16	61	16	60	17	62	17	63	17	63	17	62	17	62	16	61	17	62	16	61	17	62
Absolute maximum	26	79	32	89	31	88	29	85	28	82	31	87	31	87	30	86	29	85	30	86	24	76	25	77	32	89
Absolute minimum	10	50	10	50	10	50	10	50	14	58	15	59	15	59	14	58	11	51	12	54	12	54	12	53	10	50
Mean diurnal range	3	5	6	11	6	10	7	13	6	11	6	10	6	10	6	11	6	11	6	10	5	9	5	9	6	10

TABLE 2-5 **Relative humidity at 1400 h (monthly and annual means, %)**

Station	Years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Sandakan	1954-71	76	74	71	69	69	67	66	66	66	69	73	77	70
Ulu Dusun	1969-72	82	78	71	77	72	76	68	73	71	71	71	80	74

Evaporation

Measurements of evaporation from standard evaporation tanks have been made at Telupid (1964-72), Kiabau (1964-68), Sandakan (1967-72) and Ulu Dusun (1968-72) (*Tables 2-6a and b*). The results show that the mean annual evaporation averages between 150 and 175 cm (60-70 in); this is equivalent to half the mean annual rainfall. Monthly totals are highest between April and June (15-20 cm (6-8 in)) and lowest between October and March (10-13 cm (4-5 in)). The mean monthly value of 13 to 15 cm (5-6 in) represents a mean daily evaporation value of about 5.1 mm (0.2 in); this is a relatively constant figure.

TABLE 2-6a **Total evaporation (monthly and annual means, mm)**

Station	Years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Sandakan	1967-72	1 356	142	191	201	183	168	160	163	165	145	127	102	1 880
Ulu Dusun	1964-71	1 094	102	135	140	183	175	158	173	175	168	137	122	1 776
Telupid	1964-71	1 044	104	135	163	152	137	142	140	142	132	122	112	1 585

TABLE 2-6b **Total evaporation (monthly and annual means, in.)**

Station	Years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Sandakan	1967-72	5.3	5.6	7.5	7.9	7.2	6.6	6.3	6.4	6.5	5.7	5.0	4.0	74
Ulu Dusun	1964-71	4.3	4.0	5.3	5.5	7.2	6.9	6.2	6.8	6.9	6.6	5.4	4.8	69.9
Telupid	1964-71	4.1	4.1	5.3	6.4	6.0	5.4	5.6	5.5	5.6	5.2	4.8	4.4	62.4

Rainfall

Mean monthly and annual rainfall figures with standard variations for 13 stations are shown in Tables 2-7a and b and in Figure 2-1. Wycherley (1963) recognised an East Coast Rainfall Region with higher annual totals and more marked seasonal variation than an Interior Region. The higher annual rainfall and the strongest seasonal contrasts occur nearest the coast. Examples of stations near the coast include Beluran, Ulu Dusun, Sandakan, Kretam and Tomanggong, all of which have total values greater than 3 000 mm (118 in)/a. Totals decrease inland so that Litang, Lamag, Bode and Tangkulap all record values between 2 540 and 3 050 mm (100-120 in)/a. Pinangah has a total value of 2 515 mm (99 in) and Tulid, which lies immediately west of the western boundary of the survey area has a much lower figure, 2 108 mm (83 in) per annum.

The number of rain days recorded in each month shows a similar trend with the highest number coinciding with the highest monthly rainfall (Table 2-8). However, the peak at Tomanggong in June does not reflect a higher monthly total of rainfall and the low September total at Lamag does not coincide with lower monthly rainfall; more detailed records are required to explain this, but the existing records do indicate considerable varability in the intensity and duration of rainfall.

On the east coast the north-east monsoon results in a rainy season between October and March with a distinct rainfall maximum in December and January. This rainy season is not one of steady rain but rather the alternation of spells of heavy and prolonged rain, moderate and interrupted rain and sunny periods. An example of its potential severity can be seen in the January 1968 figures; at Sandakan rain fell every day from 27 December 1967 until 18 January 1968; the total for this period was 950 mm (37 in) of which 610 mm (24 in) fell between 12 and 15 January; a total of 254 mm (10 in) fell on 15 January. Such prolonged spells are usually the prelude to severe flooding. The rainy season is usually followed by a dry period in March and April, but the main monthly rainfall figures show that no station has a mean total of less than 61 mm (2.4 in) of rain; this is the value diagnostic of a dry month (Trewartha, 1954). The standard variations, however, indicate that dry months do occur at most stations. From May to October the mean monthly totals are higher with most of the rain falling as convectional showers. Early morning skies are clear but cloud builds up during the morning and is followed by heavy showers and thunderstorms in the afternoon. There are many variations on this theme, but it is rare for rain to occur in the mornings. Local rainfall variations are considerable and can often be related to effects of topography. The hills of the Sandakan Peninsula, for example, have a marked effect on the local air circulation and storms are frequently seen to avoid Sandakan while there is heavy rain inland and to the south of Sandakan Harbour.

The seasonal pattern inland is less marked. At Lamag, for example. the wet season maximum is not so pronounced and monthly totals are more constant. There is also a tendency for a second smaller peak in September. At Tangkulap the available records emphasise this peak and show November and February as the months of maximum rainfall; here the main dry period occurs in March and April, but it is less pronounced than on the coast.

In the western parts of the survey area there is not marked seasonal distribution of rainfall. At Pinangah, for example, the last 5 months of the year have the highest rainfall, but the difference between the highest and lowest monthly totals is only 102 mm (4 in). There is considerably less rainfall at Tulid where the most notable feature is a maximum in May. The standard variations indicate that totals of less than 61 mm (2.4 in) can occur at almost any time of the year.

The effect of relief and altitude on rainfall is marked in the mountainous areas, but no rainfall records are available. At altitudes of 1 800 m (6 000 ft) the almost permanent cloud cover results in very low evaporation rates and considerable condensation.

Periods without rain or with very low rainfall are obviously significant in the context of agriculture, but neither the mean monthly rainfall figures nor their standard deviations give a true picture of such periods. Most stations experience dry months with rainfall less than 60 mm (2.4 in) in some years, (Table 2-9). Sandakan, Lamag, Ulu Dusun and the Bode Estate have a dry month once in 2 years while Pinangah, Tangkulap, Beluran and Litang have dry months on average once in 3 years. The occurrence of dry months must be considered in relation to the preceding months, thus a dry March following heavy rains is unlikely to be significant if it is followed by a wet April, but if April is also dry then the dry months will be significant. On the east coast, 1969 was an unusually dry year; at Lamag the March and April totals were 68.6 mm (2.7 in) and 43.2 mm (1.7 in) respectively; at Sandakan the corresponding figures were 71.1 mm (2.8 in) and 0.25 mm (0.01 in). The affects were seen in extremely low watertables on the Kinabatangan floodplains and the unusual phenomenon of leaf shedding by some dipterocarp species (Fox, 1971).

A more accurate picture of dry periods is obtained by examination of daily rainfall records. A dry day can be defined as one on which less than 2.5 mm (0.1 in) of rain falls (this value is equivalent to the mean daily evaporation). It follows that a dry period can be defined as one or more dry days but the length of the period which is critical for plant growth varies with the plant and is also dependent on soil moisture capacity and the height of ground water. It is known, for example, that a period of 10 consecutive dry days on well drained soil can affect oil palm growth and production of palm oil at a later date (Lamb, 1972). In the Sandakan and Lamag areas, for example, there is a critical period between March and May. At Lamag September to November can also be dry and at Tulid dry months can occur at any time (Table 2-10). The longest dry periods recorded at Sandakan, Lamag and Tulid are 36, 46 and 42 days respectively.

FIGURE 2-1 Mean monthly rainfall (mm) and raindays

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FIGURE 2-1

TABLE 2-7a Mean monthly and annual rainfall and standard deviation (mm)

Station	Total years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Sandakan	70	467	262	201	119	150	191	183	221	246	267	368	470	3 126
	SD	257	183	152	79	135	76	76	97	109	86	137	178	566
Lamag	34	345	196	198	119	203	221	196	244	264	231	239	333	2 799
	SD	191	112	132	78	97	91	97	135	155	117	97	196	671
Beluran	33	513	351	269	142	188	244	229	244	262	246	252	437	3 429
	SD	323	180	158	97	79	102	135	109	99	97	104	170	709
Sandac	21	455	254	185	114	158	201	193	239	249	264	318	485	3 091
Estate	SD	307	145	122	86	86	86	97	76	119	112	140	191	574
Litang	18	386	320	198	163	236	180	196	152	201	282	257	333	2 916
	SD	300	206	91	86	74	61	84	76	56	76	89	168	615
Kretam	18	460	239	178	155	239	218	198	185	218	259	277	376	2 997
	SD	356	173	127	91	69	89	56	79	58	81	125	168	599
Tulid	17	173	145	127	158	277	213	180	170	185	155	213	163	2 111
	SD	109	107	84	97	132	224	114	107	91	61	130	117	498
Bode	16	462	269	175	99	180	221	201	224	231	244	216	292	2 812
Estate	SD	264	160	130	76	99	86	122	91	135	94	91	104	673
Pinangah	10	180	198	165	180	201	201	178	229	264	249	236	254	2 555
	SD	79	84	135	97	102	112	51	99	81	132	125	137	528
Tomanggong	8	475	307	193	117	224	208	180	180	239	290	274	404	3 188
	SD	267	231	163	79	81	61	71	81	56	91	160	203	653
Telupid	8	318	358	211	178	246	335	297	297	287	302	356	300	3 485
	SD	125	249	97	91	48	97	38	74	99	81	114	79	401
Tangkulap	8	252	447	117	140	183	170	211	185	244	262	338	226	2 548
	SD	152	282	58	89	112	97	71	89	137	125	147	74	427
Ulu Dusun	9	467	285	183	142	257	269	155	259	264	234	320	528	3 277
	SD	267	206	86	145	114	99	48	86	99	86	130	201	582

TABLE 2-7b Mean monthly and annual rainfall and standard deviation (in)

Station	Total years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Sandakan	70	18.4	10.3	7.9	4.7	5.9	7.5	7.2	8.7	9.7	10.5	14.5	18.5	123.1
	SD	10.1	7.2	6.0	3.1	5.3	3.0	3.0	3.8	4.3	3.4	5.4	7.0	22.3
Lamag	34	13.6	7.7	7.8	4.7	8.0	8.7	7.7	9.6	10.4	9.1	9.4	13.1	110.2
	SD	7.5	4.4	5.2	3.1	3.8	3.6	3.8	5.3	6.1	4.6	3.8	7.7	26.4
Beluran	33	22.2	13.8	10.6	5.6	7.4	9.6	9.0	9.6	10.3	9.7	9.9	17.2	135.0
	SD	12.9	7.1	6.2	3.8	3.1	4.0	5.3	4.3	3.9	3.8	4.1	6.7	27.9
Sandac	21	17.9	10.0	7.3	4.5	6.2	7.9	7.6	9.4	9.8	10.4	12.5	19.1	121.7
Estate	SD	12.1	5.7	4.8	3.4	3.4	3.4	3.8	3.0	4.3	4.4	5.5	7.5	22.6
Litang	18	15.2	12.6	7.8	6.4	9.3	7.1	7.7	6.0	7.9	11.1	10.1	13.1	114.8
	SD	11.8	8.1	3.6	3.4	2.9	2.4	3.3	3.0	2.2	3.0	3.5	6.6	24.2
Kretam	18	18.1	9.4	7.0	6.1	9.4	8.6	7.8	7.3	8.6	10.2	10.9	14.8	118.0
	SD	14.0	6.8	5.0	3.6	2.7	3.5	2.2	3.1	2.3	3.2	4.9	6.6	23.6
Tulid	17	6.8	5.7	5.0	6.2	10.9	8.4	7.1	6.7	7.3	6.1	8.4	6.4	83.1
	SD	4.3	4.2	3.3	3.8	5.2	8.8	4.5	4.2	3.6	2.4	5.1	4.6	19.6
Bode Estate	16	18.2	10.6	6.9	3.9	7.1	8.7	7.9	8.8	9.1	9.6	8.5	11.5	110.7
	SD	10.4	6.3	5.1	3.0	3.9	3.4	4.8	3.6	5.3	3.7	3.6	4.1	26.5
Pinangah	10	7.1	7.8	6.5	7.1	7.9	7.9	7.0	9.0	10.4	9.8	9.3	10.4	100.6
	SD	3.1	3.3	5.3	3.8	4.0	4.4	2.0	3.9	3.2	5.2	4.9	5.4	20.8
Tomanggong	8	18.7	12.1	7.6	4.6	8.8	8.2	7.1	7.1	9.4	11.4	10.8	15.9	125.5
	SD	10.5	9.1	6.4	3.1	3.2	2.4	2.8	3.2	2.2	3.6	6.3	8.0	25.7
Telupid	8	12.5	14.1	8.3	7.0	9.7	13.2	11.7	11.7	11.3	11.9	14.0	11.8	137.2
	SD	4.9	9.8	3.8	3.6	1.9	3.8	1.5	2.9	3.9	3.2	4.5	3.1	15.8
Tangkulap	8	9.9	17.6	4.6	5.5	7.2	6.7	8.3	7.3	9.6	10.3	13.3	8.9	100.3
	SD	6.0	11.1	2.3	3.5	4.4	3.8	2.8	3.5	5.4	4.9	5.8	2.9	16.8
Ulu Dusun	9	18.4	11.2	7.2	5.6	10.1	10.6	6.1	10.2	10.4	9.2	12.6	20.8	129.0
	SD	10.5	8.1	3.4	5.7	4.5	3.9	1.9	3.4	3.9	3.4	5.1	7.9	22.9

TABLE 2-8 **Number of rain days in days per month**

Station	Total years of record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Sandakan	12	22	17	14	10	14	16	14	16	16	18	20	23	200
Lamag	13	15	12	7	7	14	13	11	15	10	14	15	16	150
Tulid	10	12	8	6	8	11	7	9	9	11	9	9	10	138
Pinangah	7	18	14	11	11	16	14	12	15	15	14	16	17	174
Tomanggong	9	20	16	14	10	18	19	14	17	18	20	21	21	209
Telupid	8	22	16	15	15	21	21	20	20	19	21	22	20	231
Ulu Dusun	4	16	13	11	12	16	17	15	20	16	19	19	25	200
Litang	15	17	14	11	10	15	12	13	11	14	17	14	15	163

TABLE 2-9 **Frequency of years with dry months**

Station	Total years of record	Years with 1 or more dry months	
		Total	Proportion %
Sandakan	70	36	51
Lamag	41	21	51
Beluran	34	10	29
Sandac Estate	21	10	48
Litang	18	4	22
Kretam	18	6	33
Tulid	17	16	94
Bode Estate	16	8	50
Tomanggong	9	2	22
Telupid	8	1	13
Tangkulap	8	3	38
Ulu Dusun	7	3	43

TABLE 2-10 **The occurrence of dry periods of 10 days or more**

Station	Total years or record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sandakan	12	2	2	4	11	5	1	3	1	1	2	-	-
Lamag	13	2	3	9	6	5	2	3	1	4	5	4	2
Tulid	10	6	6	9	10	3	8	4	5	2	8	7	6

Soil temperature

Records of soil temperature taken at depths of 30 cm (12 in) and 120 cm (48 in) at Sandakan Airport (1956-71) are shown in Table 2-11. These show high mean annual temperatures of 29°C (84°F) with maximum values of 32°C (90°F) in April and May and minimum values of 26°C (79°F) in January and February at 30 cm (12 in). The annual range at 30 cm (12 in) is 3°C (6°F). At a depth of 120 cm (48 in) the mean annual temperature is one degree higher and the range is one degree lower. These temperatures are consistently higher than air temperatures, but show very little daily or seasonal variation. In terms of soil temperature regimes used in soil classification, the majority of the survey area has an isohyperthermic regime i.e. the mean annual soil temperature is more than 22°C (71.6°F) and the difference between mean 'summer' and mean 'winter' soil temperatures is less than 5°C (41°F). Land above about 1 200 m (4 000 ft) however has an isothermic regime; here the difference between mean 'summer' and mean 'winter' temperatures is still less than 5°C (41°F) but the mean annual soil temperature is between 15° and 22°C (59-71.6°F) (United States Department of Agriculture, 1967a).

Soil moisture

Effective rainfall for soil formation is that part of rainfall which remains after losses by interception, evapotranspiration and run off. A number of attempts have been made to estimate this amount, but they have all been based on measurements of rainfall and evaporation which neglect the role of run off. Mohr and van Baren (1959) carried out water balance studies involving rainfall, runoff, percolation and evaporation in Indonesia. Using the parameter for dry months of 60 mm (2.4 in) they calculated that during these months runoff and percolation approach zero and all rainfall is evaporated. They recognised a wet month as one with more than 100 mm (4.2 in) rainfall in which some surplus rainfall would almost certainly enter the soil. Using this approximation it can be said that in the survey area 10 out of 12 months in the year are wet months, in which water will move through the soil; in terms of soil moisture regimes for soil classification purposes the survey area has an udic moisture regime; this is defined as a regime in which in most years the moisture control section is not dry in any part for as long as 90 days; it is common to the soils of humid climates with well distributed rainfall (United States Department of Agriculture, 1967b).

TABLE 2-11 Soil temperatures at Sandakan (monthly and annual means °C and °F)

Depth cm (in)	Years of record	Jan. °C	Jan. °F	Feb. °C	Feb. °F	Mar. °C	Mar. °F	April °C	April °F	May °C	May °F	June °C	June °F	July °C	July °F	Aug. °C	Aug. °F	Sept. °C	Sept. °F	Oct. °C	Oct. °F	Nov. °C	Nov. °F	Dec. °C	Dec. °F	Mean °C	Mean °F
30 (12)	1956-71	27	81	27	81	29	84	30	86	30	86	30	85	29	84	29	84	29	84	29	84	28	83	28	82	29	84
120 (48)	1956-71	28	83	28	83	29	85	31	87	31	87	31	87	30	86	30	86	30	86	30	86	29	85	29	84	29	85

VEGETATION

Twelve broad forest types are recognised in the survey area (Text Map 2-3); they are based on previous work in Sabah (Wood and Meijer, 1964) supplemented by information from sample plots made during this survey. In particular cases forest types are good indicators of soil conditions and these, with their characteristic appearance on aerial photos, are referred to.

Lowland and Hill Dipterocarp Forest

Lowland and Hill Dipterocarp Forests, which occur throughout the Sandakan and Kinabatangan Districts from sea level up to about 900 m (3 000 ft), are composed of many species of trees as well as shrubs, herbs and woody climbers. The upper discontinuous storey is usually about 30-45 m (100-150 ft) high although trees up to 60 m (200 ft) are present. The main storey at about 20-30 m (70-100 ft) from the ground consists of young trees of the upper storey species together with members of other families such as Burseraceae, Clusiaceae, Myrtaceae (*Eugenia* sp.) and Sapotaceae. The under-storey consists of saplings of the two upper storeys together with shrub species of such families as Anonaceae, Euphorbiaceae, Flacourtiaceae and Rubiaceae.

The herb layer consists mainly of seedlings of the other layers and lianes, with some aroids and ferns. As the name inplies the forests are dominated by the family *Dipterocarpaceae* of which 10 genera comprising about 150 species are known to occur in Sabah. Of these the genera *Shorea, Parashorea, Hopea, Dipterocarpus, Dryobalanops, Anisoptera* and *Vatica* are well represented in the survey area. Their distribution is related in part to altitude and in part to soil as determined by landform and drainage, but only broad generalisations concerning distribution can be made.

Shorea is the largest genus and comprises *Anthoshorea* (*melapi*), *Richetia* (yellow seraya), *Rubroshorea* (red seraya) and *Shorea* (*selangan batu*). *Anthoshorea* spp. are fairly scattered in forest in rather flat or undulating land with *Shorea ochracea* and *S. lamellata* more common on inland hills and ridges. *richetia* spp. extend from the lowlands into the hill forests but are absent in swamp forests. Red serayas (*Rubroshorea* spp) are the most common large timber trees from the lowlands up to about 600-900 m (2 000-3 000 ft) with common species including *S. leprosula, S. argentifolia, S. leptoclados, S. pauciflora* and *S. parvifolia.* From 900-1 200 m (3 000-4 000 ft) *S. venulosa* is fairly common. On hills and ridges on the east coast the most common red serayas are species like *S. smithiana, S. alman* and *S. beccariana* with *S. macrophylla* and *S. mecistopteryx* along river banks. The distribution of Selangan batu (*Shorea* subgenus *Shorea*) is still imperfectly known but the most common species in flat and slightly undulating lowland forest is *Shorea superba,* while definite hill species are *S. laevis, S. maxwelliana, S. atrinervosa* and *S. hypoleuca. Parashorea* is a small genus with only 4 species in Sabah known collectively as urat mata or white seraya. Of these only 2 occur in the survey area. Observations suggest that forests with good stands are at the same time often rich in *kapur* (*Dryobalanops lanceolata*) and keruing puteh (*Dipterocarpus caudiferus*). About 40 species of the genus *Hopea* are known in Borneo; they occur over a wide altitudinal range. *Hopea nervosa* seems to be peculiar to forests on wet flat land on the east coast. *Hopea* spp. also occur in heath forest. *Dipterocarpus* (*keruing*) is the second largest genus of the Dipterocarpaceae with about 50 species known in Borneo. They occur from the lowlands to about 900 m (3 000 ft). Ecological preferences differ widely. A species like *Dipterocarpus grandiflorus* is often typical of hills not far from the coast; *D. warburgii* prefers seasonal swamp forests; *D. caudiferus* flat or slightly undulating country; *D. exalatus* low wet soils; *D. acutangulus* steep ridges and *D lowii* is fairly characteristic of poor heath and ultrabasic soil. *Dryobalanops* (*kapur*) is a rather small genus of which 5 species are known in Sabah. Rich stands of *D. lanceolata* occur on the east coast and there is fine sample of a natural *kapur* swamp forest of *D. beccarii* on an old beach on the Sungai Kapur. Only 4 species of the genus *Anisoptera* are at present known in Sabah, of which only *A. costata* is fairly common though of rather scattered occurrence. The trees of the genus *Vatica* are generally smaller in size, but little is known of their distribution.

Detailed studies of two contrasting types of dipterocarp forest were made at Sepilok, west of Sandakan (Fox, 1972), one on low undulating mudstone hills and the other on sandstone ridges. On the former *Parashorea tomentella* and *Shorea leptoclados* are the most typical species in a forest with an upper canopy at about 36-45 m (120-150 ft). *Eusideroxylon zwageri* is present in the middle storey at about 20-33 m (70-110 ft) from the ground. Other prominent genera are *Diospyros* sp., *Hydnocarpus* and *Chisocheton.* Smaller trees of the upper emergent canopy e.g. *Shorea* sp., *Dipterocarpus* sp., and *Dryobalanops lanceolata* occur in the middle and lower layers. Trees characteristic of the lower canopy are small species of Anonaceae e.g. *Meiogyne virgata* and *Polyalthia* spp, of Euphorbiaceae e.g. *Mallotus* spp. and *Aglaia* spp. *Eugenia* spp. and *Diospyros* spp. Seedlings of the more common dipterocarps are generally abundant on the forest floor and lianes are frequent. This forest is described as *Parashorea tomentella/Eusideroxylon zwageri* Lowland Dipterocarp Forest. On sandstone ridges *Shorea multiflora, S. beccariana* and *Dipterocarpus acutangulus* are the abundant species while *Parashorea tomentella, Shorea leptoclados* and *Eusideroxylon zwageri* are absent. In this forest the main upper layer is at 30-40 m (100-130 ft) with emergents such as *D. acutangulus* above this height. A similar forest to this was described on a steep-sided sandstone ridge at Batu Puteh. This contained 250 trees per acre of which 140 were over 60 cm (24 in) in girth. *Shorea multiflora* was the most abundant species with 10 trees in a one acre plot up to 45 m (150 ft) in height and 168 cm (67 in) in girth and with abundant seedling regeneration. *Dipterocarpus acutangulus* was the second most common species. Such forests are described as *Dipterocarpus/Richetia* Hill Dipterocarp Forests.

Similar contrasts between forest types on soils developed from shales and from sandstones were found in Brunei (Ashton, 1964). It is possible to detect differences of this kind on aerial photos but the boundaries are often too diffuse for homogeneous areas to be delineated with any consistency.

Heath Forest

Heath Forests have at least two-canopied communities of scrub and low forest with an undergrowth in which pitcher plants are common. Such forests occur notably on low terraces and dipslopes of sandstone hills where Podzols are dominant and are locally referred to as Kerangas (Plate 2-22). On an extensive terrace in the Penawan Plain a Heath Forest in which *Dacrydium elatum* was dominant contained, in addition, the following species: *Palma* sp., *Callophyllum blanco, Garcinia parvifolia, Ternstroemia magnifica, Neoscortechinia* sp., *Tristania bilocularis, Decaspermum vitis-idaea, Alseodaphne* sp, and *Lasianthus borneenis. Tristania* was also codominant with *Dryobalanops beccarii* on a terrace south of the Sungai Maruap, there being 6 *Tristania* and 11 *D. beccarii* over 150 cm (60 in) in girth on an acre. Few other species were present. Similar forests occur on remnant terraces in the Lokan peneplain. The forest on the dip slopes of sandstone cuestas in Sepilok Forest Reserve contains examples of almost pure *Tristania clementis* of low height and small girth with scattered *Baeckia*, pitcher plants (*Nepenthes)* and bryophytes. Slightly taller forest contains such species as *Shorea multiflora* and *Ixonanthes reticulata* reaching 185 cm (72 in) in girth and *Eugenia* sp. are also common. Near Sandakan the natural heaths have in part been replaced by a secondary forest fire climax with many small scattered trees, and dominant fern (*Gleichenia*).

Kerangas is easily differentiated on air photographs; it has sharp boundaries, a low dense canopy and a light grey tone (Stereogram 2-5).

Heath Forest also occurs on boulder covered flats and in swamps on the Tawai Plateau (Stereogram 2-17); on the boulder covered flats the low mossy forest was dominated by *Gymnostoma sumatrana* and *Tristania grandifolia* with the dipterocarps, *Hopea pentanervia* and *Shorea venulosa* also present; in the swamps the wet Heath Forest contained in addition several species of conifer including *Podocarpus* spp.; *Pandanus* sp., were also present.

Dipterocarp and Heath Forest

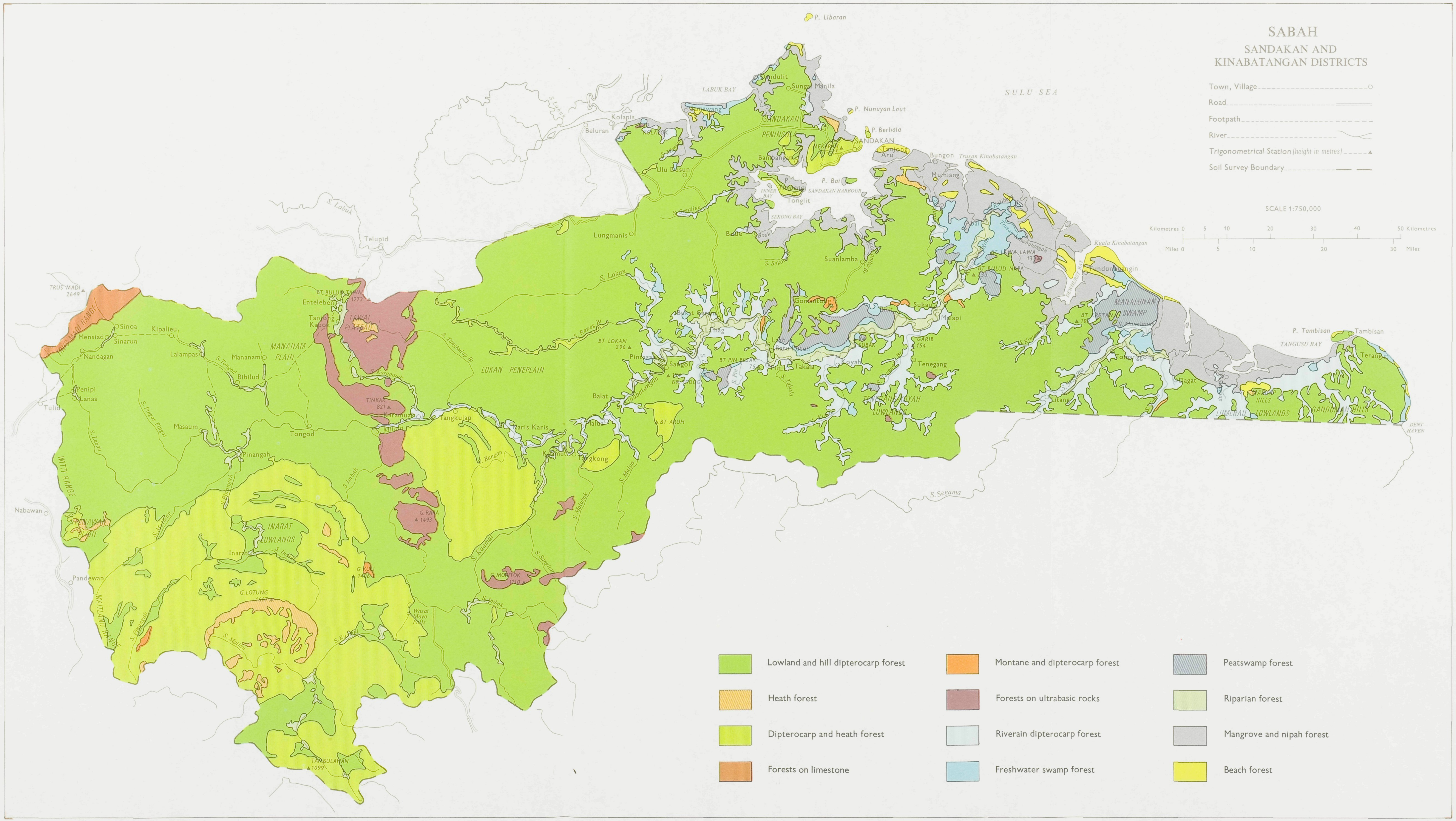
Dipterocarp and Heath Forests occur in close proximity on many terraces and sandstone hills. The species contained are combinations of those outlined above.

Montane Forest

Lower Montane and Montane Forests occur on the Trusmadi Range. On the lower slopes of the mountains dipterocarp forests gradually give way with increasing altitude to Lower Montane Forest between 750 and 1 950 m (2 500-6 500 ft). This forest is dominated by Fagaceae and Lauraceae species and has a canopy about 9 m (30 ft) high at 1 950 m. In collections made at 1 500 m (5 000 ft) Podocarpaceae, Theaceae, Lycopodiaceae, Burmanniaceae, Myrsinaceae, Guttiferae and Myrtaceae were also present. Above about 1 950 m (6 500 ft) the Montane Forest ('Moss' Forest) consists of low trees and shrubs covered with leafy hepatics and mosses. The summit as well as many of the ridges and secondary peaks are xeric in nature with vegetation similar to heath vegetation and dominated by small leathery-leafed shrubs (Ericaceae and Theaceae), southern conifers (Podocarpaceae) and 'tree' ferns.

Forests on Limestone

The forest cover on limestone is very variable and includes both Lowland Dipterocarp Forest and forests of smaller trees rich in Lauraceae. In addition communities of short plants occur on exposed vertical faces. At Batu Puteh *Cynometra elmeri* and *Eusideroxylon zwageri* were both common in the Dipterocarp Forest. The largest tree



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recorded was *Dryobalanops lanceolata,* 48 m (160 ft) in height and there was also abundant seedling regeneration of this species. In two plots at Gomantong the forest comprised predominantly small trees; *Shorea guiso (selangan batu)* and Lauraceae (medang) were dominant. *Rubroshorea* spp. (red seraya). *Palaquium rostratum* (nyatoh), *Eugenia* spp. (obah), *Pterospermum* (Sterculiaceae), Anonaceae and *Aglaia denticulatum* (Meliaceae) were also common.

Forests on Ultrabasic Rocks

Mountain ranges derived from ultrabasic rocks are clothed with low, dense, xerophytic forest in which most of the larger trees do not exceed 120 cm (48 in) in girth or 12 m (40 ft) in height. The forest is notable for the dense understorey of rotan, thin climbing bamboo, (*Racemobambos*), *Mapania,* stemless spiny palm and for the presence of orchids and pitcher plants. Dipterocarps present include *Dipterocarpus lowii, Shorea laxa, S. andulensis, S. atrinervosa, S. venulosa* and *S. geniculatus.* These occur in association with *Tristania grandifolia, Gymnostoma sumatrana, Podocarpus* spp. and *Eugenia* spp. On the lower slopes of the mountains the trees are somewhat higher with additional dipterocarps including *Shorea scabrida* and *S. multiflora* and with *Gymnosperma sumatrana* and *Eugenia* spp. on exposed rocky ridges. *Fagaceae* spp. up to 18 m (60 ft) in height also occur.

Riverain Dipterocarp Forest

Riverain Dipterocarp Forests occur widely on the floodplains of the Segama, Kinabatangan and their tributaries and are comprised of mixed dipterocarp species tolerant of high water tables and periodic flooding and species which occur in freshwater swamp forest described below. The forest is in general poorly developed with canopy heights of less than 30-36 m (100-120 ft). Examples described during the survey included a rather poor dipterocarp forest with *Shorea leprosula* and *Dipterocarpus applanatus* in the upper canopy and an abundance of *Eugenia* sp., *Diospyros* sp., and *Anonaceae* in the understorey; a rather open *Alstonia* swamp forest with other species including *Parkia* spp. and *Glochidon* spp; a forest with trees typical of disturbed or old secondary forest including *Pterospermum diversifolium, Vitex pubescens* and *Dillenia excelsa,* the only dipterocarp being *Dipterocarpus warburgii;* and a swamp forest with canopy height at 18-24 m (60-80 ft) of almost pure *Mallotus muticus* which also contained the dipterocarp *Vatica subcordata.*

Freshwater Swamp Forest

Freshwater Swamp Forests occur extensively on the lower Segama and Kinabatangan flood plains and sporadically in ill-drained minor valleys. Swamp forest consists of low trees often with stilt roots and pneumatophores and a dense undergrowth of small bushes, grasses and sedges of which *Mapania* is widespread. An example of such a swamp forest near the Sungai Koyah had an irregular canopy with the larger trees such as *Vitex pubescens, Dialium* sp., and *Kibessia galeata* reaching 36 m (120 ft), an intermediate upper canopy at 18-30m (60-100 ft) with smaller trees including *Glochidion hypoleucum* and *Dillenia* sp. in the understorey. In places trees are completely lacking and the vegetation consists largely of sedges and grasses.

Peatswamp Forest

Peatswamp Forests are extensive in the lower Segama and Kinabatangan. They contain small trees many of which are fungus covered and in varying stages of decay, with a ground vegetation of sedges, *Mapania* sp. (Plate 2-16); *Nepenthes* species are also common. Four plots were sampled during the survey. At Subak a swamp forest with *Mapania* was described in which the most abundant species group was *Eugenia.* Other species included *Ilex cymosa, Buchanania arborescens, Ficus sundaica, Nothaphoebe kingiana* and *Diospyros elliptifolia.* The general canopy level was 18-21 m (60-70 ft) with a few trees reaching 30 m (100 ft). Nearer the edge of the swamp a more open swamp forest with *Mapania* was described with canopy height at 15 m (50 ft) and

Eugenia again dominant. Other species included *Baccaurea puberula, Lophopetalum multinervium, Alstonia angustiloba, Pouteria malaccensis* and *Calophyllum globuliferum.* In swamp forest with *Mapania* at Bilit, *Santiria oblongifolia* and *Eugenia sarawakensis* were the most common species in a forest with a canopy height of about 18 m (60 ft). North of the confluence of the Koyah with the Kinabatangan the swamp forest was open with small trees reaching 12 m (40 ft). *Glochidion* sp. were abundant with some *Nauclea subdita.*

Peatswamp Forest has a dark even tone on aerial photos and this contrasts with adjacent Swamp and Riverain Dipterocarp Forests (Stereogram 2-2). In some areas, however, the pattern is weak and is less easily distinguished.

Riparian Forest

Riparian Forests occur along many of the upper tributaries of the Kinabatangan and Segama and also on their meander belts. Much of the land has been used by shifting cultivators and as a result the forest is often of a secondary nature and several types occur. At Tanjong Kapok on the Karamuak the secondary vegetation included *Pterospermum* sp., and *Vitex* sp., with occasional large *Intsia palembanica, Dipterocarpus oblongifolia* overhanging the river and Durian, *Octomeles sumatrana* in old clearings. In a sample plot on the Segama *Parkia javanica* and *Pterospermum* sp., were common with many small Anonaceae and climbers and on the Kinabatangan at Subak a vigorous riverside stand of *Octomeles/Anthocephalus* regenerating forest with abundant grass and ferns was described (Plate 2-17). Riparian Forests on levees are invariably taller than forests on adjacent floodplains and are clearly detectable on aerial photographs.

Mangrove and Nipah Forest

Mangrove forests occur in tidal swamps and also along the banks of deep tidal channels. The broad term mangrove covers a range of species whose distribution is closely related to landform. *Rhizophora mucronata, Bruguiera parviflora* and *Excocaria agallocha* (Buta Buta) occur on the tidal flats. Somewhat drier sites on low crab mounds support *Ceriops tagal* (Tengar), *Xylocarpus granatum* and *Avicennia alba* (Api Api) with *Acrostichum aureum* (Piah fern) on the summits of the mounds (Plate 2-12). On platforms above normal tidal levels piah fern often forms a dense ground cover with *Ceriops tagal* near channels.

Nipah palm *Nypa fruticans* is dominant in extensive areas of tidal swamps notably in thethe Kinabatangan delta and Segama estuary. In general it occurs inland from mangrove swamps and extends inland as narrow fringes along rivers, but it can also occur close to the sea suggesting that is is tolerant of a wider salinity range than mangrove. On photographs it can easily be distinguished from mangrove forests by its dense even tone but because the 2 types often occur in intimate association and because soil conditions are similar they are not separated (Stereogram 2-1).

Beach Forest

Many of the beaches west of Mumiang have been planted with coconuts but along the coast from Mumiang as far as the Segama estuary *Casuarina equisitifolia* is dominant. On old beaches inland from the present day coastline Beach Forest of low, often dense thickets with nibong palm (*Onchosperma* sp) are found. At Sungai Kapis a low thicket secondary forest with *Pternandra* sp., and *Glochidion* sp. had a canopy at about 15 m (50 ft). The largest tree in this forest was a strangling fig of 12.6 m (42 ft) girth.

PARENT MATERIALS OF THE SOILS

Reconnaissance geological surveys have been carried out over the whole of the Sandakan and Kinabatangan Districts (Fitch, 1955 and 1959, Haile and Wong, 1965, Collenette, 1965b and Lee, 1970). For the purposes of this survey 12 broad groups of parent materials are recognised (Text Map 2-4).

Undifferentiated alluvium

Undifferentiated alluvium includes both terrace and recent alluvium. Terrace alluvium occurs sporadically from the Dent Peninsula to the western boundary of the survey area at heights ranging from less than 6 m (20 ft) near the coast to over 450 m (1 500 ft) on some interior terraces. It is believed to be largely derived from sedimentary rocks except in the upper Karamuak valley where it is in part derived from igneous rocks. The alluvium is mainly medium, rarely fine, in texture and also contains pebbles, which are mainly of quartz and sandstone, but are also formed from chert and igneous rocks; coarse-textured alluvium occurs on some terraces, where it usually overlies medium-or fine-textured alluvium. Terrace alluvium is strongly weathered and is considered to be of Quaternary age (Lee, 1970). Similar deposits have been recognised in West Malaysia and Singapore and are referred to as Older Alluvium (Burton 1964).

Recent alluvium, derived largely from sedimentary rocks, is widespread on floodplains and in freshwater swamps. It is mostly fine-textured and contains high reserves of magnesium. Adjacent to sandstone hills, on levees and in the upper reaches of valleys, the alluvium is medium-or coarse-textured and has low nutrient reserves. On beaches it is coarse-textured and contains more than 90% of silica minerals, mainly as quartz.

Alluvium derived from basic and ultrabasic igneous rocks

These alluvial deposits occur in the Karamuak, Tongod and Mananam valleys and range from those almost wholly derived from ultrabasic igneous rocks to complete mixtures of sedimentary, basic and ultrabasic igneous rocks. The former are deposited in outwash fans and terraces adjacent to outcrops of ultrabasic igneous rocks; they are very low in exchangeable cations, but are high in iron oxides and may have appreciable contents of nickel, copper and chromium. Textures are usually medium to fine and iron concretions occur, notably where groundwater is near the surface. The latter are characterised by medium to fine textures, high base saturation and usually high values of exchangeable magnesium.

Calcareous alluvium

Calcareous alluvium includes both coarse-textured coralline sand and medium-to fine-textured alluvium. Coralline sands have more than 40% carbonates as Ca Co^3 equivalent; they consist of loosely compacted, porous rubble and coarse sand derived from shells and coral. Medium-to fine-textured calcareous alluvium lies over coral along the Dent Coast.

Sulphidic alluvium

Sulphidic alluvium has 0.75% (dry weight) or more sulphur mostly in the form of sulphides and has less than three times as much carbonate (as Ca Co^3 equivalent) as sulphur (USDA, 1973). The bulk of the sulphide is iron sulphide or pyrites which accumulates under reducing conditions in the presence of large amounts of organic material. The most favourable conditions for this accumulation are in areas which are regularly inundated by saline tidal water (Pons, 1970; van Beers, 1962). Sulphidic alluvium is extensive around the coast notably in the Segama and Kinabatangan deltas and around Sandakan Harbour.

Peat

Peat occurs in swamps in the lower Kinabatangan and Segama and is particularly extensive north of the Kinabatangan downstream from Batu Puteh and in the Manalunan swamp. The peat is derived from swamp forest remains and is composed of wood and sedges in varying stages of decomposition; it is at least 6 m (20 ft) deep in places. It also occurs at high altitudes in the Trusmadi Range where it is associated with moss forest.

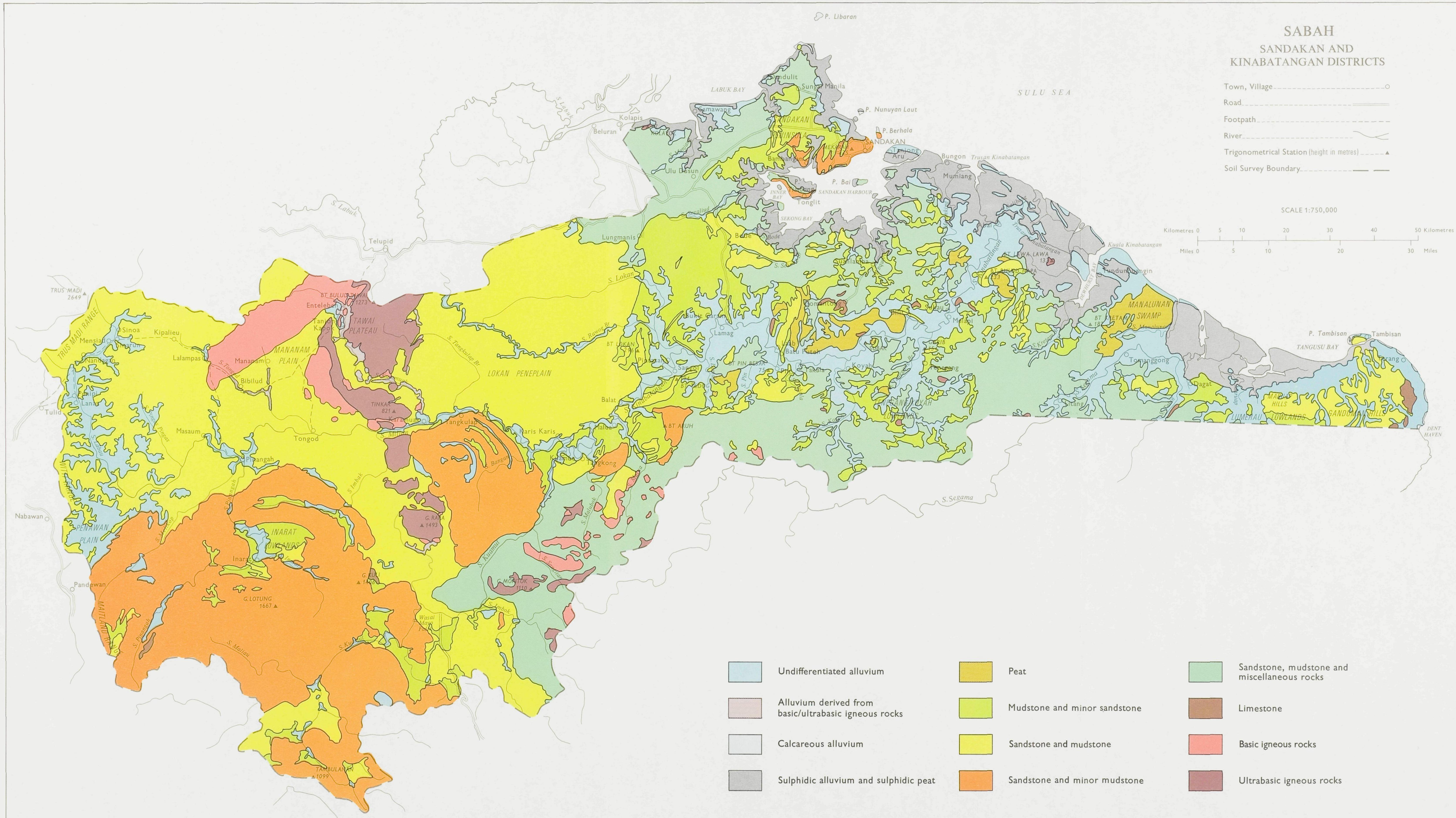
Mudstone/Sandstone

Text Map 2-4 shows three subdivisions of this group: Mudstone and minor sandstone; Sandstone and mudstone; Sandstone and minor mudstone. For soil classification purposes as explained below, the above three broad groups are recognised as parent materials. From a geological point of view, the situation is more complex. Sandstone, mudstone and shale are the major constituents of 11 sedimentary formations although the proportions of rocks differ locally within and between each formation. Three groups of formations have been recognised according to age and each group has broad structural and lithogical similarities.

The Rajang Group includes the Sapulut, Trusmadi, Crocker and Kulapis Formations and is found in the western part of the survey area. The formations range from Late Cretaceous to Mid-Tertiary and all are strongly folded. The Sapulot Formation contains predominantly argillaceous strata of mudstone with greywacke, light buff quartzitic sandstone and purple sandstone. It extends from the Labau valley in the west and curves eastwards around the north end of the Maliau Basin to the Sungai Sinoa. The Trusmadi Formation consists mainly of dark bluish-grey mudstone, shale and argillite, mildly metamorphosed in places to slate, with subordinate beds of quartzite, sandstone, siltstone and limestone breccia. Quartz veining is characteristic of the formation. It is bounded on the east and west by faults, and is confined to the Trusmadi Range. The Crocker Formation comprises greywackes, siltstone and grey, green and black mudstone and shale; it is restricted to the Crocker Range. The Kulapis Formation consists of red, purple and grey sandstone interbedded with red, buff, green and grey mudstone and less commonly with red chert (Plate 2-9). It is extensive in the Mananam Plain, the Karamuak valley and in the Lokan Peneplain where it extends from the Tawai Range east to the Sungai Lokan and from the Sungai Milian north to the Sungai Labuk.

The Kinabatangan Group includes the Labang, Tanjong, Kapilit and Bongaya Formations, which are found mainly in the central part of the survey area. The Tanjong Formation at Sandakan has been renamed the Sandakan Formation (Lee, 1970). These formations range from Lower Miocene to late Miocene in age and were formed in synclines. The Labang Formation comprises a thick sequence of steeply dipping sandstone, shale and mudstone with foraminiferal limestone, and rare conglomerate and tuffaceous beds; it is steeply and irregularly folded and faulted. It occurs in the upper Pinangah and middle Kuamut valleys but is extensive in the lower Kinabatangan extending from Kuamut east to Bukit Bulud Napa and south of Sandakan Harbour across the Kinabatangan valley to the Segama. The Tanjong and Sandakan Formations consist of mudstone and siltstone with prominent, but generally subordinate, beds of sandstone, minor marl, coal and conglomerate and rare limestone. The mudstone is mostly dark grey in colour; less commonly it is greenish or bluish-grey and in places it is marly or contains carbonaceous partings. It gives rise to low hills of subdued relief in the Inarat Lowlands, between Lamag and the Sungai Segaliud, north and west of Sandakan and in the upper reaches of the Sungai Kuamut. Resistant beds of sandstone form numerous bold ridges and scarps and form topographically rugged, subcircular, synclinal basins such as the Bangan and Maliau Basins in the catchment of the Kuamut. The sandstones are fine-grained and grey to brownish grey in colour. Coarser sandstones, which are less common, are lighter in colour and are composed largely of quartz grains. The Bongaya Formation is similar to the Tangong Formation, but contains a greater proportion of sandstone to mudstone. It is restricted to the Manjang valley in the Sandakan Peninsula. The Kapilit Formation consists of dominant sandstone with mudstone and rare coal. It is folded into gentle synclines and steep anticlines in the southermost part of the survey area.

The most recent beds of sandstone and mudstone occur in the Sebahat and Ganduman Formations of the Dent Group, which lie in the eastern part of the survey area. They are late Miocene to Pliocene in age and form the major part of an anticline in which the strata are gently folded. The Sebahat Formation contains predominant dark grey to black mudstone with subordinate marls, limestone, sandstone and conglomerate. It occurs in the south of the Lumerau Lowlands, east of the Tabin, where it is bounded by a steep ridge of limestone, and as an outlier northwest of the middle Tabin valley; In the Lumerau Lowlands mudstones predominate, but elsewhere thick beds of sandstone



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and conglomerate also occur. The Ganduman Formation comprises a succession of clay and sandstone with abundant carbonaceous matter and some lignite seams; it extends from the boundary with the Lahad Datu District, north and west to Evans Island. The formation has upper and lower divisions; in the upper division, typical of the area south and west of Tambisan, clays are dominant and contain ferruginous concretions; the lower division has a greater sand content and may contain small pebbles. Morphologically it is characterised by very steep and broken relief with well bedded and moderately dipping sandstones and clays, which produce a series of well marked cuestas north of the Lumerau Lowlands.

Because the sandstones, mudstones and shales are interbedded they produce mixed regolith. Where sandstones or mudstones and shales are locally dominant, however it is possible to make a separation. Three broad groups are therefore recognised for soil classification purposes (Text Map 2-4) and soil associations are assigned to these groups in Part 3.

1. Mudstone and minor sandstone
2. Sandstone and mudstone
3. Sandstone and minor mudstone

Descriptions of the constituent minerals of the sandstones are only available for the Crocker, Trusmadi and Sandakan Formations (Jacobson, 1970, Lee, 1970) (Table 2-12).

TABLE 2-12 The mineral constituents of sandstones in the Crocker, Trusmadi and Sandakan Formations (%)

Constituent	Crocker Formation (15 samples)	Trusmadi Formation (14 samples)	Sandakan Formation (8 samples)
Quartz	48.5	52.0	82
Chert	3.2	2.9	4
Feldspar	4.0	2.4	Tr
Others	0.1	0.5	–
Rock fragments	2.2	1.6	–
Matrix and cement			
Silica	21.5	19.7	nd
Carbonate	6.4	3.6	nd
Undifferentiated	15.1	17.1	14

Quartz is the dominant mineral and is considerably higher in the Sandakan Formation than in the other 2, which are very similar. There is a higher percentage of feldspars in the Crocker Formation; the feldspars in the Sandakan Formation are underestimated (Lee, 1970). Sandstones may be locally calcareous. The majority of sandstones are fine-grained and weather to yellow, brownish yellow and white.

There is no available information on the chemical properties of the mudstones and shales. There is evidence from soil analyses that illite, vermiculite and montmorillonite are important clay minerals, but the significant feature is high content of magnesium.

Sandstone, mustone and miscellaneous rocks

These occur in 4 sedimentary-volcanic formations, namely the Chert-Spilite, Ayer, Kuamut and Garinono Formations. The Chert-Spilite Formation is believed to range from Upper Cretaceous to Ecocene in age, while the others formed during the late Miocene. They were all deposited under marine conditions with periods of submarine slumping alternating with epiclastic and pyroclastic deposition. They are loosely referred to as slump formations and contain sedimentary rocks, mainly sandstone and mudstone, mixed with volcanic rocks; they differ mainly in the proportions of the constituent rocks.

The Chert-Spilite Formation contains chert, sandstone, siltstone, mudstone and associated basalt and tuff. As the name implies both chert and generally spilitised basic extrusive rocks are common in the formation. The chert is generally reddish brown to purple and in places is veined with secondary quartz. The spilitic rocks are normally fine-grained, amygdaloidal and contain veins of calcite and quartz. The formation occurs in the headwaters of the Malubok, Malua and Imbok rivers.

The Ayer Formation comprises highly disturbed tuff, tuffite, slump breccia, boulder beds, chert, pebbly mudstone and includes blocks of spilite and ultrabasic rocks. Fine-grained tuffs and coarse-grained tuffites occur mainly west of the Sungai Tabin, at Tomanggong and Bukit Kretam.

The Kuamut Formation occurs in the lower Kuamut valley and comprises sandstone, mudstone and conglomerate with rare occurrences of limestone, chert, tuff, spilite, basalt, dolerite and ultrabasic igneous rocks.

The Garinono Formation (Collenette, 1965a) is a slump breccia consisting of fragments and blocks of assorted rock types in a dominantly mudstone matrix (Plate 2-10). The fragments and blocks consist mainly of sandstone, limestone, chert, basalt, serpentinite, ophicalcite, gabbro and diorite. They are mostly angular to subangular, but rounded pebbles which appear to be water-worn have been observed. They range from less than an inch to large blocks up to 200 m (600 ft) across. The mudstone matrix is predominately grey to bluish grey when fresh but in places it is reddish grey with green bands. Sandstones comprise quartzite and greywackes. Chert blocks found in the slump breccia are generally small, but a few are more than 15 m (50 ft) across. Basalt is the most common igneous rock; it is fine-to medium-grained and frequently has calcite veinlets. Blocks of serpentinite and ophicalcite are quite common, but gabbro, diorite and spilitic blocks are rare. Mudstone, sandstone, tuff and tuffite also form interbedded sequences in the Garinono Formation. Mudstone, which is common in the Sungai Manila area, is grey to greenish grey in colour; in places it is purplish grey or red. Thin layers of medium-to fine-grained sandstone are grey when fresh and weather to buff or red. Bedded andesitic tuff and tuffite range from very fine to coarse in texture and contain feldspars, quartz and pyroxene. The coarse-grained members may contain pebbles of volcanic rocks. The formation extends from the Sandakan Peninsula westwards along the nothern edge of the Lokan Peneplain and east of Sandakan Harbour to the Sungai Melanking.

Mud volcanoes are associated with slump formations and occur in 4 areas. (Wilford, 1967a). The Segama Group lie on the watershed of the Segama and the Kretam with an outlier on the north bank of the Segama near Litang. At Kretam there are two volcanoes in the headwaters of the Sungai Kretam Kechil. The Rasang volcano occurs in the headwaters of the Sungai Rasang almost midway between the Sungai Kretam Besar and the Sungai Kinabatangan and the remnants of a volcano occur on Pulau Bakungan Kechil, a small coral island, to the north-east of Sandakan. The mud volcanoes form clearings surrounded by high forest; in the centre of the clearings are muddy areas with one or more cones or basins which produce inflammable or non-inflammable gas, or both, also salt water, mud and rock boulders. Boulders and mud constitute the parent materials in and adjacent to the clearings. 'The boulders are sometimes cracked like volcanic bombs and may have a baked appearance. The mud, too, which is usually bluish grey may have a baked appearance and purplish red colour. Boulder sizes vary from walnut-size to a cubic metre. The consist predominantly of clay, shale, marl, sandstone and sandy limestone and sometimes chert, amygdaloidal spilite, serpentinite and gabbro occur.' (Reinhard and Wenk, in Haile and Wong, 1965).

The sandstones and mudstones of the slump formations are very similar in mineralogy, colour and texture to those in the sedimentary formations. However, the regolith derived from them is more variable as it may be in part derived from other rocks.

Limestone

Limestone occurs as the dominant component in the Gomantong and Togopi Formations. The Gomantong Formation, which is of late Miocene age, comprises compact, detrital, greyish-orange limestone, much of it crystalline, composed of foraminifers, algae and corals and rare quartz sand. The main occurrence is at Gomantong, and there are also a number of small outcrops near Sukau. The Togopi Formation consists of loosely cemented, rubbly, reef limestone, calcareous sandstone, clay and marl laid down during the Plio-pleistocene. It is restricted to the eastern tip of the Dent Peninsula. Thick limestone lenses also occur in the Labang Formation in the upper Pinangah, middle Kuamut and lower Kinabatangan valleys. In the Sebahat Formation a thick bed of hard, grey massive foraminiferal limestone, which is partly crystalline, forms a high ridge to the east of the Tabin at Quoin Hill and similar features occur in the Tanjong Formation at Batu Puteh. The limestones are generally impure and weather to produce fine-textured deposits on gentle slopes; these normally contain limestone fragments, but they may be stoneless and decalcified.

Basic and intermediate igneous rocks:

Basic intrusions in which the principal rock types are olivine gabbro and troctolite, with associated serpentinite, are exposed in the mountains around Gunong Moritok and in the Karamuak valley. Microgabbro is exposed in the lower Sinoa and Imbak valleys.

Basic extrusive rocks are predominantly basalt and spilite lavas, extruded at two different periods. The older ones are major components of the Chert-Spilite Formation. Younger basalt and spilite occur to the west and east of the Mananam Plain, in the west comprising a broad mountain arc and in the east smaller bodies in a discontinuous arc between the Karamuak and Milian valleys. In addition to the main occurrences, basic igneous rocks also occur as blocks in slump formations.

Intermediate igneous rocks are rare but andesite occurs as dykes in the Sinoa valley and diorite may outcrop south of Gunong Rara.

The chemical composition of basic, intermediate and ultrabasic igneous rocks is described below in the section on the latter group.

Ultrabasic igneous rocks

Ultrabasic rocks are the most widespread igneous rocks in the area and belong to two groups. One group, in which peridotite predominates, occurs north and south of the Milian valley. The other, which is comprised mainly of serpentinite in association with olivine gabbro, outcrops east of the Kuamut. The peridotite group has been mapped in the Imbak and Sinoa valleys and on Gunong Rara; the principal rock types are serpentinised wehrlite, harzburgite, iherzolite and serpentinite. Although the ultrabasic rocks of the Sinoa and Imbak form a number of individual bodies at the surface, they are probably offshoots of a single body in depth, which continues north of the Milian valley, where larger outcrops occur in the vicinity of Bukit Tinkar and in the hills to the west of the Karamuak. Ultrabasic rocks also occur in the Segama valley, where they are associated with the Chert-Spilite Formation, at Bukit Lawa Lawa and sporadically in the headwaters of the Tenegang and Koyah.

There is a broad similarity between the chemical compostion of basic and intermediate rocks; in both iron, silica, aluminium, magnesium, calcium and sodium are the important elements. The ultrabasic rocks differ in having lower silica, calcium and sodium and aluminium but have disproportionately high magnesium together with chromium and nickel. They weather to produce regolith rich in iron. On the Tawai Plateau the weathering product is composed largely of goethite and a hardpan of ironstone described as laterite by Wilford (1968b) has formed on its surface (Table 2-13).

TABLE 2-13 **Chemical composition of some basic, intermediate and ultrabasic igneous rocks**

Constituent	Basic		Intermediate	Ultrabasic	
	Basalt/ Spilite (9 samples)	Gabbro/ Troctolite (6 samples)	Andesite (1 sample)	Ultrabasic rock (4 samples)	Tawai Plateau weathering product
SiO_2	50.4	48.5	58.0	36.6	1.5
TiO_2	0.9	0.8	0.3	Tr	0.14
Al_2O_3	14.0	16.4	15.8	1.8	7.1
Fe_2O_3	2.3	4.2	1.8	3.8	68.9
FeO	6.4	2.9	3.7	3.6	0.1
MnO	0.2	0.14	0.13	0.12	0.5
MgO	7.0	7.6	3.6	37.5	0.6
CaO	8.0	12.5	6.0	2.6	0.05
Na_2O	4.0	3.0	5.4	0.6	0.04
K_2O	0.3	0.3	2.6	0.1	0.04
P_2O_5	0.6	0.5	0.8	0.8	0.04
S	–	Tr	–	–	Tr
H_2O+CO_2	4.6	2.7	2.1	10.7	15.5
Cr_2O_3	nd	nd	nd	0.4	4.7
NiO	nd	nd	nd	0.3	0.7
CoO	nd	nd	nd	nd	0.11

After Kirk (1965) and Wilford (1968b)

LANDFORMS AND DRAINAGE

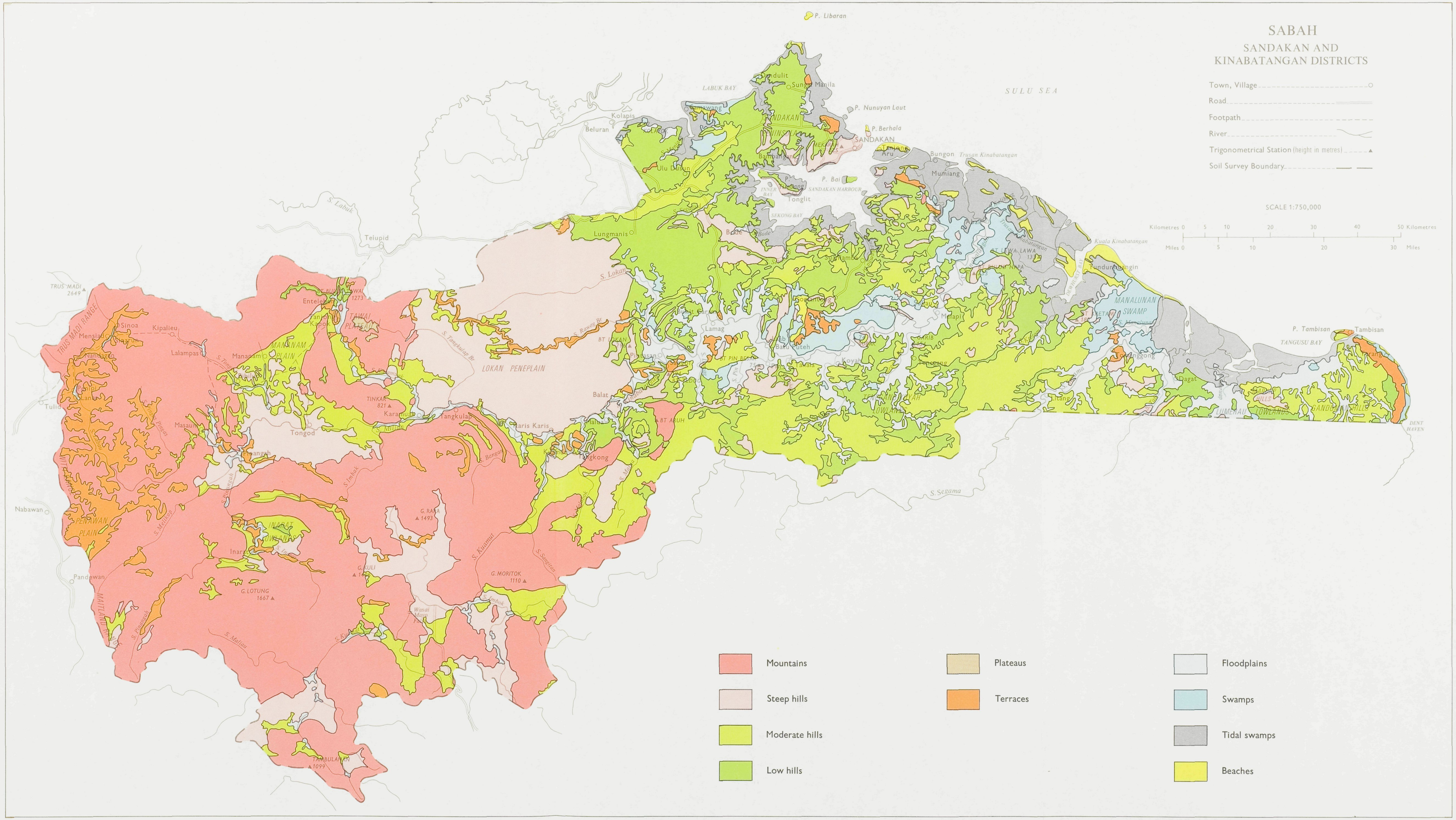
Introduction

Sabah can be divided into 4 broad physiographic regions (Collenette, 1963) and the survey area covers parts of 3 of these, namely the Western Cordillera, the Central Uplands and the Eastern Lowlands.

The Western Cordillera consists of subparallel mountain ranges and intermontane plains and includes the Trusmadi, Witti and Maitland Ranges which form the western boundary of the Kinabatangan District. The Trusmadi Range has several peaks over 2 400 m (8 000 ft) and the other ranges are between 600 and 1 200 m (2 000-4 000 ft), all being characteristised by steep terrain. The Penawan Plain is an intermontane plain consisting of dissected terrace remnants of previously more extensive valley infillings.

The Central Uplands form a complex area of rugged terrain including parts of the Labuk, Kuamut and Segama Highlands which consist of mountains above 300 m (1 000 ft) separated by foothills and valleys below 300 m. Of these the Mananam Plain and the Inarat Lowlands are most extensive.

The Esatern Lowlands are defined as land below 300 m (1 000 ft) and consist of 5 main areas, namely the Lokan Peneplain, the Kinabatangan Lowlands, the Sandakan Peninsula, the Dent Hills and the Eastern Deltas. The Lokan Peneplain lies to the north of the Kinabatangan and is drained in an easterly direction by the Sungai Lokan and the Sungai Rawog. It comprises a series of steep ridges of deceptively level appearance from the air. The Kinabatangan Lowlands include the major valleys of the Kinabatangan and Segama Rivers and consist of rolling to hilly terrain drained to the north-east. The Sandakan Peninsula is bordered by Sandakan Harbour to the south and



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by the sea to the north and east; it comprises areas of low hills and a series of cuestas. The Dent Hills occupy the larger part of the Dent Peninsula, which in the northern half consists of the broad Lumerau Lowlands bordered by in-facing scarps and ridges. The Eastern Deltas consist of a broad belt of swamps, which have been built up from the deposits of the main rivers flowing into the Sulu Sea. Each physiographic region is made up of characteristic individual landforms and these are described briefly in subsequent sections and their distribution is shown on Text Map 2-5.

Landforms are the basis of the soil mapping units in the survey area. Landforms can be broadly defined as being residual or depositional and are expressed in terms of relief, slope, form and areal extent. The term relief includes both absolute relief or altitude above sea level and relative relief, which is the difference in altitude between valley bottom and hill crest.

Residual landforms

Residual landforms include mountains and hills. Mountains are characterised by an absolute relief greater than 300 m (1 000 ft) and by steep or very steep slopes greater than 25°. Three main forms can be distinguished namely ranges, cuestas and upthrust blocks.

Ranges are mountains without well defined form, although some areas may have characteristic drainage patterns. They result from major regional tectonic movements and those in the Western Cordillera and in the Segama Highlands are of this form.

Cuestas are structurally controlled with steep, often sheer, scarp slopes and gentle dip-slopes. The best expression of this form is seen in the Maliau and Bangan Basins where series of concentric escarpments have very steep outfacing scarps and steep dip-slopes (Stereogram 2-5 and Plate 2-25). Outliers are seen at Bukit Aruh and east of Pinangah.

In the Labuk, Kuamut and Segama Highlands, mountains of igneous rocks protrude through sedimentary rocks as prominent domes or towering peaks. They are described by Wilford (1968) as upthrust blocks and have youthful, often superimposed, drainage, active scree slopes and sharp ridges and crests in contrast to surrounding landforms. Examples include Gunong Rara, Gunong Gunitong, Gunong Tinkar and Gunong Moritok. The Trusmadi Range is also an uplifted block.

Hills have absolute relief of less than 300 m (1 000 ft). Three main groups are differentiated in terms of relative relief and slopes, with subdivisions based on form and drainage pattern:

1. Steep hills (hills of high relief and steep slopes)
2. Moderate hills (hills of moderate relief and moderate slopes)
3. Low hills (hills of low relief and gentle slope)

The majority of hills of high relief and steep slopes are structurally controlled features formed on interbedded sandstone, mudstone, tuffite and limestone. They occur as ridges, cuestas, massifs and ranges. Parallel ridges of sandstone and limestone form striking features near Batu Puteh, Tomanggong and the Sungai Tabin and isolated hogs-back ridges occur at Bilit, Pin and Bulud Napa. These ridges are 90 to 240 m (300-800 ft) with slopes greater than 25° and with occasional sheer cliff faces and landslides. The Lokan Peneplain is strongly dissected into parallel ridges and has a gentle northerly tilt from 300 m (1 000 ft) in the south to about 90 m (300 ft) in the north, with concordant summits, related to old erosion surfaces, at a number of levels. Cuestas occur in the Sandakan Peninsula as a series of prominent subparallel fault scarps and in the Maruap Hills. They are similar to, but lower than, the mountain cuestas. Gomantong (Plate 2-29) is the sole example of a limestone massif with a summit at about 240 m (800 ft); it is hollowed into caverns and shows karst features. Hill ranges occur primarily as foothills bordering the mountain ranges and are extensive in the Central Uplands.

Hills of moderate relief and moderate to steep slopes are the main landforms of the Eastern Lowlands. They are hills in which the range of relief is up to 150 m (500 ft). A wide range of slopes occurs but most are between 10° and 25°. The Ganduman Hills comprise subparallel, broad ridges aligned from north to south, which are separated by narrow, often poorly drained valleys (Stereogram 2-3). The ridges have a steep topography with narrow crests and convex upper slopes, which become concave and level off to gentle midslope flats. Relief ranges from 0 to 90 m (0-300 ft) and slopes from 10 to 20°. Hills developed on slump deposits occur between the Tabin and the Kinabatangan valleys, south of Sandakan Harbour and in the west of the Sandakan Peninsula. They have a relative relief of up to 120 m (400 ft) and slopes of 10-20°, but lack well defined relief and drainage patterns. In the foothills drained by the Pin, Lamag, Malua and Malubok, the relative relief may be as great as 210 m (700 ft) with slopes ranging from 15 to 25°, but slopes may be as little as 5-15° on broad ridge crests and upper slopes. In contrast, hills formed on interbedded mudstones, shales and sandstones of the Tanjong, Kulapis and Crocker Formations in the Inarat Lowlands, Mananam Plain, north of Lamag and in the valleys of the Karamuak and Latangan, show structural control and a regular pattern of relief and drainage. Relative relief is as great as 120 m (400 ft) and the hills have convex upper and middle slopes of 10-20° and steeper concave lower slopes.

Low hills with relief of generally less than 75 m (250 ft) and with slopes generally less than 15° occur in 4 main areas. Two are the counterparts of moderate hills formed on slump and bedded formations described above. The low relief slump formations have relative relief ranging from 0 to 45 m (0-150 ft) and slopes ranging from 5 to 15°. The bedded formations are of a similar height but have slopes in the 10 to 15°. Both are extensive in the Sandakan Peninsula, between Sandakan Harbour and the Kinabatangan valley and in the Lumerau Lowlands. Lower hills with a relative relief of about 15 m (50 ft) and slopes of 0-10° and broad valley flats are widespread in the Lungmanis area, between the Koyah and Teneggang valleys and in the Lumerau Lowlands. Inland from Dent Haven low hills are formed on gently dipping limestone of the Togopi Formation; here slopes are long and gentle and rarely exceed 5°.

Depositional landforms

Depositional landforms include terraces, plateaus, floodplains, swamps and beaches.

The Penawan Plain and associated high plains are dissected remnants of formerly more extensive terraces in the upper reaches of the Labau and Pingas Pingas and their tributaries. Parts have been strongly dissected as a result of rapid downcutting following capture of the formerly westward flowing tributaries of the Sungai Pegalan. Landforms comprise flats, low hills with gently sloping convex crests and short, steep incised upper slopes on which underlying sandstones may be exposed. In the Labau valley the highest parts form high level terraces concordant with the Sook Plain to the west.

Inland terraces are extensive in the Mananam Plain and in landlocked basins in the Pinangah and Kuamut catchments. They may well have been deposited in lakes and evidence for this is provided by the gorges through which the Pinangah and Kuamut now flow immediately downstream from the terrace areas. It is also conceivable that the extensive terraces in the Lokan, Kinabatangan and Segama valleys may have been formed in lakes. The level of the terraces varies from 15-30 m (50-100 ft) to 550 m (1 700 ft) in the Labau valley. They have flat tops with strongly dissected edges and with slopes of 15-25°. The best examples occur at Tomanggong and south of Gomantong. Series of low terraces occur in the valley floors of the upper reaches of most of the larger rivers of the region. They are formed on deposits of recent alluvium and many are liable to flooding. They include alluvial fans, which are small but significant landforms occurring in the Karamuak valley and on the eastern flanks of the Tawai Range. Along the coast, terraces occur intermittently from the Labuk Estuary to Tambisan; at Sandakan Airport 3 different levels have been recognised (Lee, 1970) at approximately 5, 15 and 24 m (15, 50 and 80 ft). Between the hills of the Dent Peninsula and the fringing coral beaches is a broad coastal plain which is the result of recent uplift; this slopes gently to the coast at about 6 m (20 ft).

The Tawai Plateau is a unique feature. It is situated in the Tawai Range and is a level area surrounded by mountain peaks to the north and south. It is divided into two parts; the larger area to the north lies between 390 and 420 m (1 300-1 400 ft) and the smaller area at between 330 and 360 m (1 100-1 200 ft). It is crossed by minor streams draining from surrounding hills and is the source of the Meliau and Tangkulap rivers which descend from the plateau edge in spectacular waterfalls. The plateau is considered to have been formed during a period of stability when at the height of the adjacent Lokan Peneplain; it was subsequently uplifted.

The floodplains of the Kinabatangan and Segama and their tributaries comprise meander belts, floodplains and freshwater swamps. Meander belts are made up of levees, meander scrolls and cutoff lakes and they slope gradually to the flood-plains which are drained by small streams. The valleys of minor streams and rivers lack swamps and meander belts but usually have weak levees. Floodplains are the most extensive depositional landforms found in the Eastern Lowlands.

Tidal swamps subject to daily inundation form the major part of the Eastern Deltas.

Beaches fringe much of the coastline and also occur as old beaches in the swamps; their surfaces are generally level but have distinct poorly drained swales aligned parallel to the coastline.

Drainage

The area is drained by 2 main rivers namely the Kinabatangan and Segama and their tributaries which flow in a north-easterly direction to the Sulu Sea. A number of smaller rivers drain into Sandakan Harbour, into the Labuk Bay from the Sandakan Peninsula and north from the Dent Hills.

The catchment of the Kinabatangan occupies three quarters of the total survey area. It is the largest river in Sabah and is navigable for most of the year as far as Pinangah, about 320 km (200 m) from the sea. Above Pinangah the river has all the characteristics of a rapidly downcutting youthful stream with gorges and rapids. Between Pinangah and Tangkulap the river flows through the Central Uplands cutting across the main geological formations with erosional surfaces on either side (Fitch, 1959). From Tangkulap to Pintasan the valley gradually widens and the river is bordered by extensive dissected terraces. The two major tributaries of the Kinabatangan, namely the Kuamut and Pinangah join it from the south in this stretch. Both drain major catchments in the Central Uplands and both have features of youthful streams with gorges, rapids and falls. From Pintasan to Sukau the river meanders across a broad plain. It is believed to have undergone major changes of course on at least 2 occasions, having possibly flowed further south between the Lamag and Pin valleys and further north in what is now the Sungai Menungal. The main tributaries in this stretch are from the south; this is attributed to a localised tilting of the land to the north and both the Sungai Tenegang and Sungai Koyah are unusual in that their valleys are long and broad for their size and they have extensive alluvial flats close to their sources. (Haile and Wong, 1965). North of the river between Lamag and Batu Puteh are deep embayments with scattered lakes and from Batu Puteh to Bilit the north bank is bordered by an extensive swamp. The main north bank tributary is the Sungai Lokan; this flows to within a few miles of the Segaliud but instead of flowing into Sandakan Harbour turns abruptly south to join the Sungai Kinabatangan. Old terrace features and erosion surfaces in the Lokan Peneplain indicate that a larger river once flowed across it and that the Sungai Lokan might well have been the former valley of the Labuk on a more southerly course and entering Sandakan Harbour via the Segaliud. At Sukau the Kinabatangan has cut through limestone hills forming a narrow gorge-like feature; this together with widespread terrace deposits around the edge of the flood-plain suggest that there may once have been an extensive lake above Sukau. At Abai the river divides into 2 main distributaries and a number of minor ones and it meanders across its delta before entering the sea between Mumiang and Dewhurst Bay.

The lower reaches of the Segama River cross the survey area and by comparison with the Kinabatangan the valley is narrow. There are tortuous meanders between Litang and Tomanggong where the river turns abruptly east and flows around the southern edge of the Manalunan Swamp. An old levee development at this point indicates that the Segama may once have been continuous with the Sungai Manalunan.

Part 3

The soil associations

The interaction of the soil-forming factors, climate, vegetation, parent materials and landforms, has been described in Volume 1, Part 3 and the classification of the resulting soils has been summarised in terms of the FAO classification scheme and in terms of mapping units called soil associations. Fifty-one associations are defined in Volume 1; of these, 36 are recognised in the Sandakan and Kinabatangan Districts (Table 2-14). They are described* here in the following order:

Soils on alluvium

Soils on mudstone, sandstone and limestone

Soils on igneous rocks

These 3 main groups are further subdivided as shown below:

Soils on alluvium

These soils are described under 4 main headings:

1. Tidal swamps and beaches
2. Floodplains
3. Valley floors and associated terraces
4. Terraces

Soils on mudstone/sandstone

Mudstone and sandstone are by far the most common parent material in the survey area. The dominance of either mudstone or sandstone is variable, although a broad generalisation is that the higher and steeper the land the more common is sandstone. Thirteen soil associations have been defined, ranging from Acrisols and Luvisols formed on predominantly low mudstone hills to Podzols and Histosols on mountains of sandstone. In this report the associations are divided into 3 groups:

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

*Soil profiles are described separately in Volume 5, Appendix 1.

Soils on limestone

Limestone outcrops sporadically and 2 Associations of Luvisols and Redzinas have been described.

Soils on igneous rocks

These are divided into 2 groups:

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

TABLE 2-14 Areas of soil associations in Sandakan and Kinabatangan

Association	Ha	Ac	Km^2	Mi^2	% of total
Weston	131 900	316 550	1 320	495	6.2
Tanjong Aru	15 720	37 730	160	60	0.7
Usukan	1 280	3 060	15	5	0.1
Kepayan	4 300	10 320	45	15	0.2
Sapi	32 640	78 330	330	120	1.5
Kinabatangan	120 940	290 250	1 210	455	5.7
Tungku	5 630	13 510	55	20	0.2
Tuaran	18 480	44 350	185	70	0.9
Binalik	2 380	5 720	25	10	0.1
Karamuak	3 620	8 680	35	15	0.2
Labau	7 380	17 700	75	30	0.4
Klias	30 760	73 830	310	115	1.4
Lungmanis	82 260	197 420	825	310	3.9
Sook	11 400	27 360	115	45	0.6
Semporna	2 110	5 070	20	10	0.1
Rumidi	11 750	282 100	1 175	440	5.5
Silabukan	56 870	136 480	570	215	2.7
Tapang	2 650	6 370	25	10	0.1
Kretam	221 550	531 720	2 215	830	10.3
Tengah Nipa	24 070	57 770	240	90	1.1
Brantian	24 860	59 670	250	95	1.2
Kalabakan	47 670	114 405	475	180	2.2
Dalit	52 270	125 450	525	195	2.4
Sinarun	35 830	86 000	360	135	1.7
Dagat	9 040	21 700	90	35	0.4
Gumpal	5 260	12 630	55	20	0.2
Lokan	345 650	829 560	3 455	1 295	16.1
Tawai	1 530	3 660	15	5	0.1
Gomantong	2 860	6 860	30	10	0.1
Maliau	355 060	852 150	3 550	1 330	16.5
Malubok	51 610	123 870	515	195	2.4
Bidu Bidu	55 850	134 050	560	210	2.6
Mentapok	53 720	128 930	535	200	2.5
Crocker	187 230	449 350	1 870	700	8.7
Trusmadi	10 250	24 160	105	40	0.5
Serudong	10 480	25 160	105	40	0.5
Total	2 036 860	5 142 375	20 370	8 045	100

Soil associations on alluvium 1. Tidal swamps and beaches

Tidal swamps and beaches are extensive along the coast from Kolapis to Dent Haven. Three associations are mapped and of these the Weston Association is by far the most extensive; it is formed on alluvium laid down in tidal swamps and comprises Thionic and Calcaric Fluvisols, Dystric Histosols and Calcaric, Dystric and Eutric Gleysols. The Tanjong Aru and Usukan Associations are of restricted extent and are both formed on beaches. The Tanjong Aru Association is formed on beaches of siliceous sand both at the present day coastline and on old beaches further inland; it comprises Eutric Fluvisols and Regosols, Cambic Arenosols, Gleyic Podzols and Eutric and Humic Gleysols. The Usukan Association is formed on beaches of coralline sand on the coast and comprises Calcaric Regosols, Calcaric Gleysols and Calcic Cambisols (Table 2-15).

WESTON ASSOCIATION

The Western Association extends along the coast from Kolapis to Dent Haven and can be divided into 5 main areas. In the Labuk Bay it occurs as a thin fringe along the coast and penetrates up to 10 km (6 mi) inland along the Samawang and Gum Gum estuaries. Between Tanjong Pisau and the Kinabatangan it is up to 10 km wide and increases in width to a maximum of 25 km (15 mi) between the Kinabatangan and Dewhurst Bay. It borders much of Sandakan Bay and surrounds many islands being most extensive in the south and west where it is up to 3 km (2 mi) in width. Between the estuaries of the Manalunan and the Maruap, including the Segama estuary (Plate 2-11), the association occurs in a deep embayment up to 13 km (8 mi) wide; south of Tambisan it is discontinuous to the District boundary at Dent Haven. It covers collectively an area of 1320 km^2 (495 mi^2).

The predominant parent material is a fine-textured sulphidic alluvium, but coarse-textured deposits occur where the association adjoins sandy beaches. Peat occurs in embayments in the north of Sandakan Harbour and is likely to occur elsewhere. The coarse deposits are generally quartzitic but coral sand occurs between Tanjong Pisau and Pulau Berhala and south of Tambisan.

The association is formed on tidal flats with a unique microtopography of crab mounds in various stages of development. The alluvium which is deposited under tidal conditions is, regardless of its composition, subsequently reworked by crabs into mounds, which are then in part eroded by a combination of tidal fluctuation and rain-water. These processes contribute to 3 main stages in landform development all of which occur in the association, namely tidal flats, crab mounds and the platforms. Tidal flats are permanently waterlogged and are only exposed at low tide. There is minimal faunal activity with isolated miniature crab mounds and flows. Extensive areas of crab mounds are separated by tidal flats in the form of narrow winding channels or broad flat gullies. The sides of the mounds which are 30-120 cm (12-48 in) in height receive fresh deposits of alluvium after each high tide. The summits, which are above the high water level, are usually topped by active 'cones'. Platforms are flat-topped areas formed from coalescent and eroded crab mounds. They vary considerably in surface area but are generally little more than 6 m (20 ft) in diameter and are separated by narrow tidal flats. They are about 120 cm (48 in) above low water level and are rarely flooded. Scattered crab mounds and cones also occur above the platform level.

The natural vegetation, which covers the whole association, comprises forests of mangroves and nipah palm *Nypa fruticans* (Stereogram 2-1; Plates 2-11 and 2-31). In broad terms the more saline areas close to the sea and along the banks of deep channels are colonised by mangrove species. Nipah usually occurs inland from mangrove and extends as narrow belts along river banks, but it is also found close to the sea suggesting that it is tolerant of a wider range of conditions than mangrove. The term mangrove covers a range of species whose distribution is closely linked to landform. *Rhizophora mucronata (bakau), R. apiculata (bangkita), Bruguiera parviflora* and

TABLE 2-15 Soil association on tidal swamps and beaches

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Weston	Tidal flats and crab mounds	Mangrove and Nipah Forest	Sulphidic alluvium	Thionic Fluvisol	Weston
				Thionic-dystric Gleysol	Metah
			Alluvium	Thionic Fluvisol	Kalibong
				Thionic-eutric Gleysol	Libur
			Calcareous alluvium	Calcaric Fluvisol	Nunuyan
				Calcaric Gleysol	Lari
			Sulphidic peat	Dystric Histosol	Arang
Tanjong Aru	Coastal beaches, beach strands and old beaches	Beach Forest	Alluvium	Eutric Fluvisol	Pegalan
				Eutric Regosol	Tanjong Lita
				Cambic Arenosol	Kabili
				Gleyic Podzol	Baiayo
				Eutric Gleysol	Bangawat
				Humic Gleysol	Guan
Usukan	Coastal beach	Beach Forest	Calcareous alluvium	Calcaric Fluvisol	Nunuyan
				Calcaric Regosol	Usukan
				Cambic Arenosol	Pisau
				Calcaric Gleysol	Lari

Excoelania agallacha (buta buta) occur on the tidal flats. Somewhat drier sites on low crab mounds support *Ceriops tagal (tengar)*, *Xylocarpus granatium*, and *Avicennia alba (api api)* with the piah fern *Acrostichum aureum* on the summits of the mounds. Piah fern sometimes forms a dense ground cover on the platforms beneath an open upper storey of *Avicennia alba* with *Ceriops tagal* near channels (Plate 2.12). Nipah palm is associated with crab mounds and is dominant over large areas particularly in the Kinabatangan delta and the Segama estuary.

The association comprises Fluvisols, Histosols and Gleysols all of which can be related to the particular stages in landform development outlined above. Thionic and Calcaric Fluvisols and Dystric Histosols all form on tidal flats. They also form on crab mounds, which although reworked and much altered from the original deposits, show no true horizon development. Thionic-Dystric, Thionic-Eutric and Calcaric Gleysols form on the platforms (Figure 2-2).

Thionic Fluvisols: Weston and Kalibong Families

Thionic Fluvisols occur both on sulphidic and non-sulphidic alluvium (Weston and Kalibong Families respectively); the alluvium ranges from fine to coarse in texture. The soils are very poorly drained on the most recent sediments and poorly drained on reworked sediments or mounds; very poorly drained soils are waterlogged even at low tide and all horizons are gleyic. Colours are dark greyish brown to grey or dark reddish brown to dark brown where organic matter contents are high. Poorly drained Thionic Fluvisols, subject to daily flooding, develop on reworked sediments in the form of crab mounds and are best developed in nipah swamps. The crab mounds resemble miniature volcanic cones being composed of successive layers of alluvial materials; these are exuded by crabs from channels up to 5 cm (2 in) in diameter which permeate the mound interiors. Active cones are topped and covered by flows of grey clay; they contrast strongly with older flows and dormant cones, which have been subject to erosion by rainwater and the periods of drying and oxidation and which have yellowish brown and reddish brown mottles, iron encrustations between successive flows, pale yellow jarosite mottles and structural development.

These soils are all saline, but the degree of salinity is governed by proximity to sea water and the stage of crab mound development. Thus all very poorly drained Thionic Fluvisols are strongly saline, but poorly drained profiles on crab mounds are only moderately to slightly saline. The majority of the soils have high contents of total sulphur and those of the Weston Family have total sulphur contents of more than 0.75%. They are all potentially acid sulphate soils. The fine- and medium-textured soils are known as 'catclays' and the coarse-textured soils are referred to as 'catsands' (Profiles Jt 1 and 4).

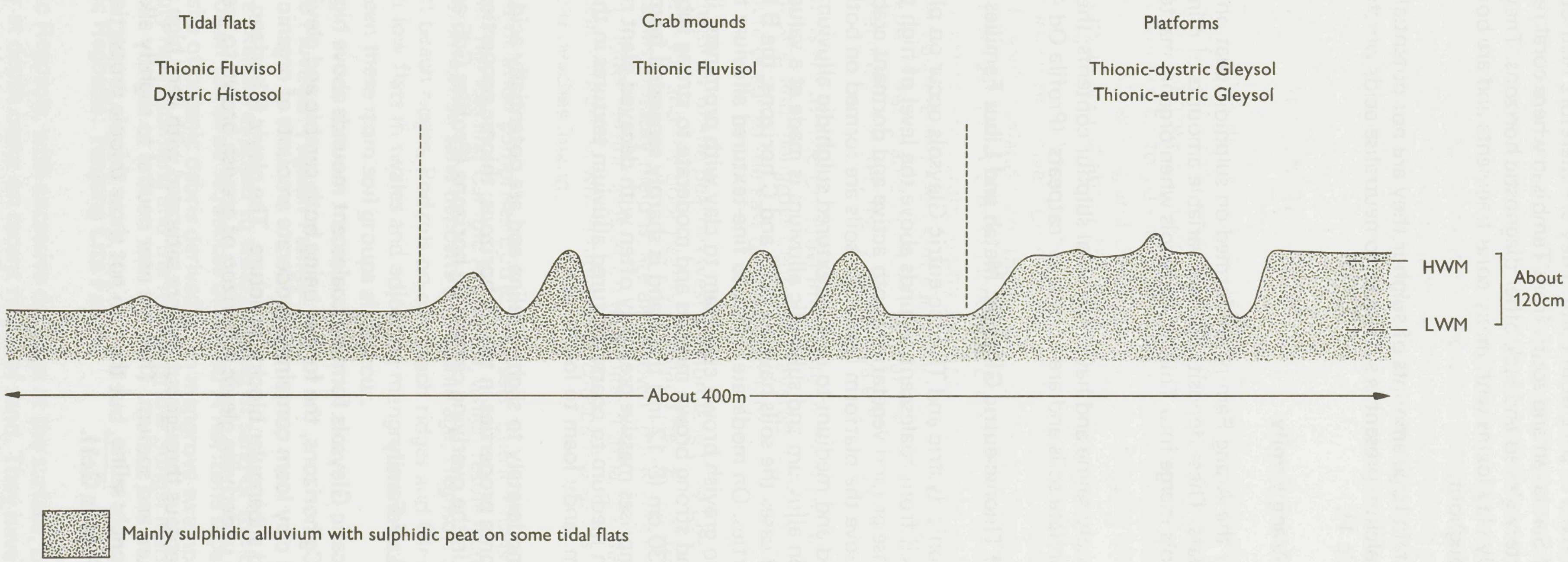

FIGURE 2-2 Theoretical cross-section of the Weston Association

D.O.S. 3182 B

Prepared by the Directorate of Overseas Surveys 1974

FIGURE 2-2

Calcaric Fluvisols: Nunuyan Family

Calcaric Fluvisols of the Nunuyan Family are formed on permanently waterlogged tidal flats on alluvium derived in part from coral. They are therefore restricted to the coastline to the north of Sandakan and south from Tambisan where coral reefs occur. Profiles are completely gleyed and lack other diagnostic horizons. They comprise dark greyish brown sandy clay loams with many coral fragments and are both calcareous and strongly saline throughout.

Although they contain large amounts of sulphur they are not potential acid sulphate soils, because the calcium present is sufficient to neutralise acids which form on oxidation (Profile Jc 1).

Dystric Histosols: Arang Family

Dystric Histosols of the Arang Family are formed on sulphidic peat on permanently waterlogged tidal flats. These deposits contain variable amounts of mineral matter so that Dystric Histosols merge into Thionic Fluvisols when organic matter contents fall below 30%.

These soils are strongly saline and have high total sulphur contents; they are potentially acid sulphate soils and are known as 'catpeats' (Profile Od 4).

Thionic-dystric and Thionic-eutric Gleysols: Metah and Libur Families

Poorly drained Thionic-dystric and Thionic-eutric Gleysols occur on platforms. The platforms are formed from coalescent mounds above the level of high tides and they often support a dense ground vegetation; both active and dormant crab mounds and cones may occur above the platform level. The soils are formed on both moderately fine-to fine-textured and medium-to coarse-textured sulphidic alluvium and alluvium; the division between alluvium and sulphidic alluvium is made at a value of $>$ or $<$ 0.75% total sulphur. In all cases the soils have gleyic B and C horizons; the B horizons also have cambic properties. On moderately fine-to fine-textured alluvium the Bg horizon consists of brown to greyish brown clay loam to clay with prominent light grey, yellowish brown and strong brown mottles and moderate to strong subangular blocky structures; it is 20-30 cm (8-12 in) thick and is sharply separated from they gleyic C horizon, which comprises massive grey clay often with decayed plant remains and jarosite mottles. On medium-to coarse-textured alluvium textures in the Bg and Cg horizons range from sandy loam to loamy sand.

These soils are all moderately to slightly saline and are potentially acid sulphate soils showing strong thionic properties in the Cg horizons; thionic properties are less strongly expressed in the overlying cambic Bg horizons (Profiles Gd5 and Ge4).

Calcaric Gleysols: Lari Family

Poorly drained Calcaric Gleysols form on coalescent mounds above high tide level. They have Bg and Cg horizons, the former being both cambic and gleyic; it consists of prominent mottled clay loam containing moderate amounts of organic matter with coral fragments and subangular blocky structure. The gleyic B horizon is sharply separated from the underlying gleyic C horizon of greyish brown to grey clay loam.

These soils are calcareous throughout and are saturated with very high amounts of exchangeable calcium and sodium. They are near neutral to slightly alkaline in reaction and are strongly saline, but they do not show thionic properties owing to high calcium contents (Profile Gc1).

Limitations to agriculture development

The soils of the Weston Association are subject to daily flooding with severe limitations imposed by salinity and the widespread occurrence of potential acid sulphate soils. At the International Symposium on Acid Sulphate Soils held in 1972 the following resolution was agreed. 'Acid sulphate soils are problem soils which require high inputs for improvement and therefore should only be given priorities in reclamation, improvement and research if, and where, growing populations are or will become dependent on these soils for their subsistence' (Dost, 1973). The Weston Association is therefore not recommended for agricultural development.

TANJONG ARU ASSOCIATION

The Tanjong Aru Association extends along the coast almost continuously from Tanjong Aru to Tambisan with small areas to the north of Sandakan at Tanjong Pisau and in the Samawang estuary. In addition it occurs as 'islands' within mangrove and nipah swamps up to 10 km (6 mi) inland from the present coastline notably between the Sungai Melanking and Dewhurst Bay and fringing hills to the east of Sungai Kapur. It covers an area of about 155 km^2 (60 mi^2).

It is formed on actively developing coastal beaches, beach strands and also on remnants of old beaches inland from the present day coast. These beaches are mostly linear and vary from 2-8 km (1-5 mi) in length and up to 3 km (2 mi) in width. They are level but have a distinct microtopography of minor ridges and swales which are aligned parallel to the coastline and represent successive stages in seaward development. They occur at altitudes of less than 3 m (10 ft) so that they are all subject to the fluctuation of regional ground water; many of the swales are swampy.

The soils are formed on alluvium mainly in the form of siliceous sand. Deposits of mixed sand and mangrove debris and layered deposits of sand and fine-textured alluvium occur to the east of Dewhurst Bay.

The majority of the beaches west of Mumiang have been planted with coconuts (Plate 2-13) and the poor heathy grassland below is grazed by cattle. Some fruit and vegetables, notably melons, are also grown (Plate 2-14). East of Mumiang the beaches remain under natural vegetation with pine *(Casuarina maritima)* on the coastal beaches and beach forest, in which nibong *(Onchosperma* sp.) is prominent, on beach strands and old beaches inland.

The association comprises Eutric Regosols, Eutric Fluvisols, Gleyic Podzols, Eutric and Humic Gleysols and Cambic Arenosols, which result from the processes of gleying and podzolisation on sand deposits of variable age; Regosols and Fluvisols occur on very recent beach ridges, Podzols on old beach ridges and Gleysols and Arenosols occur on broad low flats in swales and adjoining mangrove swamps (Figure 2-3). Intergrades between these main soil groups also occur.

Eutric Fluvisols: Pegalan Family

Where sites are exposed to wind blowing of sand or to flooding at very high tides the soils often comprise sequences of buried A horizons separated by layers of sand. Deep deposits of organic debris derived from mangrove swamps also occur on active beaches notably near Mumiang and the mouth of the Sungai Manalunan.

Eutric Regosols: Tanjong Lita Family

Eutric Regosols, with excessive drainage at the surface, but with fluctuating groundwater at depth occur on recent ridges of sand. They have A, C and Cg horizon sequences. The ochric A horison is normally a shallow greyish brown loamy sand; it merges through a transition AC horizon of yellowish brown to pale brown sand into gleyic horizons of light grey structureless sand.

Coastal beaches and beach strands

Old beaches

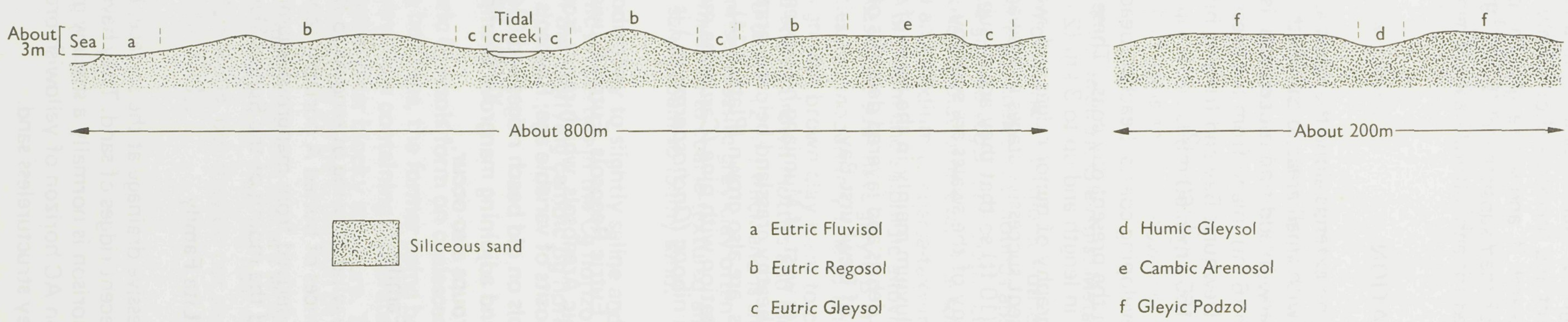

FIGURE 2-3 Theoretical cross-section of the Tanjong Aru Association

D.O.S. 3182C

Prepared by the Directorate of Overseas Surveys 1974

FIGURE 2-3

The soils are moderately to slightly acid with very low cation exchange capacities (Profile Re1).

Cambic Arenosols: Kabili Family

Cambic Arenosols of the Kabili Family occur on broad low beach flats on the inland parts of the present day beaches and also on narrow beaches within mangrove and nipah swamps. They are similar to the Eutric Regosols of the Tanjong Lita Family but have profiles with B horizons in addition to the A and Cg horizons. The ochric A horizon is normally 8-15 cm (3-6 in) deep and is composed of greyish brown sand. It is underlain by transition AB and B horizons of brownish yellow to yellowish brown weakly structured sand. These horizons show characteristics of cambic horizons but they do not qualify because their textures are too coarse. The lower parts of the B horizon are strongly mottled with rust and light grey colours due to the fluctuations of groundwater. The underlying gleyic C horizon is regularly wet or waterlogged and is composed of light grey to olive grey structureless sand.

Cambic Arenosols are strongly to extremely acid with very low cation exchange capacities and total exchangeable bases.

Gleyic Podzols: Baiayo Family

Gleyic Podzols of the Baiayo Family develop on the broad level ridges of old beaches inland from the present day coastline. Typically the Gleyic Podzol profile comprises O, A, E, Bhfe and Cg horizons. The E horizon is albic; it is often 30 cm (12 in) and occasionally up to 90 cm (36 in) thick and is composed of light grey structureless sand. It passes abruptly into the spodic B horizon which is composed of sand, either stained or more commonly indurated by humus and iron. It is sharply separated from the underlying gleyic C horizon composed of light grey to pale brown structureless and waterlogged sand. In addition to groundwater fluctuating in the Cg horizon, water often perches above the spodic horizon and causes gleying in the lower parts of the albic horizon.

Less well developed profiles which are intergrades to Regosols and Arenosols have O, A, E and BCg horizon sequences. The E horizon of light grey, bleached sand is rarely more than 8-15 cm (3-6 in) thick. The underlying BCg horizon of sand with humus staining represents an early stage in the development of the spodic horizon of the Gleyic Podzol.

Eutric Gleysols: Bangawat Family

Eutric Gleysols with poor drainage occur mainly in swales between low beach ridges; they are subject to fluctuations of brackish ground water and to periodic flooding. They have A and Cg horizon sequences, the gleyic C horizon occurring within 50 cm (20 in) of the surface. The A horizon is typically composed of grey to greyish brown sand with occasional rust mottles and weak structural development. It overlies greyish brown, strongly mottled and grey structureless sand gleyic horizons (Profile Ge2).

West of Sandakan Airport Eutric Gleysols occur on a low lying spit which extends towards the Sungai Sibuga Besar; here the soil has a humic coarse sand A horizon and a light grey, gleyic E horizon of sand and pebbles which is loose, structureless and often waterlogged; it merges into a waterlogged gleyic C horizon of loose, coarse sand and pebbles.

Humic Gleysols: Guan Family

Very poorly drained Humic Gleysols of the Guan Family occur in narrow swales often with pools of brackish water. They comprise gleyic C horizons of sand overlain by accumulations of organic matter; depths of 60-90 cm (24-36 in) of mixed sand and organic matter overlie Cg horizons composed of sand and occasionally mixed sand and fine-textured alluvium between Dewhurst Bay and the Manalunan Swamp.

Limitations to agricultural development

In the Tanjong Aru Association limitations to agricultural development are imposed by excessive drainage in Regosols, Arenosols and Fluvisols, poor drainage in Gleysols and Gleyic Podzols and indurated horizons in Gleyic Podzols together with general conditions of high acidity and nutrient deficiencies, so that some areas are quite unsuited to agriculture and others have limited use. Large areas are under coconuts and the potential of the land is shown at Mumiang, for example, by the successful cultivation of fruit and vegetables using irrigation and manure.

USUKAN ASSOCIATION

This inextensive association occurs on islands off the east coast of the Sandakan Peninsula including Selingan, Libaran, Nunuyan Laut and Berhala and from Tambisan south to Dent Haven fringing the tip of the Dent Peninsula (Plate 2-21; Stereogram 2-12); it covers about 15 km^2 (5 mi^2).

It is formed on small coral islands and on lowlying flat beaches about 3 m (10 ft) a.s.l. These beaches occur parallel to the coastline and occasionally show ridge and swale development. On the Dent Peninsula a narrow backswamp occurs inland from the beaches.

Parent materials consist of coral debris overlying coral; the coral debris includes shells and shell fragments, varying from medium to corase gravel in size. Swales and backswamps are infilled with medium-to coarse-textured alluvium, which also contains abundant coral fragments. Small rock outcrops may also occur; examples include agglomerate on Selingan, sandstone on Libaran and chert to the north of Libaran.

Most of the association has been planted with coconuts, the undergrowth being poor heathy grassland. In the swamps the vegetation comprises dense stands of low trees with climbers, sedges and grasses.

The association is dominated by Calcaric Regosols, which form in association with Cambic Arenosols and Calcaric Fluvisols on the beaches (Plate 2-15); Humic Gleysols form in swales and backswamps (Figure 2-4).

Calcaric Fluvisols: Nunuyan Family

Calcaric Fluvisols consist of deposits of coral sand.

Calcaric Regosols: Usukan Family

Calcaric Regosols of the Usukan Family have shallow dark brown to black ochric A horizons which often contain shell fragments; they overlie C horizons composed of coral debris and shell fragments; buried A horizons occur sporadically. They are excessively drained and watertables are normally below 125 cm (50 in).

The A horizon has low organic matter contents and moderate cation exchange capacity values; it is saturated with exchangeable calcium and magnesium. The C horizons have very low cation exchange capacities and they are similarly saturated. All horizons are moderately to strongly alkaline.

Cambic Arenosols: Pisau Family

Well drained Cambic Arenosols of the Pisau Family have A, B and C horizon sequences. The ochric A and C horizons are identical to those in the Calcaric Regosols of the Usukan Family, but the B horizon, which is lacking in soils of the Usukan Family, is comprised of yellowish brown to strong brown sandy loam with dominant fine coral fragments. It is too coarse in texture to qualify as a cambic horizon (Profile Qc1).

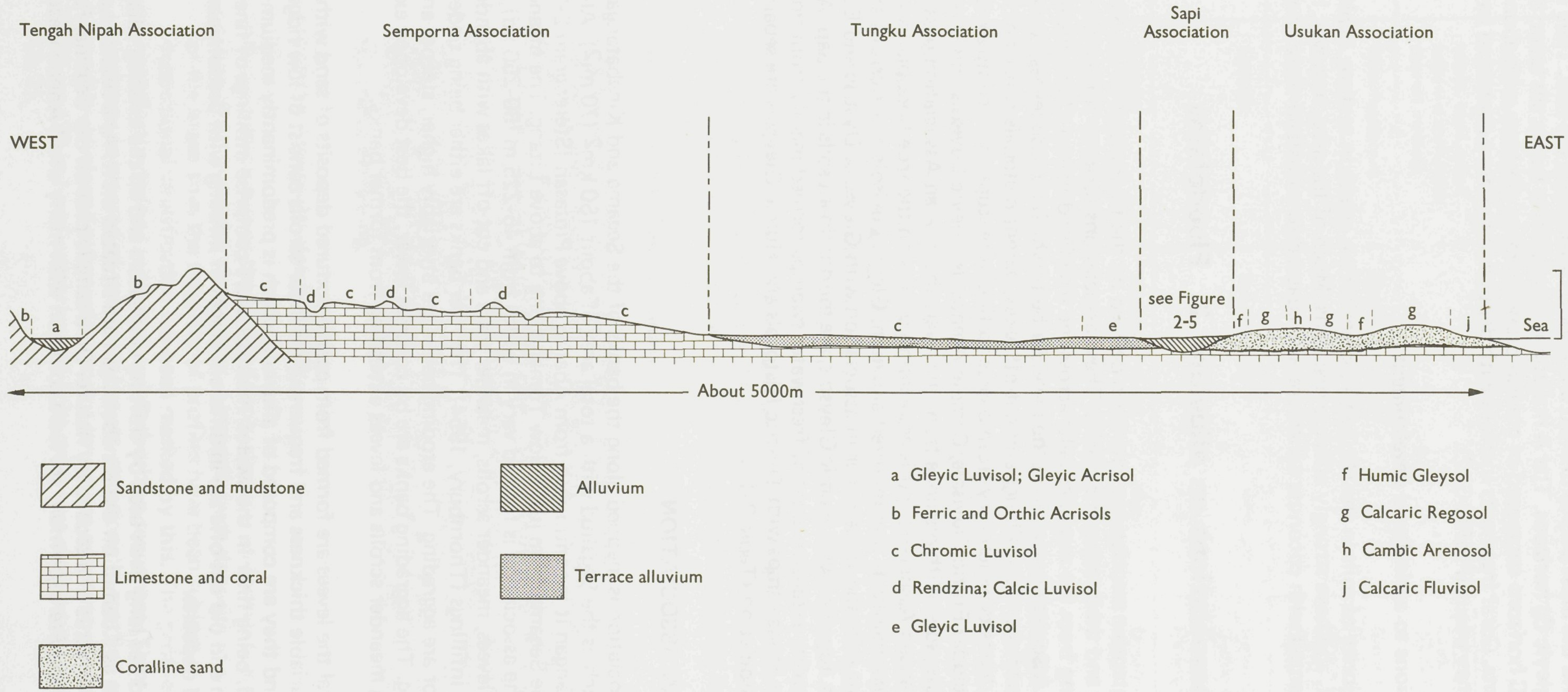

FIGURE 2-4 Theoretical cross-section of the Dent coast showing the Tengah Nipah, Semporna, Tungku and Usukan Associations

Humic Gleysols: Berhala Family

Humic Gleysols of the Berhala Family are all subject to the fluctuations of groundwater and the most poorly drained are flooded throughout the year. They have umbric A and gleyic Cg horizons. The A horizon is commonly a humic silt loam; it overlies gleyic C horizons composed of greyish brown loam to silt loam with abundant coral fragments. Coral fragments increase with depth and horizons composed largely of coral debris may occur (Profile Gh7).

Limitations to agricultural development

The majority of soils in the Usukan Association are coarse in texture, liable to severe drought, and have strongly alkaline reactions. Much of the area, however, has already been planted with coconuts which are well adapted to withstand these conditions.

Soil associations on alluvium 2. Floodplains

Four extensive associations have been defined on the floodplains of the Kinabatangan, Segama and their major tributaries. These associations together form a sequence extending from the meander belts across the true floodplains to backswamps. The Tuaran Association occurs on the meander belts which include levees, scrolls, scars, abandoned channel infillings and cut-off lakes; parent materials consist of recent alluvial deposits which vary from coarse to fine in texture and a complex range of soil units includes Eutric Fluvisols, Cambic Arenosols, Gleyic Luvisols and Dystric and Eutric Gleysols. With distance from the rivers the Tuaran Association passes into the Kinabatangan Association; this association occurs on the true floodplains which are composed mainly of fine-textured alluvium; Gleyic Luvisols and Acrisols are the dominant soils and these occur in association with Gleysols. Dystric and Eutric Gleysols, together with Humic Gleysols, are the dominant soils in the Sapi Association which covers extensive areas of freshwater swamps formed mainly from fine-textured alluvium. Peatswamps with Dystric Histosols and Humic Gleysols are separated as the Klias Association (Table 2-16).

TUARAN ASSOCIATION

This association is mapped along the banks of the Segama and Kinabatangan and lesser rivers such as the Segaliud with a total area of about 180 km^2 (70 mi^2). Along the Kinabatangan it is continuous from Abai to above Pintasan (Stereogram 2-11) and along the Segama from just below Tomanggong to above Litang. The meander belts on which the association is formed vary in width from 45-225 m (50-250 yd); they include levees, meander scrolls, meander scars and cut-off lakes with abandoned channel infillings (Thornbury, 1954). The river banks are either being undercut and eroded or are aggrading. The eroding banks are invariably higher, steeper and liable to slumping. The aggrading banks are by contrast lower, the best developed examples showing meander scrolls and levees extending from former banks.

In general the levees are formed from coarse-textured deposits of sand with layers of silt of variable thickness and frequency; meander scrolls consist of low ridges and swales and they are composed of alluvium which is predominantly medium-to fine-textured, being finer in the swales; meander scars comprise infillings of fine-textured alluvium and old cut-offs are in different stages of infilling with predominantly fine-textured deposits.

This land has long been used by shifting cultivators and all the existing villages as far upstream as Kuamut on the Kinabatangan are situated on it. As a result much of the riparian forest is of a secondary nature. On a sample plot on the Segama, *Parkia javanica* and *Pterospermum* sp. were common with many small Annonaceae and

TABLE 2-16 Soil associations on floodplains

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Tuaran	River meander belts including levees, scrolls, scars, cutoff lakes and abandoned channel infillings	Riparian Forest	Alluvium	Eutric Fluvisol	Pegalan
				Cambic Arenosol	Kabili
				Dystric Gleysol	Koyah
				Eutric Gleysol	Bangawat
				Gleyic Luvisol	Buran
Kinabatangan	River floodplains	Riverain Dipterocarp and Swamp Forests	Alluvium	Gleyic Luvisol	Buran
				Gleyic Acrisol	Inanam
				Dystric Gleysol	Koyah
				Eutric Gleysol	Bangawat
				Humic Gleysol	Guan
Sapi	Swamps	Swamp Forest	Alluvium	Humic Gleysol	Guan
				Dystric Gleysol	Koyah
				Eutric Gleysol	Bangawat
			Peat	Dystric Histosol	Klias
Klias	Swamps	Peatswamp Forest	Peat	Dystric Histosol	Klias
			Alluvium	Humic Gleysol	Guan

climbers and on the Kinabatangan at Subak a vigorous riverside stand of *Octomeles/ Anthocephalus* regenerating forest with abundant grass and ferns was described (Plate 2-17). At Subak an open swamp forest was described; *Baccaurea* sp., *Aporusa* sp. and *Xanthophyllum* sp. were common. Close by a rather denser swamp forest was recorded where *Nauclea maingayi* was dominant and other species included *Ficus* sp., *Glochidion breynoides* and *Colona seratifolia.* In general the tallest trees are on the levees and lines of tall trees away from the present river banks often indicate former levees. On the meander scrolls trees are lower and less dense and have grass undergrowth. Meander scars support a grass vegetation with few low trees.

Eutric Fluvisols, Cambic Arenosols and Eutric Gleysols are the dominant soil units (Figure 2-5). Gleyic Luvisols and Gleysols occur mainly on the inner edges of the meander belt and are described in the Kinabatangan and Sapi Associations below.

Eutric Fluvisols: Pegalan Family

Eutric Fluvisols of the Pegalan Family are developed on the most recent deposits on the levees and meander scrolls. They are soils in which horizon development is weak or absent; they usually comprise shallow A and C or Cg horizons. They occur on both coarse and medium-textured deposits. On the former, profiles consist of alternating layers of sand and silt, the sand being browner in colour and structureless, with thin layers of grey, rust mottled silt with blocky or platy structures; burried A horizons and organic debris may occur. On the latter, profiles are poorly drained and are composed largely of silt; distinct layers of silt overlie gleyic C horizons composed of grey, strongly mottled silty clay loam, which develops strongly blocky or prismatic structures on drying.

Cambic Arenosols: Kabili Family

Cambic Arenosols of the Kabili Family develop on former levees now at some distance from the present day river banks. Although fresh deposits of silt may occur on some of the lower sites the majority of profiles have been subject to weathering *in situ* and depositional stratification has been masked by this. The profiles are deep and imperfectly drained with A, B and Cg horizon sequences. They have weak A and B horizons composed of yellowish brown, occasionally mottled grey, loamy sand with weakly developed subangular blocky structures overlying gleyic C horizons below 50 cm (20 in) and comprised of light grey, rust-mottled structureless sand (Profile Qc 2).

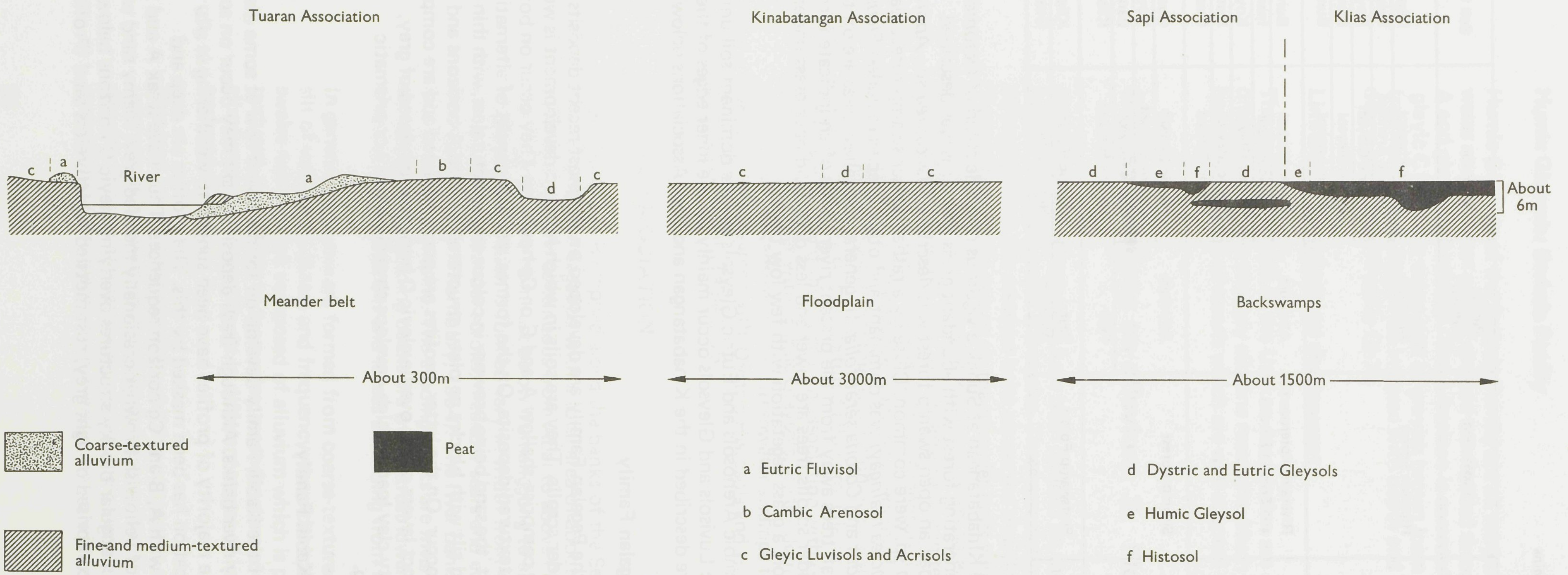

FIGURE 2-5 Theoretical cross-section of the Tuaran, Kinabatangan, Sapi and Klias Associations

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Prepared by the Directorate of Overseas Surveys 1974

Eutric Gleysols: Bangawat Family

Eutric Gleysols of the Bangawat Family occur on meander scars and meander scrolls. They are formed on deposits of fine-textured alluvium and are either poorly or very poorly drained with gleyic horizons often at the surface. Fresh silt may cover the surface, but the subsurface horizons have developed sufficient structure to be classed as cambic as well as gleyic horizons. They comprise grey, rust mottled silty clay to silty clay loam with moderate to strong subangular blocky structures (Profile Ge1).

Limitations to agricultural development

The Tuaran Association comprises a range of soils with limitations of drainage and flooding. Many soils are poorly drained and at the other extreme some Fluvisols have excessive drainage. Flooding is the most severe limitation and until this has been controlled no long term development can be recommended.

KINABATANGAN ASSOCIATION

The Kinabatangan Association extends over the floodplain of the Kinabatangan and its broad tributary valleys particularly those of the Loka, Koyah, Tenegang, Pin, Lamag and Bangan. It is also extensive on the floodplain of the lower Segama and its tributary the Tabin, on the Lumerau Lowlands, on the coastal foreland between the Sungai Kapur and the Sungai Nipah and on the floodplains of small rivers such as the Segaliud. It covers about 1 180 km^2 (455 mi^2) which is equivalent to 5.7% of the total survey area.

Landforms comprise floodplains, valley floors and coastal fringes. On floodplains the association normally occurs between meander belt and backswamp; in general it is at a slightly higher level than the backswamps and is mostly lower than the meander belts. It is crossed by numerous small streams which are sometimes quite deeply incised.

In the Kinabatangan, 4 main zones are distinguished. Above Pintasan the floodplain is confined to relatively narrow stretches along the banks and here the association includes minor levees. The association is also mapped in the tributary valleys of the Tabalin, Malua, Latangan and Bangan. Between Pintasan and Batu Puteh the floodplain is up to 3 km (2 mi) wide on the south bank with deep embayments on the north bank (Plate 2-18). The most westerly embayment is the floodplain of the Lokan; the others are areas of relatively stagnant drainage with backswamp features and occasional lakes. Between Batu Puteh and Tanjong Batu the floodplain is confined almost entirely to the south bank and to the broad valleys of the Koyah and Tenegang Besar which extend 16-24 km (10-15 mi) south. To the north, extensive swamps border the river (Stereogram 2-11). Downstream from Tanjong Batu the floodplain merges into widespread swamps adjacent to the coastal swamps. The total area covered by the Association in the Kinabatangan valley is about 725 km^2 (280 mi^2).

On the Segama the floodplain is about 2½ km (1½ mi) wide on either bank between Litang and Tomanggong. Downstream from Tomanggong, however, backswamps occur on the north bank and the association is most extensive on the floodplain of the south bank. In the Segama valley the Association covers about 260 km^2 (100 mi^2).

Parent materials comprise medium-and fine-textured alluvium. Coarse-textured alluvium occurs adjacent to sandstone hills, from which it is derived, and to the east of Dewhurst Bay coarse-textured deposits of old beach bar formations are overlain by fine-textured alluvium.

The majority of the association is covered with varieties of Riverain Dipterocarp Forest and swamp forests which in general are poor with canopy heights of less than 30-36 m (100-120 ft). Examples described include a rather poor swamp dipterocarp forest with *Shorea leprosula* and *Dipterocarpus applanatus* in the upper canopy and an abundance of *Eugenia* sp., *Diospyros* sp., and Annonceae in the under storey; a rather open

Alstonia swamp forest with other species present, including *Parkia* sp., and *Glochidon* sp.; a mixed swamp forest of *Eugenia* and *Diospyros* sp. and a swamp forest with *Nauclea* and *Diospyros* species. Examples of secondary forest included secondary swamp associations of *Glochidon* with *Pandanus* described as rather open grassy forest with abundant climbers; open secondary forest with scattered large trees (e.g. *Neesia*), abundant rotan and climbers; and low-thicket secondary forest with *Pternandra* and *Glochidon* and abundant climbers. In the past considerable areas near Bilit and Lamag were cleared and planted with tobacco. More recently cocoa was planted near Malua but was devastated by floods and oil palm on the Segama floodplain at Tomanggong has been abandoned for the same reason.

The association comprises imperfectly and poorly drained Gleyic Luvisols and Gleyic Acrisols with very poorly drained Gleysols in the wettest sites (see the Sapi Association) (Figure 2-5). Although the soils have been classified as Acrisols and Luvisols (i.e. having argillic horizons) it is possible that some of the argillic horizons may well be cambic horizons and some cutans may simply be flood coatings; the zones of clay maxima may be due to the original deposition of the alluvium and the uneven carbon distribution in some profiles supports this case. The same arguments apply to Gleyic Acrisols of the Inanam Family.

Gleyic Luvisols: Buran Family

Poorly drained Gleyic Luvisols of the Buran Family are the most common soils in the association. They have A, Bg and Cg horizon sequences with water fluctuating periodically to the surface and normally occurring within 50 cm (20 in) of the surface. The surface ochric A horizons are shallow, greyish brown, often rust mottled loams to silt loams. The B horizons are both argillic and gleyic being composed of strongly gleyed light grey to grey, rust mottled silty clay to clay with angular blocky or prismatic structures and thick cutans on the ped faces. Manganese concretions normally occur; they are usually about 2 mm in diameter being soft and round and are either spread diffusely through the horizon or are in distinct layers; they frequently occur in distinct layers at the top of the argillic horizon marking the zone of regular water table fluctuations. The underlying Cg horizons are composed of grey, weakly mottled, silty clay with coarse prismatic or massive structures; buried organic horizons may occur at any level.

Imperfectly drained Gleyic Luvisols of the Buran Family have A, B and Bg horizons; Cg horizons normally occur below 125 cm (50 in). The shallow ochric A horizon overlies B horizons composed of yellowish brown to brownish grey gley-mottled clay loam to silty clay loam; soft black manganese concretions usually occur in the lower parts. The underlying strongly gleyed Bg horizons are identical to the Bg horizons of the poorly drained profiles but occur at varying depths below 50 cm (20 in).

The soils are all moderately to strongly acid. Levels of total exchangeable magnesium are high to very high and cation exchange capacities are medium to high. In sites transitional to saline swamps where profiles are often developed on layered deposits of both fine-and coarse-textured alluvium the argillic Bg horizon contains high contents of exchangeable sodium and has near neutral pH values (Profile Lg 3).

Gleyic Acrisols: Inanam Family

Gleyic Acrisols of the Inanam Family include those profiles which are transitional to Gleyic Luvisols with moderate base saturation values in the argillic horizon (i.e. less than 50% but greater than 35%) and those which have base saturation values of less than 35%; the former are physically identical to Gleyic Luvisols of the Buran Family.

Gleyic Acrisols with base saturation values of less than 35% are associated with deposits of medium-to coarse-textured alluvium often derived as outwash from adjacent sandstone hills. Both poorly and imperfectly drained soils have been described. Poorly drained Gleyic Acrisols have A, Bg and Cg horizon sequences with water fluctuating periodically to the surface and normally occurring within 50 cm

(20 in) of the surface. The surface ochric A horizons are shallow, often gley mottled loams to sandy loams and they overlie strongly gleyed argillic B horizons composed of grey rust mottled sandy loam to sandy clay loam with subangular blocky structures, cutans and manganese concretions. Cg horizons are composed of grey structureless sand to sandy loam. Imperfectly drained Gleyic Acrisols have A, B, Bg and Cg horizons. Shallow ochric A horizons overlie B horizons composed of weakly gley mottled sandy loam to sandy clay loam with subangular blocky structures and cutans. The Bg horizon normally occurs below 50 cm (20 in) and is composed of grey, prominently mottled, sandy loam to sandy clay loam with subangular blocky structures and cutans.

These soils are strongly acid with pH values normally less than 5. Total exchangeable bases and cation exchange capacity values are low to very low but exchangeable magnesium contents are often high (Profile Ag 1).

Limitations to agricultural development

The Kinabatangan Association consists of generally poorly drained soils which are liable to severe flooding. No long term-development should be considered on this land until effective flood control measures have been taken.

SAPI ASSOCIATION

Apart from small areas adjacent to Tangusu Bay, Labuk Bay and bordering the tip of the Dent Peninsula, the Sapi Association is confined to the floodplains of the Segama and Kinabatangan. It is best developed in the lower reaches of the Segama and Kinabatangan where it adjoins coastal swamps. In the middle Kinabatangan the association borders the Bilit peat swamps (Stereogram 2-11; Plate 2-19) and also occurs as distinct areas on the floodplains of the Lamag, Pin, Koyah and Tenegang Besar to the south of the river and on the Lokan and minor streams draining extensive embayments from the north. The association covers a total of 310 km^2 (120 mi^2).

The Sapi Association is formed in backswamps, many of which are in embayments enclosed by hills at considerable distances from main drainage. In addition external drainage is impeded by broad levee zones on the main rivers, such that water tables in the backswamps are above or near the surface throughout the year. In the Dent Peninsula swamps occur behind coral beaches.

The soils are developed on deposits of medium-to fine-textured alluvium and peat, the latter often occurring as layers within the alluvium. Shallow deposits of alluvium are underlain by deep peat adjacent to peat swamps.

Swamps forests which cover the association comprise low trees, often with pneumatophores and stilt roots; there is dense undergrowth of small bushes, grasses and sedges. A plot described north of the Kinabatangan near Kuala Koyah had an irregular canopy with the larger trees (e.g. *Vitex pubescens, Dialium* sp. and *Kibessia galeava*) reaching 36 m (120 ft); an intermediate upper canopy at 18-30 m (60-100 ft) with smaller trees (e.g. *Glochidion hypolencum* and *Dillenia* sp.) as an understorey.

Very poorly drained Humic, Dystric and Eutric Gleysols dominate the association; poorly drained Gleyic Luvisols and Acrisols (see the Kinabatangan Association) and Dystric Histosols (see the Klias Association) also occur (Figure 2-5). In addition Humic Gleysols of the Berhala Family form in the coastal backswamp on the tip of the Dent Peninsula (see the Usukan Association).

Humic Gleysols: Guan Family

Very poorly drained Humic Gleysols of the Guan Family develop in sites which are normally waterlogged and support a ground vegetation rich in sedges. Profiles consist of histic O or umbric A and gleyic C horizons. Histic horizons are composed of largely undecomposed peat less than 40 cm (16 in) thick. Umbric A horizons comprise very dark brown silt loam with weak granular structure and high organic carbon contents. The gleyic C horizons are composed of grey to greenish grey silty clay to clay with coarse prismatic or massive structures; rust mottles are normally weakly developed and are confined to root channels where they sometimes form brittle tubular concretions. Decomposing sedge and wood remains and distinct layers of peat also occur.

Organic carbon percentages are extremely variable depending on amounts of decomposing plant remains contained in the alluvium. All profiles are strongly to extremely acid and have low percentages of exchangeable calcium. Exchangeable magnesium is normally high and potassium medium to high.

Dystric and Eutric Gleysols: Koyah and Bangawat Families

Dystric and Eutric Gleysols are very poorly drained soils with ochric A and gleyic C horizons. They lack histic O or umbric A horizons characteristic of the Humic Gleysols but in other respects are identical. Dystric Gleysols have base satuaration values of less than 50%; Eutric Gleysols have values in excess of 50%.

Limitations to agricultural development

The Sapi Association comprises very poorly drained soils with watertables at or above the surface throughout the year. Without large scale drainage installations this association cannot be recommended for agriculture.

KLIAS ASSOCIATION

The Klias Association occurs in 3 main areas and with other less extensive areas covers a total of 298 km^2 (115 mi^2). The Manalunan swamp is the most extensive area and covers about 125 km^2 (48 mi^2). It is bounded by the Sungai Manalunan in the east, the Sungai Segama and the Manalunan in the south-east, low hills extending from the Segama to the Sungai Merah in the west, the alluvia of Dewhurst Bay in the north-west and by coastal beaches in the north-east. Between Bilit and Batu Puteh, north of the Kinabatangan (Stereogram 2-11), about 120 km^2 (46 mi^2) are bounded by the Kinabatangan levee in the south and east, the Bilit ridge and low hills extending towards Gomantong in the north and by limestone ridges and a low dissected terrace in the west. There are 2 distinct areas in the lower Kinabatangan, one in the headwaters of the Melanking (Stereogram 2-2) and the other within the Bulud Napa basin (Plate 2-20) with a combined area of about 31 km^2 (12 mi^2).

The peat swamps, on which the association is mapped, are all associated with river flood-plains with extremely sluggish external drainage. The Manalunan swamp is, in large part, a coastal backswamp where drainage to the coast has been blocked by a series of beaches, but to the south-east it is continuous with the Segama backswamps where drainage to the river is blocked by river levees. The Bilit swamps have developed in an area lacking effective drainage to the Kinabatangan and only minor streams cross the levees. The main drainage of these swamps is by the Sungai Menungal, a sluggish stream which is considered to occupy an old course of the Kinabatangan north of the Bilit ridge (Plate 2-19). In contrast the area to the south of the Kinabatangan, opposite the Bilit swamps, is effectively drained by the Pin, Koyah and Tengang Besar and here peat swamps are confined to basin sites, similar to, but less extensive than, the Bulud Napa and Melanking swamps.

Accumulations of oligotropic peat are the main parent materials. In general the peat is formed from swamp forest remains and is composed of wood and sedges in stages of decomposition varying from slightly humified and wholly fibrous to moderately humified pseudo-fibrous. Depths of peat vary from a few centimetres at the swamp extremities to over 6 m (20 ft) at their centres. The peat overlies deposits of alluvium which are everywhere fine-textured apart from the coastal edge of the Manalunan swamp where medium-, occasionally coarse-textured alluvium occurs. In addition at the peat swamp extremities there are distinct layers of peat and mineral matter resulting from successive stages of peat growth and alluvial incursion; associated with this are deposits of mixed mineral and organic matter, either intimately mixed or as predominantly mineral layers with discrete humus such as partly decomposed remains of roots, stems and leaves.

The association is everywhere covered by swamp forest; this comprises small trees many of which are fungus covered and in varying stages of decay. The ground vegetation consists of sedges (*Mapania* sp.) (Plate 2-16).

The association is dominated by Dystric Histosols, but where the surface accumulation of peat is less than 40 cm (16 in) Humic Gleysols occur (see the Sapi Association) (Figure 2-5).

Dystric Histosols: Klias Family

Typically the Dystric Histosol has a Co, IICg horizon sequence, the former varying in thickness from 40 cm (16 in) to several metres. The Co horizon is composed of acid sedge-carr peat in varying stages of decomposition, the upper layers being less decomposed and bound by actively growing roots. The underlying IICg horizon is developed in alluvium with grey to bluish grey colours and silty clay to clay textures. Plant remains, in varying stages of decomposition, are often incorporated in the alluvium. The whole profile is waterlogged and is normally under water. Profiles with Aa, Co and IICg horizons develop when mineral matter is incorporated at the surface as a result of flooding. The Aa horizon consists of intimately mixed mineral and organic matter, with loam to silt loam textures and moderately developed granular structures (Profile Od 1).

Limitations to agricultural development

Because of the severe problems of drainage and flooding the Klias Association is not recommended for agriculture.

Soil associations on alluvium 3. Valley floors and associated terraces

Two associations are mapped on valley floors and associated terraces in the upper reaches of the Kinabatangan and its tributaries. The Karamuak Association forms in the Karamuak valley and in valleys in the Mananam Plain; it comprises Orthic and Chromic Luvisols, Eutric Cambisols and Eutric Fluvisols which are formed on mixed alluvium derived largely from basic rocks. In constrast the Labau Association, which occurs in the Kuamut, Ulu Pinangah and Labau valleys is formed on alluvium derived almost wholly from sedimentary rocks and comprises Chromic, Dystric and Eutric Cambisols, Dystric and Eutric Fluvisols and Gleyic and Orthic Acrisols (Table 2-17).

The Binalik Association, which is confined to valley floors and associated terraces and which is formed on alluvium derived largely from ultrabasic rocks is described in detail in the appropriate section.

KARAMUAK ASSOCIATION

This association is most extensive in the Karamuak valley (Stereogram 2-17) and it also occurs in the valleys of the Longkabong, Mananam and middle reaches of the Tongod (Plate 2-23). Collectively the association covers about 40 km^2 (15 mi^2).

The soils are formed on a series of terraces and narrow floodplains, the oldest terrace being narrow, discontinuous, slightly dissected and occurring above flood level. The lower terraces which are all liable to short term flooding rise in the form of narrow steps from the river banks.

Parent materials comprise mixed alluvia derived from basic, ultrabasic and sedimentary rocks. This is of variable texture, is rarely stony and lacks concretions. Coarse-textured alluvium with pebble beds is restricted to narrow floodplains, levees and eyots.

Most of the land has been cleared for shifting cultivation and is either under cultivation or more commonly at some stage of secondary regrowth.

TABLE 2-17 Soil associations on valley floors and associated terraces

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Karamuak	Valley floors and terraces	Riparian Forest	Alluvium derived from basic and ultrabasic rocks	Orthic Luvisol	Numatoi
			Alluvium	Chromic Luvisol	Sabor
				Eutric Cambisol	Bulanat
				Eutric Fluvisol	Pegalan
Labau	Valley floors and terraces	Riparian Forest	Alluvium	Chromic Cambisol	Mankawagu
				Dystric Cambisol	Kelawat
				Eutric Cambisol	Bulanat
				Gleyic Cambisol	Luba
				Dystric Fluvisol	Tenghilan
				Eutric Fluvisol	Pegalan
				Orthic Acrisol	Paliu

The association comprises Orthic and Chromic Luvisols on the upper terraces. Eutric Cambisols on lower terraces and Eutric Fluvisols on levees, channel bars and eyots (Figure 2-6).

Orthic Luvisols: Numatoi Family

Deep well drained Orthic Luvisols of the Numatoi Family form on the upper terraces. They have A and Bt horizon sequences. Shallow ochric A horizons have loam to silt loam textures and overlie argillic B horizons, which are yellowish brown to dark brown in colour with clay to clay loam textures, strong subangular blocky structures, moderately thick continuous cutans and soft black manganese concretions.

These soils are slightly to moderately acid with moderate to low cation exchange capacities. Base saturation values in the argillic B horizon, however, are high as a result of high exchangeable magnesium contents.

Chromic Luvisols: Sabor Family

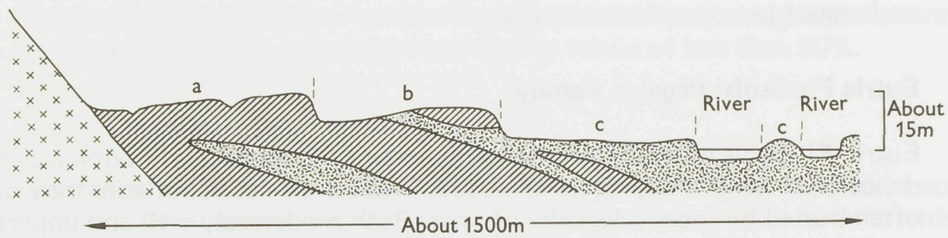
Deep well drained Chromic Luvisols of the Sabor Family occur in association with Orthic Luvisols of the Numatoi Family on upper terraces and are similar to them but have reddish brown instead of yellowish brown argillic B horizons.

Moderately well drained soils of the Sabor Family form sporadically at the back of low terraces where water drains slowly and where in addition there is seepage from adjoining terraces. Profiles are deep with A and Bt horizons. Ochric A and transition AB horizons of brown silt loam overlie agrillic horizons composed of strong brown clay loam to clay with yellowish red mottles, common manganese strains, angular blocky to prismatic structures and thick continuous cutans. Below about 50 cm (20 in) there are distinct gley mottles and greyish brown ped faces caused by minor fluctuations of ground water.

The soils are slightly acid with moderate to high cation exchange capacities and high base saturation values. They have high contents of exchangeable calcium and magnesium (Profile Lc4).

FIGURE 2-6

Karamuak Association



Coarse-textured alluvium

Medium-and fine-textured alluvium

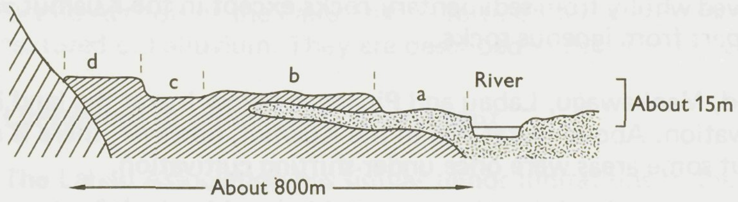
Basic igneous rocks

a Orthic and Chromic Luvisols

b Eutric Cambisol

c Eutric Fluvisol

Labau Association



Coarse-textured alluvium

Medium-textured alluvium

Sandstone and mudstone

a Dystric and Eutric Fluvisols

b Chromic, Dystric and Eutric Cambisols

c Gleyic Cambisol

d Orthic Acrisol

FIGURE 2-6 Theoretical cross-sections of the Karamuak and Labau Associations

Prepared by the Directorate of Overseas Surveys 1974

Eutric Cambisols: Bulanat Family

Deep moderately well drained Eutric Cambisols of the Bulanat Family are most extensive on lower terrace flats where they are formed on medium- to coarse-textured alluvium. They have A, B and C horizon sequences. Ochric A and transition AB horizons are brown to dark brown in colour, with sandy loam to sandy clay loam textures,subangular blocky structures and thin cutans.. At depth the soil is mottled with pale brown colours as a result of minor fluctuations of ground water.

These soils are chemically similar to the Luvisols being slightly to moderately acid with moderate to low cation exchange capacities, high base saturation values and exchangeable magnesium contents.

Eutric Fluvisols: Pegalan Family

Eutric Fluvisols of the Pegalan Family occur on the narrow floodplains and eyots on deposits of sand overlying pebble beds. Shallow ochric A horizons may occur but are often buried by recent deposits of sand. Both moderately well and imperfectly drained profiles occur, the latter having gleyic horizons of sand and pebbles below 50 cm (20 in).

Limitations to agricultural development

The Karamuak Association consists of a series of low terraces; the lower terraces have minor limitations due to drainage, flash floods and stony soils; upper terraces are above flood level and have well drained soils with high base saturation which are suitable for agriculture.

LABAU ASSOCIATION

This association is restricted to the upper reaches of the Kinabatangan and occurs along the valleys of the Kuamut, Pinangah, Tongod, Mankawagu and Labau (Stereogram 2-14). It covers about 80 km^2 (30 mi^2). It occurs on narrow valley floors comprising series of low terraces, the lower ones being subject to short term flash flooding.

Parent materials are dominantly moderately fine-to coarse-textured, often stony, alluvium derived wholly from sedimentary rocks except in the Kuamut valley, where it is derived in part from igneous rocks.

In the Tongod, Mankawagu, Labau and Pinangah below Inarat the land is under shifting cultivation. Above Inarat and in the Kuamut, however, there is no longer any habitation but some areas were once under shifting cultivation.

The association comprises Chromic, Dystric, Eutric and Gleyic Cambisols on very low terraces and narrow floodplains, with Orthic Acrisols on higher and older terraces. Dystric and Eutric Fluvisols are confined to narrow levees and eyots (Figure 2-6).

Chromic Cambisols: Mankawagu Family

Chromic Cambisols of the Mankawagu Family are formed on deposits of medium- to coarse-textured stratified alluvium. They are deep, moderately well drained soils and have A, B and C horizon sequences. Ochric A horizons overlie cambic B horizons which are of variable thickness and comprise reddish brown sandy loam with subangular blocky structures and cutans. The underlying C horizon is composed of weekly structured sandy loam to loamy sand or may be formed from stratified sand with pebbles.

The only soil analysed was from an area reverting after shifting cultivation; it was slightly acid with moderate amounts of exchangeable calcium and magnesium and high to very high percentage base saturation values in the cambic horizon (Profile Bc1).

Dystric and Eutric Cambisols: Kelawat and Bulanat Families

The Kelawat and Bulanat Families are very similar to the Chromic Cambisols of the Mankawagu Family. They are formed from deposits of stratified alluvium varying from moderately fine to coarse in texture; they are moderately deep to deep, moderately well drained soils having A, B and C horizon sequences. Shallow ochric A horizons overlie cambic B horizons which vary from brown to yellowish brown in colour with sandy loam to sandy clay loam textures, subangular blocky structures and cutans. C horizons which are often stratified comprise yellowish brown sandy clay loam to sand often with pebbles.

The Kelawat and Bulanat Families are separated on percentage base saturation values in the cambic B horizon, the former having values of less than 50%.

Gleyic Cambisols: Luba Family

Gleyic Cambisols of the Luba Family are formed on moderately fine-to coarse-textured alluvium. They are moderately deep to deep imperfectly drained soils with A, B and Bg or Cg horizon sequences. Shallow ochric A and cambic B horizons are similar to those in the Dystric and Eutric Cambisols but have mottles of low chromas and manganese concretions in addition. Gleyic horizons which are composed of light grey sandy clay loam to sand, often with pebbles, occur below 50 cm (20 in).

These soils are chemically similar to the Eutric Cambisols of the Bulanat Family with slightly acid reaction, high base saturation values and moderate contents of exchangeable magnesium.

Dystric and Eutric Fluvisols: Tenghilan and Pegalan Families

Dystric and Eutric Fluvisols of the Tenghilan and Pegalan Families are restricted to narrow levees and eyots composed of stratified coarse-textured, often stony, alluvium. They are deep moderately well to well drained soils lacking diagnostic horizons. They are separated on percentage base saturation values, Eutric Fluvisols having values of more than 50% between 20 and 50 cm of the surface.

Orthic Acrisols: Paliu Family

Orthic Acrisols of the Paliu Family form on terraces of moderately fine-to medium-textured old alluvium. They are described in detail in the Brantian Association.

Limitations to agricultural development

The Labau Association has similar minor limitations to the Karamuak Association and much of the land is suitable for agricultural development.

Soil associations on alluvium 4. Terraces

Five associations are formed on terraces and associated valley floors. Of these the Brantian Association is collectively the most extensive. It comprises broad flat terraces, series of narrow stepped terraces and dissected terraces in the form of low hills; they are composed largely of medium-textured alluvium with isolated pebble deposits. Orthic Acrisols are dominant with sporadic Ferric Acrisols and Gleyic Podzols. In addition the association includes Gleyic Acrisols, Dystric and Humic Gleysols and Dystric Histosols all of which are formed on valley floor deposits of medium-to coarse-textured alluvium. Identical valley floor deposits occur in the Sook Association, but low terraces with Orthic Acrisols and Gleyic Podzols are less extensive. Gleyic Podzols are, however, dominant in the Kepayan Association and in some areas are the only soils present; in general they form in association with Gleyic Acrisols and Dystric

Gleysols. The Sinarun Association is formed on areas of strongly dissected inland plains now in the form of terraces and low hills. These are formed from mudstone and sandstone overlain by variable depths of alluvium. The association comprises Orthic Acrisols on the low hills with Gleyic Acrisols and Gleysols on narrow valley flats.

Along the east coast of the Dent Peninsula a broad low coastal plain extends from Tambisan to Dent Haven. One association, namely the Tungku Association has been mapped on this; it comprises Chromic and Gleyic Luvisols on old alluvium overlying coral. (Table 2-18).

BRANTIAN ASSOCIATION

The Brantian Association occurs discontinuously throughout the length of the Kinabatangan valley with major developments in the Labau valley from Sinoa to Lanas (Stereogram 2-14) in the Pinangah valley, at the confluence of the Milian and Pinangah, sporadically in the Karamuak valley and Mananam Plain, from the Kuamut confluence (Stereogram 2-13) downstream to Tedog, extensively on the edge of the floodplain south of Gomantong (Stereogram 2-11), and in the Lokan valley downstream from Kuala Rawog. In the Segama valley it is restricted to the Tomanggong Estate and it also occurs near Sandakan Airport. It covers a total area of about 245 km^2 (95 mi^2).

TABLE 2-18 Soil associations on terraces

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Brantian	Terraces and terrace remnants; variable dissection with flat tops and short moderate to steep slopes (10-20^o); also valley floors	Dipterocarp and Heath Forest	Alluvium	Orthic Acrisol	Paliu
				Ferric Acrisol	Lumisir
				Gleyic Acrisol	Inanam
				Gleyic Podzol	Baiayo
				Orthic Podzol	Silimpopon
				Chromic Cambisol	Mankawagu
				Dystric Gleysol	Koyah
				Humic Gleysol	Guan
			Peat	Dystric Histosol	Klias
Sook	Terraces and valley floors	Dipterocarp and Heath Forest	Alluvium	Gleyic Acrisol	Inanam
				Dystric Gleysol	Koyah
				Humic Gleysol	Guan
				Orthic Acrisol	Paliu
				Gleyic Podzol	Baiayo
			Peat	Dystric Histosol	Klias
Kepayan	Terraces	Heath Forest	Alluvium	Gleyic Podzol	Baiayo
				Gleyic Acrisol	Inanam
				Orthic Acrisol	Paliu
Sinarun	Dissected terraces in the form of low hills with moderate to steep slopes (15-25^o)	Dipterocarp Forest	Alluvium	Orthic Acrisol	Paliu
				Gleyic Acrisol	Inanam
				Dystric Gleysol	Koyah
				Humic Gleysol	Guan
			Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat
Tungku	Coastal plain	Dipterocarp Forest	Calcareous alluvium	Chromic Luvisol	Terang
				Gleyic Luvisol	Lungpatau

The Brantian Association occurs on terraces and terrace remnants with upper surfaces in general at heights of 15-30 m (50-100 ft) above present floodplain levels at altitudes ranging from about 15 m (50 ft) in the lower Kinabatangan to 510 m (1 700 ft) in the Labau valley. In the Labau valley the association includes a series of 4 main terraces, but elsewhere it is mapped on single terraces, which are either strongly dissected with narrow flat tops and short moderate to steep slopes or slightly undulating tops and fewer short moderate slopes. The association also includes narrow valley bottoms at present-day floodplain level.

Old alluvium is the dominant parent material and this normally rests unconformably on interbedded sandstone and mudstone; rarely are the deposits thin enough for the rock to be exposed in soil profiles. The alluvium is mainly medium, rarely fine, in texture and in places contains variable amounts of pebbles. Deep pebble deposits also occur. The pebbles are mainly of quartz and sandstone but in addition are formed of chert in the Kuamut area, acid igneous rocks and chert at Tomanggong and basalt in the Mananam Plain. Alluvium at floodplain level varies from coarse to fine in texture. Lowland Dipterocarp Forest covers much of the association and is often rich in *Eusideroxylon zwageri (belia..)* while heath forest occurs sporadically. Sample plots in the Lokan valley recorded *Koompassia malaccensis, Dyera costulata, Shorea exelliptica, Dipterocarpus confertus, D. pachyphyllus* and *Scaphium macropodum* as large emergent trees up to 54 m (180 ft) in height. Species of the middle storey included *Ganua kingiana, Dacryodes rostrata, Myristica villosa, Sterculia treubii* and the understorey included *Mallotus penangensis, Polyalthia sumatrans, Baccaurea puberla, Parinari asperula.*

Orthic Acrisols are the dominant soils in the association and include deep well drained profiles on terrace tops and gentle slopes and eroded profiles on short steep slopes. Ferric Acrisols, Gleyic Acrisols and Gleyic Podzols occur sporadically with Chromic Cambisols and Orthic Podzols restricted to deep pebble deposits. Dystric Gleysols, Humic Gleysols and Dystric Histosols develop at the present day floodplain level (Figure 2-7). The Gleyic Acrisols, Dystric Gleysols, Humic Gleysols and Dystric Histosols are described in detail in the Sook Association and Gleyic Podzols are described in the Kepayan Association.

Orthic Acrisols: Paliu Family

Well drained Orthic Acrisols of the Paliu Family develop on terrace flats and edges and have O, A, E and B horizon sequences. Profiles are distinguished on the basis of the colour and texture of the argillic B horizon. The O horizon consists of reddish brown acid raw humus and overlies weakly developed A horizons of sand with medium to low organic matter contents, The sand is bleached and often forms washings on the soil surface. The E horizon is strongly developed and varies from 15-30 cm (6-12 in) in thickness. It is composed of weakly structured loamy sand to sandy loam, the upper more strongly leached parts being light grey in colour and the lower parts yellowish brown. The E horizon passes through a transition EB horizon to argillic B horizons with sandy clay loam to clay loam textures, moderate to strongly developed sub-angular blocky structures and prominent cutans. Most commonly the argillic B horizon has strong brown to yellowish red colours which contrast strongly with the yellowish E horizon. Less common are profiles with yellowish red E and red argillic B horizons and profiles which lack colour contrast, both E and argillic B horizons having yellowish brown to brownish yellow or pale yellow colours. While argillic horizons with strongly developed cutans and marked textural increases are a common feature of most Orthic Acrisols some profiles show only weak textural increases and thin cutans. In addition the argillic horizons of these profiles often have fine subangular blocky structures and very friable consistencies and in many respects are similar to oxic horizons except that cation exchange capacities of the clay fraction exceed 16 meq%. Such profiles, which occur notably on the flats of low hills in the Labau valley and Penawan Plain, have also been studied on similar sites and at similar altitudes in the Sook Plain to the west of the survey area and at Sandakan;one profile on a terrace at Sandakan showed weakly developed illuviation cutans and many features of oxic horizons (Eswaran and Sys, 1971a and b, 1972).

Many profiles contain pebbles which are either distributed haphazardly or occur as distinct depositional layers. The pebbles are most commonly formed of quartz. Sandstone and chert pebbles are less common and pebbles formed of acid igneous rocks and basalt were noted at Tomanggong and Mananam respectively. In addition iron concretions and concretions of ferruginous sandstone occur either as distinct depositional layers or in association with pebbles. Pebbles do not normally occur on terrace flats but are common on terrace edges.

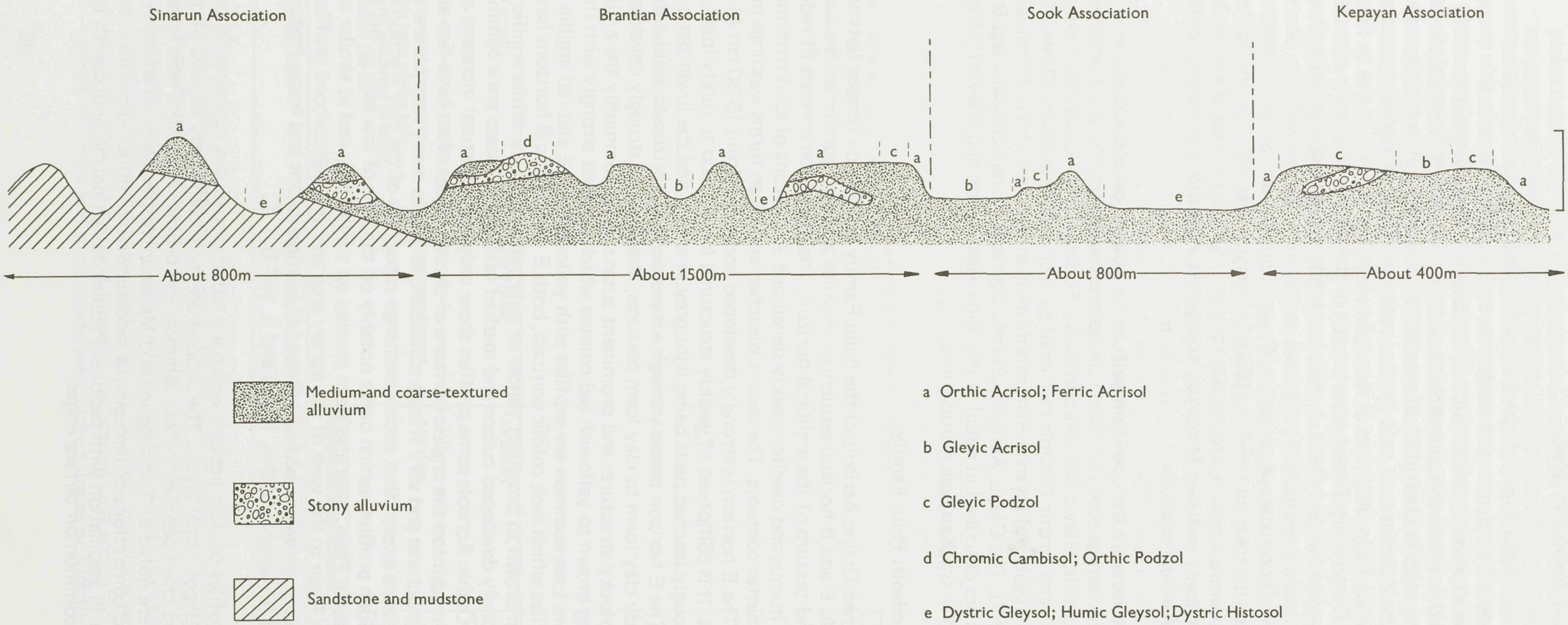


FIGURE 2-7 Theoretical cross-section of the Sinarun, Brantian, Sook and Kepayan Associations

D.O.S. 3182G

Prepared by the Directorate of Overseas Surveys 1974

Moderately well drained Orthic Acrisols of the Paliu Family closely resemble the well drained profiles, but as a result of fluctuations of ground water in the lower horizons have B or BC horizons which are mottled with colours of low chroma.

These profiles are all strongly to extremely acid, have very low amounts of exchangeable cations and very low base saturation values (Profiles Ao 3 and 4).

Ferric Acrisols: Lumisir Family

Ferric Acrisols of the Lumisir Family occur sporadically in close association with Orthic Acrisols of the Paliu Family. They are well drained with A, E, Bt and C horizon sequences. The A and E horizons are identical to those described in the Paliu Family, but the argillic B horizon is composed of variegated sandy clay loam to clay loam with prominent yellowish red colours and iron concretions. Structures are strongly developed subangular blocky and cutans are prominent. In addition pebbles may occur as in the Paliu Family.

These soils are strongly acid with very low contents of exchangeable cations and very low percentage base saturation values (Profile Af 1).

Orthic Podzols: Silimpopon Family

Orthic Podzols of the Silimpopon Family are formed on deep deposits of sand and quartz pebbles; they are of very restricted occurrence and are deep and excessively drained with A, E, Bh, Bfe and C horizons. The E horizon, which is albic, is composed mainly of quartz pebbles with a light grey sand matrix. It is of variable depth and tongues into the underlying spodic B horizons. The upper Bh horizon is normally less than 8 cm (3 in) in thickness and overlies a strongly indurated Bfe horizon. Both spodic horizons and the underlying C horizon are composed mainly of quartz pebbles with loamy sand matrices (Profile Po 1).

Chromic Cambisols: Mankawagu Family

Chromic Cambisols of the Mankawagu Family occur on dissected terraces on slopes often greater than 20°. They are also formed on deep deposits of pebbles with coarse-textured matrices. The soil surface may be covered with pebbles and all horizons are dominated by pebbles. These excessively drained soils have A, E, B and C horizon sequences. Colours range from yellowish brown in the E horizon to strong brown or reddish yellow in the cambic B horizon. Textures range from loamy sand to sandy loam or sandy clay loam; a weak textural increase is sometimes apparent in the cambic horizon. Structures are only weakly developed.

These are extremely acid soils with very low contents of exchangeable cations and percentage base saturation values (Profile Bc 2).

Limitations to agricultural development

Large areas of the Brantian Association are quite flat but slope is a severe limitation on the short steep terrace edges where stoniness could also be a limitation. The soils on the terraces are all very strongly leached and extremely acid. This is marginal land.

SOOK ASSOCIATION

The Sook Association occurs in the Penawan Plain (Stereogram 2-15) in the centre of the Lokan Peneplain (Stereogram 2-18), in the Bangan Basin and east of the Pinangah valley. The total area occupied by the association is about 115 km^2 (45 mi^2).

The landform comprises a series of low terraces and floodplains which in the Lokan Peneplain appear to represent old courses of the Sungai Lokan and its tributaries. In the Bangan Basin and east of the Sungai Pinangah the association occupies concentrically arranged troughs bounded by sandstone ridges. The troughs contain minor streams with narrow floodplains and low terraces.

The soils are formed on terraces of medium-to coarse-textured sometimes pebbly alluvium. Tiered deposits are common notably in the Penawan Plain where medium-to coarse textured deposits frequently overlie medium-to moderately-fine textured older alluvium. The floodplains comprise coarse-textured alluvium which in places is overlain by shallow peat.

Lowland Dipterocarp Forest is wide-spread with patches of heath forest on terrace remnants. The forest on the floodplains has many small trees and is often swampy with sedge undergrowth.

Gleyic Acrisols are the dominant soils in the Association and form in association with Dystric Gleysols, Humic Gleysols and Dystric Histosols on the lowest terraces and present-day floodplains. Gleyic Podzols (see Kepayan Association) occur sporadically. Orthic Acrisols (see Brantian Association) are formed on the upper terraces (Figure 2-7).

Gleyic Acrisols: Inanam Family

Imperfectly drained Gleyic Acrisols of the Inanam Family occur widely on low terraces and sporadically on present-day floodplains. They have A, E, Bt and Bg horizon sequences. The A horizon is ochric and overlies a shallow yellowish brown sandy loam E horizon. The argillic B horizon is prominently mottled throughout and has sandy loam to sandy clay loam texture and weakly developed subangular blocky structure; it becomes progressively greyer and less mottled with depth due to periodic groundwater fluctuations; it is gleyic below 50 cm (20 in).

The ochric A horizon has moderate amounts of organic matter. The soils are strongly to extremely acid throughout and contents of exchangeable bases and percentage base saturation values are very low.

Dystric Gleysols: Koyah Family

Poorly and very poorly drained Dystric Gleysols of the Koyah Family occur in swamps on the present-day floodplains and on low terraces. The poorly drained soils have A, Bg and Cg horisons. The A horizon is shallow and ochric and overlies gleyic B horizons which are prominently mottled and weakly structured, light grey loamy sands; pebbles may occur. Strong brown and yellowish red mottles are common in both the gleyic B and C horizons and indicate considerable fluctuations of groundwater (Profile Gd 4).

Very poorly drained soils have A and Cg horizons, the latter being composed of light grey sandy loam to sandy clay loam; some are developed on tiered deposits.

Humic Gleysols: Guan Family

Humic Gleysols of the Guan Family occur in swamps in close association with the Koyah Family. They have histic O and gleyic C horizons, the former comprising humic sand with high organic matter content and the latter light grey weakly structured sand. These soils are strongly to extremely acid with very low contents of total exchangeable bases in the Cg horizon (Profile Gh 3).

Dystric Histosols: Klias Family

Dystric Histosols of the Klias Family form in swamps with extremely sluggish drainage; such conditions are prevalent in narrow valley bottoms tonguing into low terraces. The soils are formed on peat overlying alluvium. The peat is generally well decomposed but contains pieces of only slightly decomposed wood; it overlies light grey structureless sand.

Limitations to agricultural development

Much of the Sook Association is unsuitable for agricultural development. Drainage limitations are severe and the nutrient status of all soils is low.

KEPAYAN ASSOCIATION

This association occurs sporadically from the Labau valley (Stereogram 2-14) in the west to the Maruap Hills in the east with occurrences for example in the Penawan Plain (Stereogram 2-15), the Ruku Ruku and Karamuak valleys, the Inarat Lowlands at Sungai Manila and at Sandakan Airport. It covers about 40 km^2 (15 mi^2) comprising terraces at heights ranging from 3-15 m (10-50 ft) adjacent to the coast to about 450 m (1 500 ft) in the Labau valley and Penawan Plain. Along the coast the terraces are presumed to be of marine origin. In all cases they are flat with only minor surface dissection.

Parent materials comprise deposits of sand which are normally underlain by medium-to fine-textured alluvium at depths of 90-150 cm (3-5 ft) from the surface. Heath forest with small stunted, often decaying, trees occurs naturally on the terraces (Plate 2-22); it passes sharply into Dipterocarp Forest at the terrace edges. In the Sandakan District, however, much of the natural vegetation has been disturbed by sand and gravel extraction, construction of the airport and by agricultural development.

Gleyic Podzols are the dominant soils with less frequent poorly drained Gleyic Acrisols and Orthic Acrisols on terrace edges (Figure 2-7). Gleyic Acrisols are described in the Sook Association and Orthic Acrisols are described in the Brantian Association.

Gleyic Podzols: Baiayo Family

Gleyic Podzols of the Baiayo Family form under heath forest and are often sharply demarcated on the ground by a change from heath to Dipterocarp Forest. Most profiles are formed on sand overlying clay within 60-150 cm (2-5 ft) of the surface. They have O, A, E, Bhfe and IIBC horizon sequences. Typically the A horizon is a humus-stained sand with weakly developed granular structure. This overlies a deep albic E horizon which is composed of light grey sand; it is normally hard and brittle, is penetrable by auger, but only with difficulty, and has many characteristics of a duripan. It is sharply separated from the spodic horizon, which occurs in the upper 15 cm (6 in) of the clay underlying the albic E horizon and has humus coatings on the structure faces and segregations of dark reddish brown humus and iron. Textures range from sandy clay loam to clay loam. The spodic horizon is underlain by a pale brown mottled IIBC horizon with clay loam texture, prismatic structure and humus coatings on ped faces. This becomes progressively greyer and less mottled with depth and a gleyic horizon often occurs within 125 cm (50 in).

Soils with indistinct spodic horizons are less common. They have deep surface accumulations of acid raw humus with very high amounts of organic matter and strongly developed albic E horizons which are composed of light grey sand, the lower parts of which are often rust mottled as a result of water perching above the finer-textured B and BC horizons. The spodic horizons rarely form distinct horizons but occur as humus coatings and iron concretions on structure faces in the upper B horizon which is composed of variegated clay. Gleying in the B an BC horisons is caused by a combination of slow percolation and groundwater fluctuations.

A minority of profiles are formed on sand and quartz pebbles. They have O, A, E, Bh, Bhfe and Cg horizon sequences. The light grey loamy sand albic E horizon is sharply separated from thin dark reddish brown Bh and weakly cemented Bhfe horizons with loamy sand to sandy loam textures. The spodic horizons are underlain by gleyic horizons of sand to loamy sand which become progressively greyer and less mottled with depth.

These extremely acid soils have very low contents of exchangeable bases and very low percentage base saturation values.

Limitations to agricultural development

The Kepayan Association is of no agricultural value largely because of the inherent nutrient deficiencies and extreme acidity of the soils. The soils are all subject to water-table fluctuations with periods of extreme wetness followed by extreme surface drying when water tables are at depth.

SINARUN ASSOCIATION

This association occurs extensively in the west of the survey area notably in the Labau valley (Stereogram 2-14) and Penawan Plain covering a total area of about 350 km^2 (135 mi^2).

It forms on strongly dissected terrace remnants of a formerly extensive inland plain at heights of about 450 m (1 500 ft). These high level terraces are mainly surrounded by mountains rising to about 1 050 m (3 500 ft) but where the Labau has incised deep gorges the terraces themselves form the positive relief. The dissected terraces are in the form of low hills and alluvial flats with an amplitude of about 30-45 m (100-150 ft), convex crests and short moderate to very steep slopes.

Parent materials comprise deposits of medium-to fine-textured, sometimes pebbly, alluvium which overlies mudstone and sandstone. The majority of low hills have cappings of alluvium and the mudstone and sandstone outcrop on the lower slopes; on some hills cappings of alluvium have been completely removed. Alluvium in the valley flats is medium-or coarse-textured. Dipterocarp Forest is widespread with swamp forests on some valley flats.

Deep well drained Orthic Acrisols are the dominant soils and are formed both on alluvium (see the Brantian Association) and on mudstone and sandstone (see the Dalit Association). Poorly drained Gleyic Acrisols and Dystric and Humic Gleysols (see the Sook Association) occur on minor valley flats (Figure 2-7).

Limitations to agricultural development

The Sinarun Association consists largely of marginal land with similar limitations to the Brantian Association.

TUNGKU ASSOCIATION

The Tungku Association is restricted to the east coast of the Dent Peninsula (Plate 2-21; Stereogram 2-12). It is about 3 km (2 mi) in width and covers about 52 km^2 (20 mi^2). Inland it adjoins low hills and towards the coast it is bordered by a coastal backswamp.

It occurs on a low level coastal plain rising very gradually to the west. The soils are formed on calcareous alluvium which is predominantly fine-textured and underlain by coral or coral debris. The depth of this alluvium is about 120 cm (48 in) and outcrops of coral are confined to the sides of minor streams and stream beds. Deposits of more recent alluvium occur adjacent to the larger streams.

Apart from the eastern edge of the association where secondary forest occurs and on Pulau Tambisan where coconuts have been planted, the association is under Dipterocarp forest.

The association includes well drained and moderately well drained Chromic Luvisols together with imperfectly and poorly drained Gleyic Luvisols on the eastern edge where it borders a coastal backswamp (Figure 2-4).

Chromic Luvisols: Terang Family

Well drained Chromic Luvisols of the Terang Family are the dominant soils in the association. They are characterised by fine textures, yellowish red colours and coral debris within 120-150 cm (4-5 ft) of the surface. Typically the ochric A horizon is little more than 3 cm (1 in) in thickness. It overlies E or EB horizons which are yellowish brown to dark brown in colour and have silt loam to clay textures. The argillic B and BC horizons are composed of variegated yellowish red clay to clay loam with strong blocky structure, cutans and the suggestion of slickenslides. The BC horizon is sharply separated from the underlying coral debris. Moderately well drained Chromic Luvisols are very similar to the well drained soils, but are subject to the fluctuations of groundwater; this is reflected in duller colours with grey mottling.

These soils are slightly acid to near neutral in reaction. They have low organic matter contents. All horizons have moderate cation exchange capacities and high exchangeable calcium values. Base saturation values are high to very high (Profile Lc 2).

Gleyic Luvisols: Lungpatau Family

Imperfectly and poorly drained Gleyic Luvisols of the Lungpatau Family complete the catenary sequence of soils in the Tungku Association. The imperfectly drained profiles have A, E, B and Bg horizons, the A and E or EB horizons being similar to those in the Terang Family. The underlying argillic B horizon is mottled in its upper parts and becomes truly gleyic below 50 cm (20 in), with prominent light grey mottles as a result of fluctuating groundwater; it has cutans and strongly developed prismatic structure; textures are in the clay loam to clay range throughout.

Poorly drained Gleyic Luvisols of the Lungpatau Family occur on the eastern edge of the association, where it borders a coastal backswamp. The water table fluctuates to the surface and the soils are periodically flooded. The typical profile consists of a dark occasionally black and humic, clay to clay loam A horizon. It overlies a brown clay to clay loam AB and gleyic Ng and BCg horizons composed of grey, rust mottled clay. Coral and shell fragments occur sporadically; coral itself underlies the BCg horizons normally within 60-90 cm (24-36 in). of the surface (Profile Lg 2).

Limitations to agricultural development

The majority of the Tungku Association is composed of high quality agricultural land eminently suitable for development.

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

Three associations, namely the Lungmanis, Silabukan and Kalabakan Associations have been mapped in areas where mudstone is the dominant parent material. The Lungmanis Association is a broad association of hills of very low amplitude and alluvial flats. It has not been possible to map the alluvial flats separately and the association therefore includes considerable areas of Gleyic Luvisols and Acrisols which are formed on alluvium and are described in the Kinabatangan Association. Gleyic Luvisols and Acrisols are also the dominant soils on the low hills and they form in association with Ferric Acrisols and Luvisols, Orthic Acrisols and Orthic Luvisols. The hills which comprise the Silabukan Association are formed mainly from mudstone and are somewhat higher than those in the Lungmanis Association; alluvial flats are minor features. A similar range of soils occur but the Gleyic soil units are less common as a result of the steeper slopes. The Silabukan Association progresses into the Kalabakan Association which comprises Orthic Acrisols and Orthic Luvisols on hills and ridges of moderate amplitude composed mainly of mudstone with subordinate sandstone (Table 2-19) (Figure 2-8).

TABLE 2-19 Soil associations on mudstone and minor sandstone

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Lungmanis Other soils described in the Rumidi Association may also occur	Hills of very low relief (slopes 0-15°)	Dipterocarp Forest	Mudstone and minor sandstone	Gleyic Acrisol	Masaum
				Ferric Acrisol	Batang Sipit
				Orthic Acrisol	Kumansi
				Gleyic Luvisol	Lunparai
				Ferric Luvisol	Lumerau
				Orthic Luvisol	Lumpongon
			Alluvium	Gleyic Acrisol	Inanam
				Gleyic Luvisol	Buran
Silabukan	Hills of low relief (slopes 0-15°) and valley floors	Dipterocarp Forest	Mudstone and minor sandstone	Gleyic Acrisol	Masaum
				Ferric Acrisol	Batang Sipit
				Orthic Acrisol	Kumansi
				Gleyic Luvisol	Lunparai
				Ferric Luvisol	Lumerau
				Orthic Luvisol	Lumpongon
			Alluvium	Gleyic Acrisol	Inanam
				Gleyic Luvisol	Buran
Kalabakan	Hills of moderate relief (slopes 10-20°)	Dipterocarp Forest	Mudstone and minor sandstone	Orthic Acrisol	Kumansi Tanjong Lipat
				Ferric Acrisol	Batang Sipit
				Orthic Luvisol	Lumpongon
				Ferric Luvisol	Lumerau

LUNGMANIS ASSOCIATION

This extensive association covers about 800 km^2 (310 mi^2). It occurs notably between the Sungai Segaliud and the Sungai Lokan (Stereogram 2-16), to the south of Sandakan Bay, in embayments extending south from the Sungai Kinabatangan which are accupied by its tributaries the Latangan, Lamag, Takala, Koyah and Tenegang Besar, in the Dent Peninsula to the west of the Sungai Tabin, and in the Lumerau Lowlands.

It is formed on low relief comprising alluvial flats and minor hillocks with a relief amplitude which rarely exceeds 15 m (50 ft) and with slopes in the 0-15° range, the majority being less than 10°. The alluvial flats are often wide and include patches of swamp; they are subject to flooding. Valley floors along upper reaches of rivers tributary to the Kinabatangan are also included but these are less vulnerable to flooding.

Parent materials comprise mudstone and rare sandstone; they are bedded in the Lungmanis, Latangan, Lamag and Lumerau areas but elsewhere occur in slump formations. Sporadic pebble deposits on low hills at Dagat and in the Koyah and Segaliud valleys suggest that some areas may well be terrace remnants. Fine-textured alluvium occurs on the alluvial flats.

The association includes a wide range of Acrisols and Luvisols. Gleyic Acrisols and Gleyic Luvisols form on the alluvial flats (see the Kinabatangan Association), on lower slopes and sporadically on flat crests of the low mudstone hills. Ferric and Orthic Acrisols and Luvisols occur on middle and lower slopes. Where slump formations occur the range of soils described in the Rumidi Association may occur; these include Ferric and Orthic Acrisols, and Ferric, Chromic and Orthic Luvisols (Figure 2-8).

Gleyic Acrisols: Masaum Family

Imperfectly drained Gleyic Acrisols of the Masaum Family are derived largely from mudstone; they occur on lower slopes and occasionally on the flat tops of low hillocks. They have A, possibly E, but more commonly EB, B and BCg horizons. The gleyic

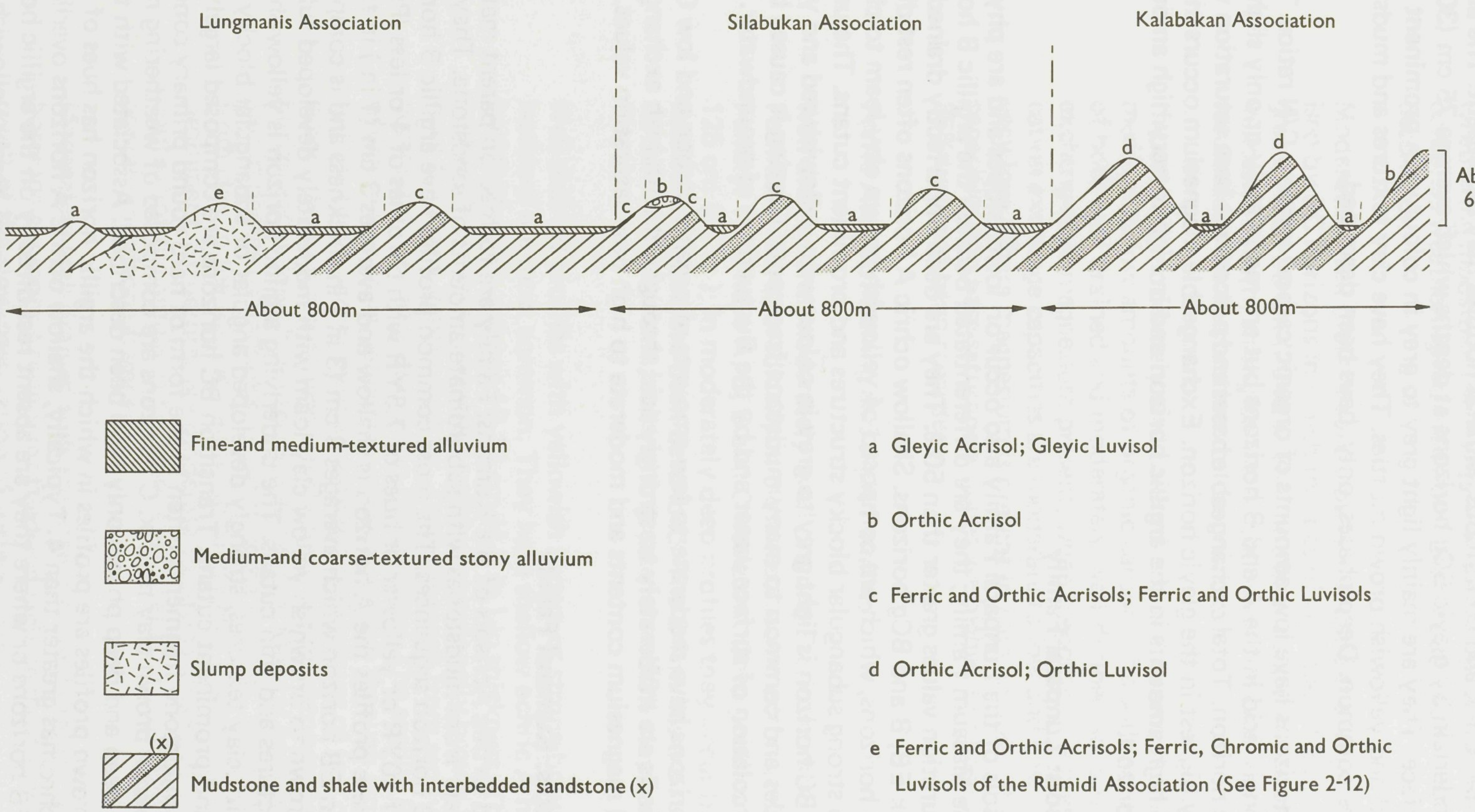


FIGURE 2-8 Theoretical cross-section of the Lungmanis, Silabukan and Kalabakan Associations

Prepared by the Directorate of Overseas Surveys 1974

horizon which occurs below 50 cm (20 in), results from a combination of slow percolation and fluctuations of groundwater, the latter being the dominant process on lower slopes adjoining alluvial flats. The A horizons are shallow and ochric. E or EB horizons where present average 10-30 cm (4-5 in) in thickness and comprise brownish yellow loam to clay loam with moderately developed subangular blocky structures. The underlying argillic B horizon is commonly yellowish brown to brownish yellow and is faintly mottled with colours of low chroma; less commonly base colours are in the strong brown to yellowish red range (Profile Ag 7). Textures are in the clay loam to clay range; structures are moderate to strongly developed subangular blocky and cutans are often thick and continuous. Mineral nodules may be present. The argillic horizon is underlain by gleyic BCg horizons at depths which average 75 cm (30 in) from the surface. They are mainly light grey to grey in colour with prominent yellowish red and yellowish brown mottles. They have clay textures and mudstone fragments are common. Deep phases, only, have been described.

The ochric horizons have low amounts of organic carbon and low C/N ratios. These soils are strongly acid in the A and B horizons but are moderately or only slightly acid in the gleyic horizon. Total exchangeable bases and percentage base saturation values are similarly highest in the gleyic horizon. Exchangeable magnesium occurs in moderate to high amounts in the argillic horizon and in high to very high amounts in the gleyic horizon.

Gleyic Luvisols: Lunparai Family

Gleyic Luvisols of the Lunparai Family also occur on lower slopes and are physically similar to the Masaum Family; they are differentiated because the argillic B horizon has base saturation values greater than 50%. They are deep imperfectly drained soils with A, weak EB, B and BCg horizons. Shallow ochric A horizons often rest directly on argillic B horizons, which are composed of yellowish brown clay loam to clay with moderate to strong subangular blocky structures and prominent cutans. The underlying gleyic BC horizon is light grey to grey in colour with yellowish red and yellowish brown mottles and common to many mudstone fragments. Gleying is caused both by the slow percolation of surface water and by the fluctuations of groundwater.

Ochric A horizons have moderate to low amounts of organic carbon and low C/N ratios. The soils are moderately to strongly acid throughout with high exchangeable calcium and magnesium contents and moderate to high base saturation values.

Orthic Acrisols: Kumansi Family

Well drained Orthic Acrisols of the Kumansi Family are formed on parent materials derived largely from mudstones with subordinate amounts of sandstone. They have A, EB, B and C horizon sequences. The most common profiles have argillic B horizons with hues of 10YR or yellower or hues of 7.5YR with chromas of 4 or less (Profile Ao 8). In these profiles the A horizon is shallow and averages 3 cm (1 in) in thickness. It overlies an EB horizon which averages 8 cm (3 in) in thickness and is composed of yellowish brown to brownish yellow clay loam with moderately developed subangular blocky structures and thin cutans. The underlying argillic horizon is yellowish brown in colour with clay textures, strongly developed angular or subangular blocky structures and prominent cutans. Transition BC horizons are composed largely of weathering mudstone fragments often in the form of hard round primary concretions with a yellowish brown clay matrix. C horizons are composed of weathering mudstone. Moderately deep and deep phases only have been described. Associated with the yellowish brown profiles are profiles in which the argillic horizon has hues of 7.5YR or 5YR with chromas greater than 4. Typically, shallow ochric A horizons overlie transition EB horizons or where they are absent rest directly on the argillic horizon. The EB horizon comprises yellowish brown to strong brown, rarely yellowish red, sandy clay loam to clay loam. Cutans are normally present. The argillic B horizon is strong brown to yellowish red in colour with clay textures. Structures are strongly developed subangular or angular blocky, often with a tendency towards prismatic and cutans are prominent. Transition BC horizons are composed of weathering mudstone with a strong brown to yellowish red clay loam to clay matrix and the C horizons are formed of weathering mudstone. Moderately deep and deep phases only have been described. Some soils are also formed on sporadic outcrops of red mudstone. Profiles have A, EB, B and C horizon sequences. The diagnostic argillic B horizon has hues of 5YR with chromas of 4 or more or redder hues. In well drained profiles shallow ochric A horizons overlie transition EB horizons which average 8-10 cm (3-4 in) in thickness and are composed of brown to reddish brown clay loam to clay, with moderately developed subangular blocky structures and cutans. The argillic B horizon is reddish brown to red in colour with clay textures, moderate to strong subangular or angular blocky structures and prominent cutans. Transition BC horizons contain many weathering mudstone fragments in a reddish brown to red clay matrix and C horizons comprise weathering red mudstone. Moderately deep and deep phases have been described.

Moderately well drained soils closely resemble the well drained soils but are characterised by BC horizons in which mottles of chromas of 2 or less are prominent at depths greater than 50 cm (20 in). The mottling is superimposed on base colours of either yellowish brown, strong brown to yellowish red or reddish brown and is considered to result from the fluctuations of groundwater.

In both the moderately well drained and well drained soils ochric A horizons have medium to low amounts of organic carbon. The soils are strongly acid. The base status of both well drained and moderately well drained soils reflects the percentage of exchangeable magnesium present; when magnesium is present in low amounts then cation exchange capacities are moderate to low and base saturation values are low to very low. Where magnesium is present in high amounts then both cation exchange capacities and base saturation values are higher, but base saturation values in excess of 35% have not been recorded.

Ferric Acrisols: Batang and Sipit Families

Well drained and moderately well drained Ferric Acrisols of the Batang and Sipit Families occur sporadically in close association with Orthic Acrisols of the Kumansi Family. They have A, E, B and C horizons. Deep profiles have C horizons below 125 cm (50 in); in moderately deep profiles they occur below 50 cm (20 in); no shallow profiles have been described. The 2 families are separated by the clay content of the argillic horizon; soils with greater than 40% clay being included in the Batang Family.

Well drained profiles with yellowish brown or strong brown to yellowish red argillic B horizons are most common. They have shallow ochric A horizons overlying E or EB horizons which average 10-13 cm (4-5 in) in thickness. The colour of the E horizon is yellowish brown to brownish yellow, occasionally brown to strong brown and may have faint pale yellow mottles. Textures range from sandy loam to clay loam. Thin cutans are present in transition EB horizons. The argillic B horizons have a base colour which ranges from yellow to yellowish brown through strong brown to yellowish red, but are prominently mottled with red and colours of low chroma such as pale yellow. Where the soils are derived largely from red mudstones the base colour of the argillic B horizon is yellowish red to reddish brown. Mineral nodules, varying in size and shape and in degree of hardness, occur in some profiles. The texture of the B horizon ranges from clay in the Batang Family to sandy clay loam in the Sipit Family and cutans are prominent. Structures are moderate to strong angular or subangular blocky. The stone content of the argillic B horizon is very variable but transition BC horizons usually contain mudstone fragments.

Moderately well drained soils are similar to well drained soils but the B and BC horizons are more strongly mottled and include mottles with chromas of 2 or less as a result of the slow percolation of surface water.

Both well and moderately well drained soils have ochric A horizons with moderate to low contents of organic carbon and low C/N ratios. pH values are moderately to strongly acid throughout and total exchangeable bases and base saturation values are normally very low. However, some profiles have high values of magnesium and low to medium base saturation.

The soils of the Sipit Family described in this association differ from those described in the Tengah Nipah Association in that they are more stony, lack fine quartz and chert gravel, have few concretions and have less red colours in the argillic B horizon.

Orthic Luvisols: Lumpongon Family

Well drained Orthic Luvisols of the Lumpongon Family are formed on mudstone *in situ* or mudstone colluvium. They have A, B and C horizon sequences; E or EB horizons are normally absent. Ochric A horizons average 2 cm (1 in) in thickness and rest directly on argillic B horizons composed of brown to yellowish brown clay loam to clay with strong angular or subangular blocky structures and prominent cutans. Transitional BC horizons are composed of yellowish brown clay loam to clay with many weathering mudstone fragments, often in the form of primary concretions; C horizons comprise weathering mudstone. Deep and moderately deep phases have been described.

Moderately well drained soils closely resemble the well drained soils but have B and BC horizons in which mottles of chromas of 2 or less are prominent at depths greater than 50 cm (20 in); the mottling is superimposed on yellowish brown to brownish yellow base colours (Profile Lo 10).

In both the well drained and moderately well drained soils the ochric A horizon contains moderate to low contents of organic carbon and has a low C/N ratio. The soils are moderately to strongly acid. The argillic B horizon has high amounts of total exchangeable bases, with exchangeable magnesium consistently present in very high amounts, and has high percentage base saturation values.

Ferric Luvisols: Lumerau Family

Moderately well drained Ferric Luvisols of the Lumerau Family occur sporadically in the Lungmanis Association. They have A, weak E or EB, B and BC horizons. Deep phases only have been described. Ochric A horizons average 2 cm (1 in) in thickness. The E or EB horizons are composed of yellowish brown sandy clay loam to clay loam. The underlying argillic horizon is basically yellowish brown in colour, but it is prominently mottled with red and also colours of low chroma. Mineral nodules are also a distinct feature of the horizon. Texture varies from clay loam to clay; structure is moderate to strong angular or subangular blocky and cutans are normally thick and continuous. The BC horizon is similar to the B horizon, but contains common to many weathering mudstone fragments.

The ochric A horizon contains moderate to low amounts of organic carbon and has a low C/N ratio; the soils are moderate to strongly acid throughout. Exchangeable bases are present in moderate to high amounts and are highest in the lower parts of the B horizon. Values of exchangeable magnesium are consistently very high. Base saturation values are medium to high throughout, but are highest in the lower parts of the B horizon where values average about 75% (Profile Lf 3).

Limitations to agricultural development

The limitations to the agricultural development of the Lungmanis Association are minor ones of slope on the hills and drainage in the valleys. Because most areas are at considerable distances from main rivers the risk of flooding is not severe. The association is therefore considered to be suitable for agricultural development.

SILABUKAN ASSOCIATION

The Silabukan Association occurs north and west of Sandakan, from the Sungai Lokan to Gomantong (Stereogram 2-16), from between the Sungai Pin and Sungai Lamag westwards to the Sungai Malua, in the Bangan Basin and in the Inarat Lowlands. It covers about 555 km^2 (215 mi^2) of low hills with an amplitude of 15-30 m (50-100 ft) and with a regular pattern of dissection. Slopes range from 0-25^o but are commonly in the 10-15^o range.

The soils are developed on those parts of the Tanjong and Sandakan Formations where mudstone is predominant, but is interbedded with sandstone. Quartz and sandstone pebbles, often in the form of stonelines, occur sporadically and are considered to be colluvial remnants of once more extensive terrace deposits; they have been observed north of the Kinabatangan at Lamag, north of Sandakan and in the Lokan valley. In addition both fine-and coarse-textured alluvium occur on the valley floors.

Dipterocarp forest is the natural vegetation but large areas have been logged to the south of the Kinabatangan at Latangan and Tedog and also at Lungmanis. Around Sandakan small farms, gardens and rubber estates have been in existence since the beginning of the century.

Orthic Acrisols and Luvisols are the dominant soils with Ferric Acrisols and Luvisols on the hills and Gleyic Acrisols and Luvisols on lower slopes and alluvial flats (Figure 2-8). They are discussed in detail in the Lungmanis Association.

Limitations to agricultural development

The limitations to the development of the Silabukan Association are similar to those in the Lungmanis Association so that this association is also considered to be suitable for agriculture.

KALABAKAN ASSOCIATION

This association occurs to the east of the Sungai Lokan (Stereogram 2-16) south of the Sungai Kinabatangan near Pintasan and Latangan, extensively in the Inarat Lowlands and in the lower parts of the Kuamut and Pinangah catchments. It covers about 460 km^2 (180 mi^2).

It is formed on low hills and ridges with a relief amplitude of about 60 m (200 ft) and slopes in the 10 to 20^o range. These hills are composed of mudstone and sandstone identical to those in the Silabukan Association; mudstone is dominant, but sandstone is more common than in the Silabukan Association.

Orthic Acrisols and Luvisols are the dominant soils with Ferric Acrisols and Luvisols as minor components (see the Lungmanis Association). The Orthic Acrisols also include soils formed largely from sandstone and these are described in the Dalit Association. (Figure 2-8).

Limitations to agricultural development

The Kalabakan Association has limitations imposed by short moderate to steep slopes and is marginal for agricultural development.

Soil associations on mudstone/sandstone 2. Sandstone and mudstone

Seven associations are defined on sandstone hills and mountains. The Tengah Nipah Association is formed on sandstone hills of moderate amplitude; it is comprised of Ferric Acrisols and is restricted to the Dent Peninsula. The Dalit Association is also formed on hills of moderate amplitude; it is extensive and is comprised largely of Orthic Acrisols, although it contains significant alluvial flats on which Gleyic Acrisols and Humic and Dystric Gleysols have developed. The Dalit Association progresses with increasing amplitude and altitude into the Lokan and Crocker Associations, the former comprising sandstone hills of high amplitude and the latter comprising mountains generally below 1 200 m (4 000 ft). In both the Lokan and Crocker associations Orthic Acrisols are dominant but Cambisols and Lithosols become more common with increasing steepness of slope. The Maliau Association is formed on cuestas with series of strongly developed dip and scarp slopes. It contains Gleyic

TABLE 2-20 Soil associations on sandstone

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Tengah Nipah	Hills of moderate relief; slopes 10-20°	Dipterocarp Forest	Sandstone and mudstone	Ferric Acrisol	Sipit
				Orthic Acrisol	Tanjong Lipat
			Alluvium	Gleyic Acrisol	Inanam
				Gleyic Luvisol	Buran
Dalit	Hills of moderate relief; slopes 10-20° and alluvial flats	Dipterocarp Forest	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kapilit
				Gleyic Acrisol	Inanam
			Alluvium	Dystric Gleysol	Koyah
				Humic Gleysol	Guan
Lokan	Hills and ridges of high relief; slopes $>$ 25°	Dipterocarp Forest	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kapilit
				Chromic Cambisol	Luasong
				Dystric Cambisol	Antulai Laab
				Lithosol	
Crocker	Mountain ranges with moderate to very steep slopes	Dipterocarp Forest	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat Kapilit
				Chromic Cambisol	Luasong
				Dystric Cambisol	Antulai Laab
				Lithosol	
Maliau	Mountain cuestas with steep often sheer scarp slopes and moderately steep to steep dipslopes	Dipterocarp and Heath Forest	Sandstone and minor mudstone	Orthic Podzol	Sibuga
				Gleyic Podzol	Pa Sia
				Lithosol	
				Dystric Histosol	Kaintano
				Orthic Acrisol	Kapilit
				Dystric Cambisol	Antulai
Serudong	Dipslopes of mountain cuestas	Heath Forest	Sandstone	Gleyic Podzol	Pa Sia
				Dystric Histosol	Kaintano
				Orthic Acrisol	Kapilit
				Dystric Cambisol	Antulai
Trusmadi	Mountain ranges mainly above 1 500 m (5 000 ft); slopes $>$ 25°	Montane and Dipterocarp Forest	Sandstone and mudstone with quartzite	Orthic Acrisol	Tanjong Lipat
				Gleyic Acrisol	Gunong Alab
				Gleyic Podzol	Pa Sia
				Humic Gleysol	Kidukarok
				Dystric Histosol	Kaintano
				Lithosol	

Podzols, Orthic Podzols and Dystric Histosols in addition to Orthic Acrisols, Dystric Cambisols and Lithosols. The presence of Podzols and Histosols, which result initially from altitudinal position, is normally noted at about 1 350 m (4 500 ft). but in the Sandakan District Podzols occur at altitudes as low as 180 m (600 ft). Where the Podzols are sufficiently extensive they are separated as the Serudong Association. The Trusmadi Association, which is restricted to the Trusmadi Range, comprises Gleyic Podzols, Humic Gleysols, Dystric Histosols, Orthic Acrisols, Gleyic Acrisols and Lithosols; the Podzols, Gleysols and Histosols occur chiefly above 1 350 m (4 500 ft) (Table 2-10).

TENGAH NIPAH ASSOCIATION

This association is widespread south of Tambisan and it extends west as far as the Sungai Kapur covering about 230 km^2 (90 m^2). The distinctive features of this area, referred to as the Ganduman Hills, are the subparallel broad ridges, which are aligned from north to south and which are separated by narrow tonguing valleys (Stereogram 2-3). The ridges, with an amplitude of about 60 m (200 ft) consist of narrow ridge crests and convex upper slopes, which become concave and level off to gently sloping flats; there may be 2 or 3 of these flats on a hillside. Slopes range from 5-15°, but may reach 20° near the crests. To the south, where the amplitude increases to approximately 90 m (300 ft), slopes are rather steeper and the tonguing valleys become narrower and more incised.

Parent materials comprise interbedded coarse soft sandstone and mudstone of the Ganduman Formation. In the narrow valleys coarse-and medium-textured alluvia have been deposited. The majority of this area is under lowland Dipterocarp forest, in which species of *Shorea acuminatissima, Shorea macroptera, Shorea smithiana, Shorea multiflora, Dipterocarpus caudiferus* and *Dipterocarpus confertus* are prominent.

Ferric Acrisols are the dominant soils on the hills with minor occurrences of Orthic Acrisols. Gleyic Acrisols and Luvisols described in the Kinabatangan Association occur on the alluvial flats (Figure 2-4).

Ferric Acrisols: Sipit Family

Deep well drained Ferric Acrisols of the Sipit Family form on middle slope, upper slope and crest sites. They have A, E, B and C horizons. Typically shallow ochric A horizons overlie weak E horizons composed of yellowish brown sandy loam to sandy clay loam and transition EB horizons of similar textures, but redder colours. The argillic B horizon normally occurs below 40 cm (16 in) and is composed of yellowish red, prominently mottled clay to clay loam with common to many rounded, platy or tubular iron concretions. Structures are moderately to strongly developed subangular blocky and cutans are moderately thick and continuous. In addition variable amounts of coarse sand and fine gravel of quartz and chert are often present in the argillic B horizon. Horizons transitional to the C horizon are composed of clay of paler colours but with distinct red mottling.

Deep moderately well drained soils develop on narrow flats where deep sandy E or EB horizons overlie the argillic B horizon. Colours of the E or EB horizons are yellowish brown, textures are in the sandy loam to sandy clay loam range and the boundary to the argillic horizon is clearly defined. The argillic horizon is basically yellowish brown to strong brown, rather than yellowish red, in colour with distinct pale yellow or grey mottling. Other profile features are identical to the well drained soils.

On the eastern boundary of the association where it adjoins the Semporna Association colluvium derived from interbedded mudstone and sandstone overlies limestone. Profiles show upper horizons characteristic of the soils of the Sipit Family overlying yellowish brown clay rich in coral fragments with very high exchangeable calcium and base saturation values.

Organic matter contents in the A horizon are very low and the soils are strongly acid throughout. Cation exchange capacities are moderate to low and amounts of exchangeable cations are very low. Percentage base saturation values are low to very low. (Profile Af2).

Limitations to agricultural development

In the Tengah Nipah Association limitations are imposed by slope particularly on upper slopes and around valley heads. The soils of the valley floors are liable to periodic high water tables and minor flooding. In general terms this is marginal land.

DALIT ASSOCIATION

The Dalit Association occurs in the Lokan Peneplain adjacent to the Sungai Ruku Ruku (Stereogram 2-18), in the Karamuak valley, the Milian valley between Kuala Karamuak and Kuala Tongod, the Mankawagu valley and extensively in the Mananam Plain to the north of the Sungai Tongod (Stereogram 2-10). It covers about 505 km^2 (195 mi^2) and consists of low hills and alluvial flats with an amplitude of about 60 m (200 ft) at altitudes below 150 m (500 ft). The hills are convex in shape with slopes ranging from 10-15^o, but exceeding this on some incised lower slopes. The alluvial flats are often more than 400 m (¼ mi) wide and are dissected by shallow gullies; They are poorly drained and often swampy.

Parent materials comprise interbedded reddish brown sandstone and mudstone on the low hills and mainly coarse-textured alluvium on the flats. In addition, in the Mananam Plain some low hills are composed of medium-textured old alluvium representing terrace remnants.

Lowland Dipterocarp Forest covers the low hills, except in the Mananam Plain, where large areas are either under shifting cultivation or have reverted to secondary forest following cultivation. Poor forest often with small trees and an undergrowth of sedges occurs on many of the wet alluvial flats.

Orthic Acrisols are the dominant soils in the association. They include well drained and moderately well drained soils, the latter occurring on lower slopes adjacent to alluvial flats. They are formed mainly on reddish brown sandstone, but profiles on reddish brown mudstone (see the Lungmanis Association) and medium-textured old alluvium (see Brantian Association) also occur. Gleyic Acrisols and Dystric and Humic Gleysols occur on the alluvial flats; they are described in the Sook Association (Figure 2-9).

Orthic Acrisols: Tanjong Lipat and Kapilit Families

Orthic Acrisols of the Tanjong Lipat and Kapilit Families, formed on reddish brown sandstone and mudstone are the dominant soils in the Dalit Association. The 2 families are separated by the amount of clay in the argillic horizon; soils with clay contents of less than 25% are included in the Kapilit Family and soils with argillic horizons containing 25 - 40% clay are included in the Tanjong Lipat Family. Both well drained and moderately well drained profiles with A, E, B and C horizon sequences occur.

Well drained soils with argillic B horizons with hues of 7.5YR and 5YR with chromas of more than 4 are most common. Typical profiles have shallow ochric A horizons. These overlie E horizons which average 8 - 19 cm (3 - 4 in) in thickness. They are yellowish brown to strong brown in colour with sandy loam to sandy clay loam textures and weak to moderate subangular blocky structures. Cutans are absent but they may be present in transitional EB horizons. The underlying argillic B horizon is strong brown, reddish yellow or yellowish red in colour with sandy clay loam to clay loam textures, moderate to strong subangular blocky structures and prominent cutans. Stone contents of the argillic horizon are very variable. Where the soil is derived from sandstone *in situ* the horizon is often stoneless, but where it is derived from sandstone colluvium then sandstone fragments are common. The soils are generally deep with C horizons occurring below 125 cm (50 in).

Soils in which the hue of the argillic B horizon is 5YR with chromas of 4 or less, or redder hues, are comparatively rare. They are associated with outcrops of red sandstone and mudstone. In these soils shallow ochric A horizons overlie E horizons which average 8 cm (3 in) in thickness and are composed of brown to reddish brown sandy loam to sandy clay loam. The underlying argillic B horizon is reddish brown to dark reddish brown with sandy clay loam to clay loam textures, moderately developed subangular blocky structures and cutans. Transition BC horizons comprise reddish brown sandy clay loam to clay loam with fragments of red sandstone and C horizons comprise weathering red sandstone. Moderately deep and shallow phases, only, have been described.

Moderately well drained soils occur on lower slopes adjoining alluvial flats. They are similar to the well drained soils, but because of minor fluctuations of groundwater have mottles with chromas of 2 or less superimposed on yellowish brown, strong brown or yellowish red argillic B horizons.

All soils regardless of colour are strongly acid throughout and the argillic horizons have very low contents of exchangeable bases and very low percentage base saturation values. The ochric A horizons have low amounts of organic carbon and medium to low C/N ratios.

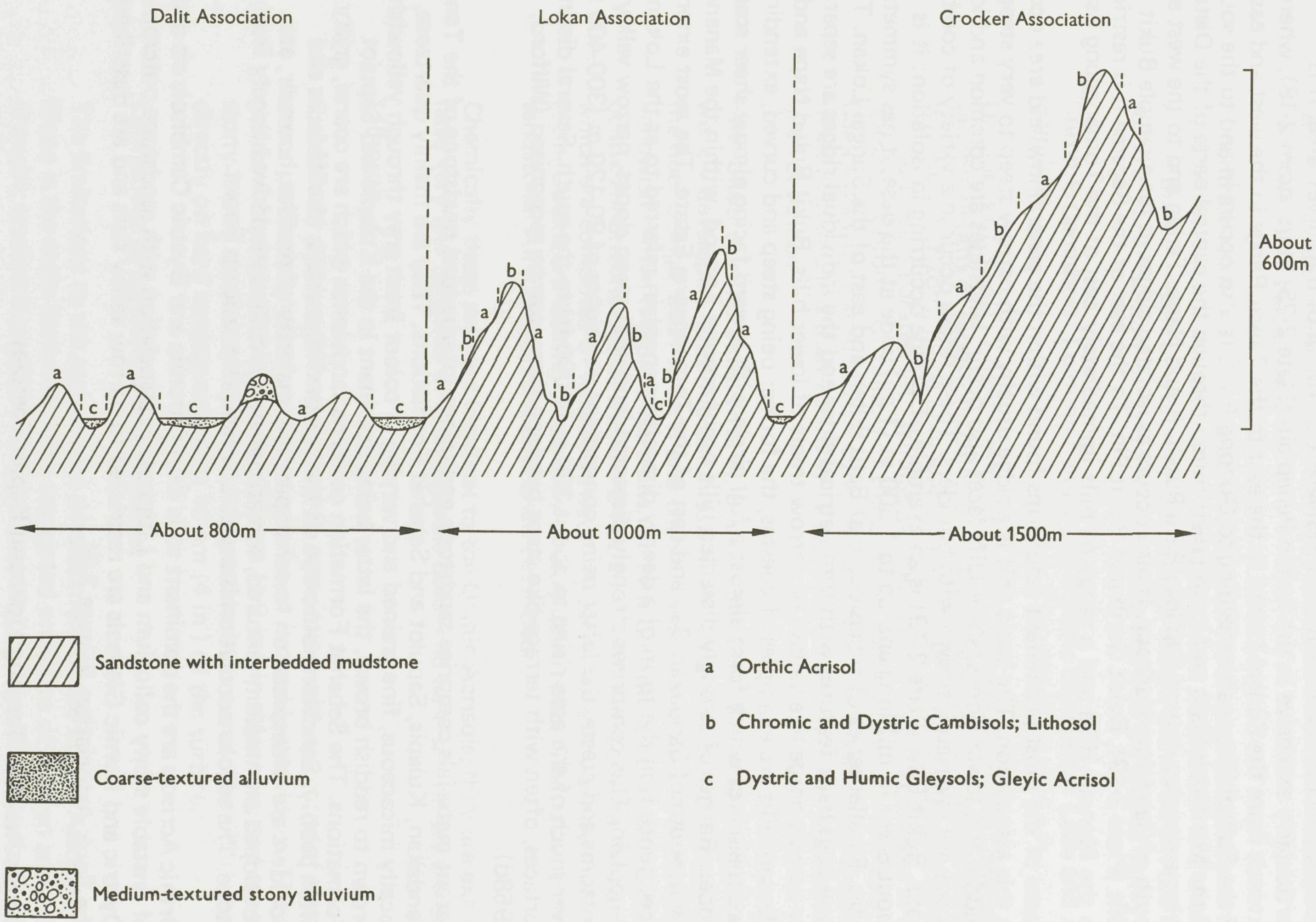


FIGURE 2-9 Theoretical cross-section of the Dalit, Lokan and Crocker Associations

FIGURE 2-9

Prepared by the Directorate of Overseas Surveys 1974

Limitations to agricultural development

The Dalit Association is marginal in terms of agricultural development because slopes are short and often moderate to steep and the soils on the alluvial flats are not only poorly drained, but are also extremely low in plant nutrients.

LOKAN ASSOCIATION

This is the second most extensive association in the survey area. It covers about 3 350 km^2 (1 205 mi^2) which is equivalent to 16.1% of the survey area. It is particularly extensive in the Lokan Peneplain (Plate 2-25; Stereogram 2-18), where it extends from the Sungai Lokan in the east to the Tawai Range in the west and east of the Sungai Pinangah extending to Gunong Rara. It also occurs in and to the south of the Mananam Plain and is well distributed through the central parts of the District being extensive around Sepilok, Batu Puteh, Bulud Napa, Tedog and to the west and south of Sandakan Harbour. It also occurs as isolated ridges at for example Bukit Bilit (Plate 2-19), Bukit Garib and Bukit Pin. To the east of the Segama it is restricted to the Maruap Hills and a range of hills immediately east of the Tomanggong Estate.

Some of the most prominent landforms found within the general lowland area occur in this association. The basic unit is a ridge usually with narrow steep to very steep middle and lower slopes; sheer cliff faces also occur, landslides are common and lower slopes are invariably strewn with boulders. These ridges occur in a variety of combinations. Bukit Bilit (Plate 2-19) is an example of a ridge occurring in isolation; it is about 8 km (5 mi) long and up to 1 500 m (1 mi) wide at the base; it has symmetrical sides. Parallel series of ridges occur at Batu Puteh and east of the Sungai Lokan. These have hogs back features with symmetrical sides and the individual ridges are separated by narrow gorge-like valleys or narrow tracts of lower hills. Bukit Bulud Napa and the Maruap Hills are examples of cuestas, the former being steep and curved, extending in two main arcs which form almost a full circle with inward facing almost sheer scarp slopes. Ranges of strongly dissected hills occur around Tongod, within the Mananam Plain, south of Sandakan Bay and east of the Tomanggong Estate. The most extensive occurrence is in the form of a deeply dissected peneplain referred to as the Lokan Peneplain. This comprises strongly dissected land with steep slopes, narrow valley bottoms and crests, the latter being concordant at heights of 90-120 m (300-400 ft) over much of the area rising to about 300 m (1 000 ft) in the south. Several distinct surfaces, often with terrace-like steps between them, can be recognised (Wilford, 1968d).

Parent materials comprise sandstone and minor interbedded mudstone of the Tanjong, Sandakan, Kulapis, Sapulot and Sebahat Formations. They are mainly quartzose, locally micaceous, fine grained and varying in colour from grey through yellowish brown to reddish brown, the latter being dominant in the Kulapis and Sapulot Formations. The Sebahat Formation contains sandstones which are coarse, gritty and often pebbly. Sandstone outcrops on the narrow ridge crests, in cliff faces and boulders are widespread on lower slopes. The majority of profiles, however, are developed on medium-textured, sometimes stony, colluvium derived largely from sandstone. The whole association is under Lowland Dipterocarp Forest.

Orthic Acrisols are the dominant soils with Chromic and Dystric Cambisols on deposits of unstable stony colluvium and Lithosols in association with sandstone outcrops. Dystric and Humic Gleysols are restricted to narrow valley flats and are described in the Sook Association (Figure 2-9).

Orthic Acrisols: Tanjong Lipat and Kapilit Families

Well drained Orthic Acrisols of the Tanjong Lipat and Kapilit Families have argillic horizons in which the hue varies from yellowish brown to reddish brown. Soils with strong brown to yellowish red argillic horizons are most common; they are described in the Dalit Association. In this association, however soils with argillic B horizons with hues of 10YR or yellower or 7.5YR with chromas 4 or less are common (Profile Ao 14). In these soils shallow ochric A horizons overlie E horizons, which average 15 cm

(5 in) in thickness and are composed of yellowish brown to brownish yellow sandy loam to loam with weak to moderate subangular blocky structures. The underlying argillic B horizon is yellowish brown, rarely brownish yellow, with sandy loam textures in the Kapilit Family and sandy clay loam to clay loam textures in the Tanjong Lipat Family; it has moderate to strongly developed subangular blocky structure and cutans. Transition BC horizons are composed of yellowish brown sandy loam to clay loam with common to many fragments of weathering sandstone and C horizons comprise weathering sandstone.

Profiles in which the hue of the argillic B horizon is 5YR with chromas of 4 or less, or redder hues, are comparatively rare; they are associated with outcrops of red sandstone (see the Dalit Association).

In contrast to the Dalit Association deep profiles are comparatively rare. Moderately deep profiles are more common on slopes between 20 and 30^{o} and shallow profiles, in which the C horizon of weathering sandstone occurs within 50 cm (20 in) of the surface, occur notably on narrow ridge crests and also on incised valley sides.

Chromic Cambisols: Luasong Family and Dystric Cambisols: Laab and Antulai Families

On slopes of 30-40^{o} where erosion is active Chromic or Dystric Cambisols form on variable depths of sandstone colluvium. They are essentially intergrades to Acrisols but the B horizons, being only weakly developed, are designated as cambic horizons. The soils are separated into families on the basis of clay percentages in the cambic horizons. Chromic Cambisols of the Luasong Family have 25-40% clay; Chromic Cambisols with less than 25% clay have not been described. Dystric Cambisols with more than and less than 25% clay (Laab and Antulai Families respectively) have both been described.

The soils are well drained with A, B and C horizons; E horizons when present are weakly developed. Chromic Cambisols have strong brown to red cambic B horizons, the hues being 7.5YR to 5YR and chromas are greater than 4. Dystric Cambisols have yellowish brown cambic B horizons. In both Chromic and Dystric Cambisols shallow ochric A horizons overlie shallow E horizons or rest directly on the cambic B horizons which are composed of weakly structured, generally stony sandy loam to sandy clay loam. Cutans are lacking or are only weakly developed. C horizons comprise weathering sandstone. All depth phases have been described.

Chemically these soils are identical to the Orthic Acrisols; they are extremely acid and have very low contents of exchangeable bases and base saturation values.

Lithosols

Excessively drained Lithosols occur in association with outcrops of sandstone, which occur particularly on upperslopes and also on incised lower slopes. They have shallow ochric A horizons, which average 3-5 cm (1-2 in) in thickness, and are composed of stony loamy sand to sandy loam with granular structures. The ochric horizons rest directly on hard sandstone within 10 cm (4 in) of the surface.

Limitations to agricultural development

The limitations to the agricultural development of the Lokan Association are severe. Slope is the main limitation with associated problems of erosion and liability to drought; erosion is already active on steep slopes. In addition surface stoniness and shallow stony soils would present severe problems if the land were cleared for cultivation. The association is not recommended for agriculture.

CROCKER ASSOCIATION

The Crocker Association is extensive in the west of the survey area. It extends westwards from near Gunong Rara and is well developed in particular to the north of the

Sungai Labau and Sungai Milian between Pinangah and Lanas. It covers about 1 810 km^2 (700 mi^2) which is about 8.7% of the total survey area, and comprises mountain ranges with altitudes up to about 1 200 m (4 000 ft). Slopes are everywhere steep and both ridge crests and valley bottoms are extremely narrow (Stereogram 2-4).

The soils are formed on sandstone and subordinate mudstone of the Crocker and Sapulot Formations. On the Crocker Formation the pattern of dissection is notably regular with narrow steeply incised interfluves (Plate 2-24). The majority of the soils are actually formed on mixed colluvium but sandstone outcrops on ridge crests and also on many steep slopes.

Much of the association is under Lowland Dipterocarp Forest but there is shifting cultivation in the Tongod valley above Lalampas and also on the mountains adjoining the Labau valley to the east of Sinarun.

The association is dominated by well drained Orthic Acrisols and also includes Chromic Cambisols, Dystric Cambisols and Lithosols (Figure 2-9) (see the Lokan Association).

Limitations to agricultural development

The Crocker Association is quite unsuitable for agricultural development largely because of the steepness of the majority of slopes. Other limitations are identical to those described in the Lokan Association.

MALIAU ASSOCIATION

The Maliau Association is the most extensive association in the survey area. It covers 2 275 km^2 (1 330 mi^2), which represents 16.5% of the total, and is most extensive in the catchment of the Kuamut extending westwards to the Sungai Pinangah and north to the Sungai Milian. It also occurs east of Kuamut and at Sandakan.

It occurs on hills and mountains at altitudes ranging from about 150 m (500 ft) to over 1 650 m (5 500 ft). These hills and mountains are often arranged in series of concentric circles around a central core with outward facing scarp slopes and inward facing dip slopes. This feature is spectacularly developed in both the Maliau and Bangan Basins (Stereogram 2-5) (Plate 2-25) and is partially seen at Sandakan in the series of cuestas extending westwards from Pulau Berhala (Plate 2-1). Scarp slopes are very steep and often sheer with talus deposits at their base. Crests are narrow, often knife-edged, and pass into long moderately steep dipslopes with deeply incised valleys.

Sandstones which vary in colour from white, through yellow to yellowish red and which are mainly composed of fine sand are the dominant parent materials. Interbedded mudstone is less common but it occurs notably in the low concentrically arranged troughs within the basin structures.

Apart from the Sandakan area, where a variety of vegetable and fruit crops are grown in small gardens, the whole association is under natural vegetation. This comprises Dipterocarp Forest on scarp slopes and dissected dipslopes with heath forest on long plane dipslopes.

The association comprises Gleyic Podzols, Orthic Podzols, Dystric Histosols, Orthic Acrisols, Dystric Cambisols and Lithosols (Figure 2-10). Acrisols, Cambisols and Lithosols are described in the Lokan Association; Orthic Acrisols with reddish brown argillic B horizons, however, have not been described in the Maliau Association.

Orthic Podzols: Sibuga Family

Deep moderately well drained Orthic Podzols of the Sibuga Family occur on the dipslopes under heath forest. They have O, E, Bh/fe and B horizon sequences. The histic O horizon is composed of decomposing leaf litter and roots and is regularly moist or wet. It overlies a light grey fine sand, albic E horizon. The spodic Bh horizon is often

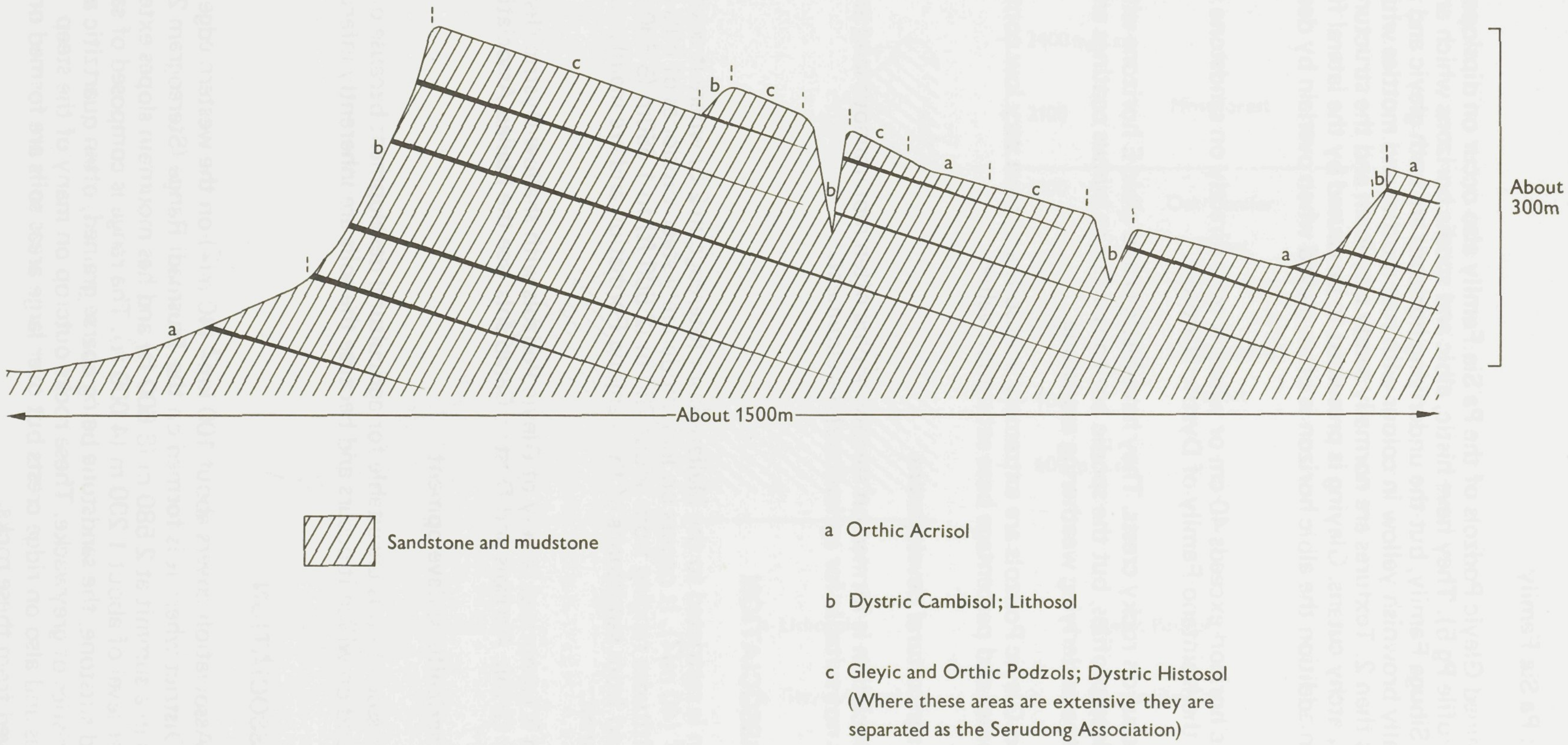


FIGURE 2-10 Theoretical cross-section of the Maliau Association

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slightly hard and the spodic Bfe horizon is concretionary in the form of a discontinuous ironpan. Underlying the spodic horizons there are brownish yellow to reddish B horizons composed of sandy loam to sandy clay loam with moderately developed subangular blocky structures and patchy cutans. One particular profile has been studied in detail by Eswaran and Sys (1972) and the B horizon underlying the spodic horizons has been described as an oxic horizon.

Gleyic Podzols: Pa Sia Family

Imperfectly drained Gleyic Podzols of the Pa Sia Family also occur on dipslopes under heath forest (Profile Pg 5). They have histic, albic and spodic horizons which are similar to those in the Sibuga Family, but the underlying horizons are both gleyic and argillic. They are basically brownish yellow in colour with rust mottles and mottles with chromas of less than 2. Textures are normally sandy clay loam and the structures are prismatic with patchy cutans. Gleying is presumed to be caused by the lateral flow of groundwater. In addition the albic horizon is often gleyed when overlain by deep histic O horizons.

Where the histic horizon exceeds 40 cm or where it rests directly on sandstone the soils are included in the Kaintano Family of Dystric Histosols.

Shallow soils occur on rocky crests. They have histic O and albic E horizons which are similar to the deep profiles, but the spodic horizons occur as humus coatings and iron concretions in the underlying weathering sandstone.

Both Orthic and Gleyic Podzols are extremely acid soils and have very low contents of exchangeable bases and percentage base saturation values.

Limitations to agricultural development

The Maliau Association is formed on steeply sloping often mountainous land and for this reason it is not suitable for agricultural development.

SERUDONG ASSOCIATION

This association is restricted to the Maliau Basin (Stereogram 2-5) where it covers about 105 km^2 (40 mi^2). It occurs on long moderately steep dipslopes of hills and mountains at altitudes ranging from about 750 m (2 500 ft) to 1 650m (5 500 ft). These are formed from sandstones of the Tanjong Formation and are mainly clothed in low heath forest.

The association is comprised largely of Gleyic Podzols with shallow Dystric Histosols and only minor Orthic Acrisols and Dystric Cambisols (see the Maliau Association).

Limitations to agricultural development

The Serudong Association is unsuitable for agricultural development because of the mountainous land on which it occurs and because the soils are inherently infertile.

TRUSMADI ASSOCIATION

The Trusmadi Association covers about 100 km^2 (40 mi^2) on the western edge of the Kinabatangan District where it is formed on the Trusmadi Range (Stereogram 2-6); this culminates in a summit at 2 580 m (8 600 ft) and has mountain slopes extending down to a lower level of about 1 200 m (4 000 ft). The range is composed of sandstone, shale and siltstone, the sandstone being coarse grained, often quartzitic and with many characteristics of greywacke. These rocks outcrop on many of the steep mountain slopes and also on ridge crests but over large areas soils are formed on mixed colluvium derived from these rocks.

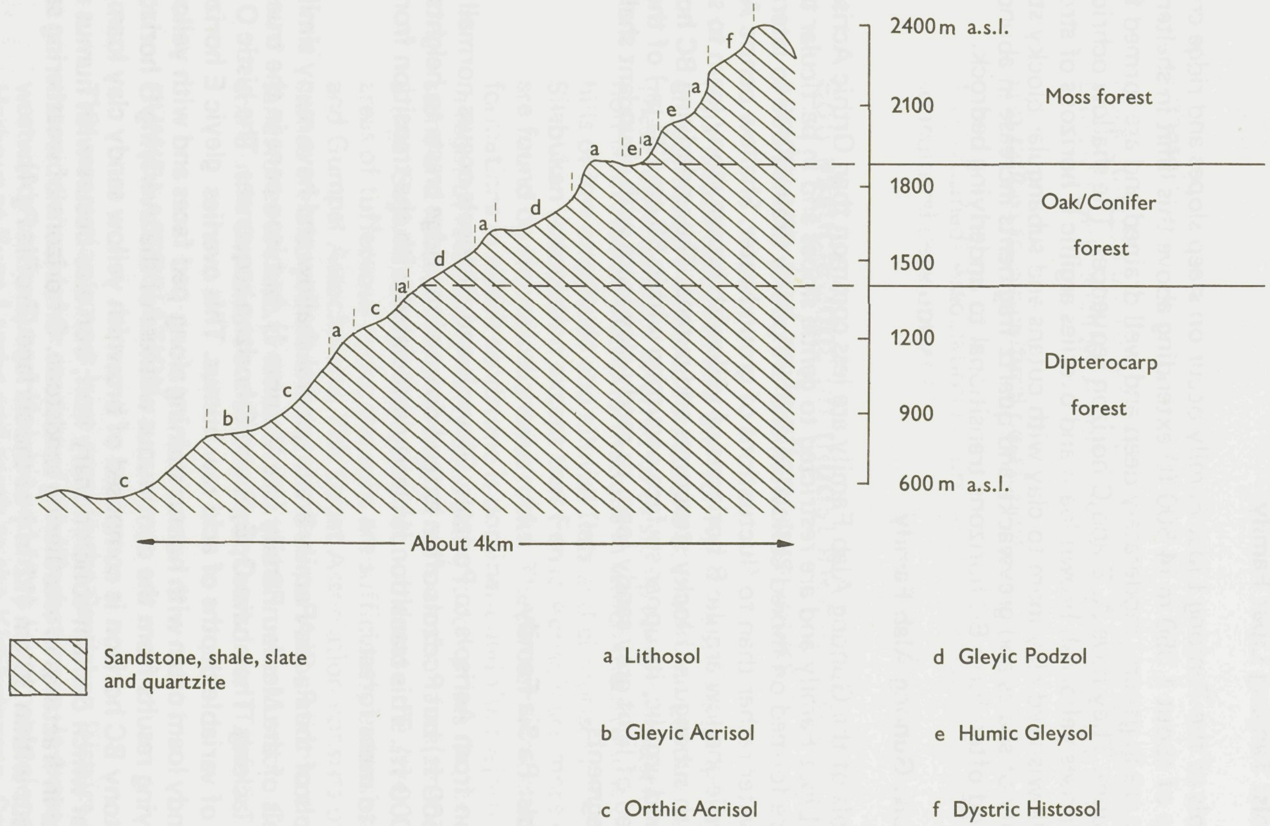

FIGURE 2-11 Theoretical cross-section of the Trusmadi Association

FIGURE 2-11

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Dipterocarp Forest covers the lower slopes of the association below about 1 350 m (4 500 ft) and also extends upwards beyond this height in sheltered valleys. It gives way to an oak/conifer forest dominated by Fagaceae and Lauraceae species and above 1 950 m (6 500 ft) low trees and shrubs are covered by leafy hepatics and mosses in what can be described as a moss forest. Species include Ericaceae, Podocarpaceae, Fagaceae, Theaceae, Lycopodiaceae, Burmaniaceae, Mysinacea, Guttiferae and Myrtaceae. Virtually all the speciments collected have also been identified under similar conditions on Gunong Kinabalu, about 55 km (35 mi) north of Trusmadi.

The association includes Orthic and Gleyic Acrisols, which are extensive below about 1 350 m (4 500 ft), Gleyic Podzols, Lithosols, Humic Gleysols and Dystric Histosols (Figure 2-11).

Orthic Acrisols: Tanjong Lipat Family

Orthic Acrisols of the Tanjong Lipat Family occur on steep slopes and ridge crests up to an altitude of about 1 350 m (4 500 ft) extending above this limit in sheltered valleys. They are in general moderately deep and well drained and are formed from mixed colluvium. They have A, B and C horizon sequences. The shallow ochric A horizon comprises yellowish brown loam and overlies argillic B horizons of strong brown to yellowish red clay loam to clay with cutans and subangular blocky structures. Stones, mainly of shales and greywacke and quartz fragments increase in abundance with depth and often form BC horizons transitional to underlying bedrock.

Gleyic Acrisols: Gunong Alab Family

Gleyic Acrisols of the Gunong Alab Family are less common than Orthic Acrisols of the Tanjong Lipat Family and are restricted to gentle slopes and in particular to flush sites. They are formed on mixed colluvium and are poorly drained due to lateral percolation of water rather than to fluctuations of groundwater. Shallow ochric A horizons overlie shallow argillic B horizons of yellowish brown stony loam to sandy clay loam with subangular blocky structures and cutans. The underlying BC horizon is both gleyic and argillic, its upper surface occurring within 50 cm (20 in) of the surface. It is composed of light grey sandy loam to sandy clay loam with abundant shale and sandstone fragments.

Gleyic Podzols: Pa Sia Family

The transition from Acrisols to Podzols, Gleysols and Histosols occurs normally above 1 350 m (4 500 ft) but Podzols often extend down along ridge crests to heights of about 1 200 m (4 000 ft). This transition is clearly associated with the transition from Dipterocarp to moss forest.

Gleyic Podzols of the Pa Sia Family are in general shallow and have many similarities to Placic Podzols of the Mesilau Family (see Volume 1), but iron pans in the true sense of the term are lacking. They have O, E, B and C horizon sequences. The histic O horizon is composed of variable depths of acid raw humus. This overlies gleyic E horizons of light grey sandy loam often with humus staining along ped faces and with yellowish red mottles. Gleying results from the continuous wetness of the overlying O horizon. The underlying stony BC horizon is composed of brownish yellow sandy clay loam, the upper parts of which contain concretionary iron; iron also occurs with humus along ped faces and in fractures in weathering sandstone. C horizons of weathering sandstone normally occur within 30 cm (12 in) of the surface (Profile Pg 4).

Humic Gleysols: Kidukarok Family

On gentle slopes in the moss forest Humic Gleysols of the Kidukarok Family are formed on mixed colluvium of variable depth. In addition to gleying which results from the continuously wet, raw humus surface, gleying is also caused by the lateral percolation of water. Profiles, which in general are moderately deep, have O, Eg, Bg and Cg horizons. The histic O horizon comprises variable depths of acid raw humus and this overlies gleyic B horizons of light grey to white, somewhat stony, sandy loam to sandy clay loam. The underlying gleyic B horizon is similarly composed of light grey, somewhat stony, sandy clay loam, but is prominently mottled with yellowish brown and yellowish red colours particularly on ped faces and in root channels. Profiles become progressively more stony with depth (Profile Gh 5).

Dystric Histosols: Kaintano Family

Dystric Histosols of the Kaintano Family are widespread above 1 500 m (5 000 ft) forming under dense moss forest. They comprise moss and acid raw humus exceeding 50 cm (20 in) in thickness. The raw humus not only covers the ground surface but also covers the intertwined roots and low branches. The underlying horizons are gleyed and comprise light grey sandy clay loam with variable mottling and iron concretions. Dystric Histosols also form on acid raw humus overlying rock *in situ.* In these profiles the depth of raw humus varies from a few centimetres to over 50 cm (20 in)

Lithosols

Rock outcrops on many of the steep slopes and ridge crests and in these locations Lithosols, with shallow A horizons resting on rock, are common.

Limitations to agricultural development

The Trusmadi Association occurs on mountainous land and is quite unsuitable for agricultural development.

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

Four associations, namely the Rumidi, Kretam, Dagat and Gumpal Associations occur on sedimentary-volcanic formations of mudstone, sandstone,and miscellaneous rocks. These formations are referred to as slump formations (see Part 2). The Rumidi Association is formed on slump formations in which mudstone is dominant. It covers extensive hills of low amplitude and alluvial flats and comprises a similar range of soils to the Silabukan Association except that Ferric Acrisols are more widespread; a range of soils are found on the miscellaneous rocks. The Kretam Association is formed from slump formations in which sandstone is dominant and the majority of profiles are developed in regolith resembling stony colluvium; it comprises Orthic and Ferric Acrisols on sandstone and mudstone and a range of soils on the miscellaneous rocks. Between the Sungai Segama, Sungai Tabin and Mount Hatton the Ayer slump formation includes areas of tuffaceous rocks; the soils are sufficiently extensive to be separated as the Dagat and Gumpal Associations. The Dagat Association consists of low hills in which mudstones are also prominent and the Gumpal Association comprises steep ridges in which sandstones are also present. Orthic and Chromic Luvisols, Orthic Acrisols and Dystric and Eutric Cambisols are the dominant soil units (Table 2-21).

RUMIDI ASSOCIATION

This association covers large areas in the Sandakan District and it is also extensive in the middle and lower reaches of the Kinabatangan. It extends from the Sungai Sebyte westwards to the Sungai Kolapis and from Lungmanis along the south of Sandakan Harbour to Suan Lamba and south to the Kinabatangan. South of the Kinabatangan it is widespread from the Sungai Kretam in the east to the Sungai Pin in the west (Stereogram 2-8). Collectively it covers an area of 1 140 km^2 (440 mi^2) equivalent to 5.5% of the survey area.

It is formed on low hills and narrow alluvial flats with an amplitude of 15-30 m (50-100 ft) and short slopes ranging from 5-15° on the hills (Plates 2-26 and 2-32). There is no regular pattern of dissection because the slump formations from which the hills are formed are largely unstratified. The Garinono Formation which is most extensive consists 'mainly of slump breccia and includes sequences of interbedded

TABLE 2-21 Soil associations on slump formations of mudstone, sandstone and miscellaneous rocks

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Rumidi	Hills of low relief; slopes 0-15°; and valley floors	Dipterocarp Forest	Mudstone and sandstone	Gleyic Acrisol	Masaum
				Ferric Acrisol	Batang Sipit
				Orthic Acrisol	Kumansi Tanjong Lipat
				Gleyic Luvisol	Lunparai
				Ferric Luvisol	Lumerau
				Orthic Luvisol	Lumpongon
			Tuffaceous rocks	Chromic Luvisol	Libong
				Orthic Luvisol	Talid
			Basic igneous rocks	Chromic Luvisol	Beeston
				Orthic Luvisol	Kobovan
				Gleyic Acrisol	Inanam
			Alluvium	Gleyic Luvisol	Buran
Kretam	Hills of moderate relief; slopes 10-20°	Dipterocarp Forest	Sandstone and mudstone	Orthic Acrisol	Tanjong Lipat
				Ferric Acrisol	Sipit
			Tuffaceous rocks	Chromic Luvisol	Libong
				Orthic Luvisol	Talid
			Basic igneous rocks	Chromic Luvisol	Beeston
				Orthic Luvisol	Kobovan
			Chert	Chromic Cambisol	Juak
Dagat	Hills of moderate relief; slopes 10-20°	Dipterocarp Forest	Tuffaceous rocks	Chromic Luvisol	Libong
				Orthic Luvisol	Talid
				Orthic Acrisol	Dagat
			Mudstone and sandstone	Orthic Luvisol	Lumpongon
				Orthic Acrisol	Tanjong Lipat
Gumpal	Hills and ridges of high relief; slopes > 25°	Dipterocarp Forest	Tuffaceous rocks	Orthic Luvisol	Talid
				Eutric Cambisol	Hatton
				Dystric Cambisol	Tenggara
				Lithosol	
			Sandstone	Dystric Cambisol	Antulai
				Orthic Acrisol	Kapilit
				Lithosol	

mudstone, tuff, tuffite and minor sandstone and calcarentite' (Lee, 1970). The slump breccia is made up of fragments and blocks of assorted rocks in a mudstone matrix; included blocks consist mainly of 'sandstone, limestone, chert, basalt, serpentinite, ophicalcite and gabbro' (Lec, 1970). Although the Garinono Formation is by definition complex, the majority of soils are formed from mudstone and sandstone often in the form of mixed colluvium. Mudstone and sandstone are particularly common near the Sungai Segaliud, Sungai Dumundong, Sungai Koyah and north of the Labuk road. The miscellaneous rock types are rarely extensive but tuffite is common near Sandakan, at Sungai Manila and east of the Sungai Samawang. Pebble deposits occur sporadically and are considered to be remnants of former terraces. In addition alluvium occupies the main valley floors; this is normally fine-textured, but coarse-textured deposits occur adjacent to sandstone hills.

Lowland Dipterocarp Forest is the natural vegetation of the association, but has been, or is in the process of being logged. Logged areas within Forest Reserves are in the early stages of regeneration. In the Sandakan District large areas have been clear felled and a considerable acreage has recently been planted to oil palm.

It is evident from the diversity of parent materials that a wide range of soils can occur within this association. As a broad generalisation, however, Ferric Acrisols and Ferric Luvisols formed on mudstones are dominant. Orthic Acrisols, Orthic Luvisols, Gleyic Acrisols and Gleyic Luvisols also occur on mudstone (see Lungmanis Association). Where the mudstones and sandstones form interbedded sequences within the slump formations the range of soils described in the Silabukan Association occur. In addition the association includes a range of Acrisols and Luvisols formed on outcrops of miscellaneous rocks which collectively constitute an important part of it. These may be locally dominant. For example, Orthic and Chromic Luvisols formed on tuffite (see

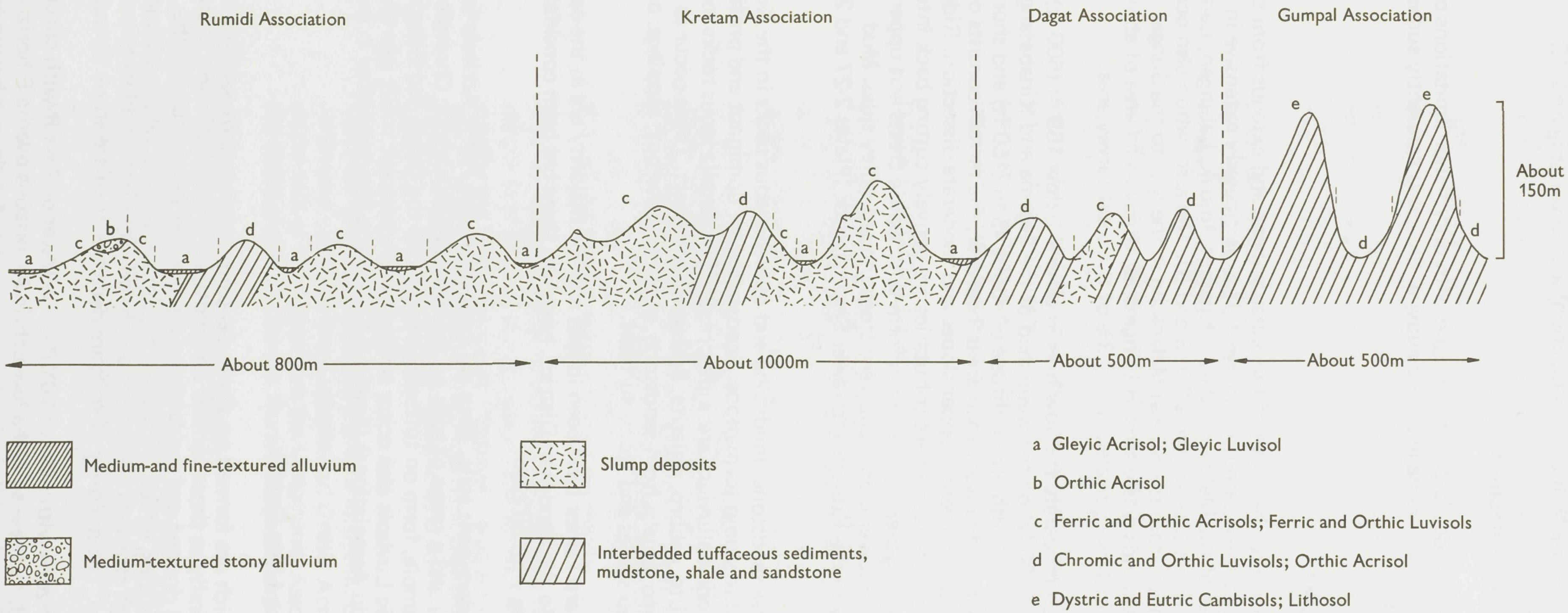

FIGURE 2-12 Theoretical cross-section of the Rumidi, Kretam, Dagat and Gumpal Associations

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the Dagat Association) occur east and west of the Sungai Samawang, at Sungai Manila and on Pulau Berhala; Luvisols formed on basic igneous rocks (see the Mentapok Association), and chert (see the Malubok Association) also occur (Figure 2-12).

Limitations to agricultural development

The Rumidi Association includes large areas of land with only minor limitations of slope on the low hills and poor drainage on the alluvial flats; it is eminently suitable for agricultural development.

KRETAM ASSOCIATION

This association is extensive to the south of the Kinabatangan and extends from the Sungai Tabin in the east to the Kuamut in the west. It is particularly extensive in the middle and upper reaches of the Malubok, Malua, Kuamut, Imbak, Latangan, Lamag, Pin, Koyah and Kretam rivers (Stereograms 2-7, 8 and 9). The association also occurs south of Sandakan Harbour from the Sungai Melanking in the east to the Sungai Segaliud from where it extends westwards to Lungmanis. It covers an area of about 2 080 km^2 (830 mi^2) which is equivalent to 10.3% of the total survey area.

The association occurs on moderate and low hills in general below 150 m (500 ft), but reaching 210-240 m (700-800 ft) on the watershed of the Segama and Kinabatangan. Large areas comprise low hills with an amplitude of about 45 m (150 ft) and short slopes in the 10-20^o range. In the watershed areas, however, the terrain consists of broad radiating ridges with long gentle upper slopes and moderate dissection. Ridges are narrower and slopes are steeper where tributaries are actively cutting back into the hills. In these parts hills are generally convex in form with gentle crests and upper slopes, steeper middle and lower clopes and very steep incised valley sides. Mud volcanoes occur notably in the Kretam and lower Segama areas (Plates 2-27 and 2-28; Stereogram 2-8).

Parent materials comprise sandstone, mudstone and miscellaneous rocks in the Kuamut, Garinono and Chert-Spilite slump formations. Sandstones are dominant and profiles formed on stony sandstone colluvium are widespread. The miscellaneous rocks include serpentinite, spilite, tuffite, gabbro, dolerite, limestone and chert. These occur as erratics in regolith derived largely from sandstone, as minor outcrops, cappings, or as distinct knolls with steep slopes and stony surfaces.

Large areas of Dipterocarp Foresr have been logged and the majority are in the early stages of regeneration. In the Sandakan District, however, there has been considerable clear felling and planting with oil palm.

Orthic Acrisols are the dominant soils. They are associated with Ferric Acrisols (see the Lungmanis Association) and a range of soils on the miscellaneous rocks; Chromic and Orthic Luvisols, for example, form on tuffaceous rocks (see the Dagat and Gumpal Associations) and Orthic Luvisols also occur on basic and ultrabasic rocks (see the Mentapok and Bidu Bidu Associations) (Figure 2-12). Eutric Gleysols occur in mud volcano clearings.

Orthic Acrisols: Tanjong Lipat Family

The Orthic Acrisols which are formed on slump deposits dominated by sandstone are included in the same family as those formed on sandstone in the Dalit and Lokan Associations. Both well drained and moderately well drained soils occur and the diagnostic argillic B horizons, which are mainly medium in texture vary in colour from yellowish brown through strong brown to yellowish red. Soils with reddish brown argillic horizons are rare. The majority of soils are deep but they are stony throughout.

Soils with argillic B horizons with hues of 10YR or yellower or 7.5YR with chromas of 4 or less are widespread. In these soils shallow ochric A horizons overlie E horizons which average 15 cm (5 in) in thickness and are composed of yellowish brown to brownish yellow, often stony, sandy loam to loam with weak to moderate subangular blocky structures. The underlying argillic B horizon is yellowish brown, rarely brownish yellow, with sandy loam to clay loam textures, common sandstone fragments, moderate to strongly developed subangular blocky structure and cutans. The underlying BC horizons are composed of yellowish brown sandy loam to clay loam with common to many fragments of weathering sandstone.

Eutric Gleysols: Rasang Family

Eutric Gleysols of the Rasang Family are of minor importance, being the only soils identified in mud volcano clearings (Plate 2-28). They have A and Cg horizon. The A horizon is shallow and ochric and often overlies transition AC horizons of greyish brown gritty clay with common stone fragments. Buried A horizons may also occur. The gleyic C horizon comprises massive grey clay with stone fragments.

Analyses from one profile show low organic matter contents, strongly alkaline reaction, very high exchangeable sodium, high exchangeable calcium and high base saturation values (Profile Ge 3).

Limitations to agricultural development

The limitations to the agricultural development of the Kretam Association are complex. Many areas are too steep for development and those areas which have moderate slopes are often very stony with rock outcrops, surface boulders and predominantly shallow stony soils which would present considerable problems to mechanised agriculture. In general the land is marginal.

DAGAT ASSOCIATION

This association occurs between the Sungai Segama and the Tabin and between the Tabin and the Lumerau. It covers about 90 km^2 (35 mi^2) of low hills with amplitudes up to about 75 m (250 ft). The hills are strongly dissected with short steep slopes ranging from 10-25^o, narrow crests and narrow valley bottoms; landslips are common.

Parent materials include tuffaceous rocks mudstone, sandstone and slump deposits which are included in the Ayer Formation. Tuffite, which is dominant between the Segama and Tabin, varies considerably in particle size and constituents and in many cases has the appearance of a soft white sandstone. Black mudstones are dominant to the east of the Tabin. The majority of profiles are formed on deposits of colluvium derived from these rocks and soils derived from rocks *in situ* are comparatively rare.

Much of the association is covered in Lowland Dipterocarp Forest, rich in *keruing.* A sample plot showed *Dipterocarpus caudiferus, Dryobalanops lanceolata* and *Shorea glaucescens* to be dominant. However, large areas have been felled and are either in early stages of regeneration or have been planted with oil palm. Regrowth of low thicket with small trees and climbers is common on areas which have suffered landslips.

The association comprises Chromic and Orthic Luvisols and Orthic Acrisols on tuffaceous rocks. Orthic Luvisols and Orthic Acrisols also form on mudstone notably to the east of the Tabin (see the Lungmanis Association). A range of soils occurs on the slump deposits (see the Rumidi Association) (Figure 2-12).

Chromic Luvisols: Libong Family

Deep well drained Chromic Luvisols of the Libong Family occur extensively on tuffite *in situ* and on colluvium. They have A, B and BC horizon sequences; E horizons are normally absent but transition EB horizons may occur. Ochric A horizons average 2 cm (1 in) in thickness and overlie argillic B horizons with colours ranging from yellowish red to reddish brown. Textures range from clay loam to clay; structures are moderate to strong subangular blocky and cutans are prominent. Transition BC horizons contain many tuffite fragments in yellowish red clay loam to clay matrices.

The ochric A horizon contains moderate to low organic matter contents and has moderate to low C/N ratios. The soils are strongly acid throughout. The B horizon contains high amounts of exchangeable bases with high to very high amounts of exchangeable magnesium. Exchangeable calcium amounts are variable. Base saturation values average 60% (Profile Lc 7).

Orthic Luvisols: Talid Family

Moderately deep and shallow well drained Orthic Luvisols of the Talid family occur on tuffite *in situ* and on colluvium on moderate to steep slopes. They have A, B and C horizon sequences; E horizons are normally absent. Ochric A horizons rest directly on argillic B horizons composed of brown to yellowish brown clay loam to clay with strong angular or subangular blocky structures and thin cutans. Transitional BC horizons contain common to many tuffite fragments and C horizons comprise weathering tuffite.

The ochric A horizon contains moderate to low contents of organic carbon and has a low C/N ratio. The soils are moderate to strongly acid. The argillic B horizon has high amounts of total exchangeable bases with very high amounts of exchangeable magnesium and high percentage base saturation values (Profile Lo 8).

Orthic Acrisols: Dagat Family

Moderately deep and deep well drained Orthic Acrisols of the Dagat Family occur on tuffite either *in situ* or as colluvium. They are physically similar to the Libong and Talid Families, but base saturation values in the argillic B horison are less than 50%. Soils in which the B horizon has hues of 7.5YR and 5 YR with chromas of more than 4 are the most common. They have A, EB, B and C horizon sequences. Shallow ochric A horizons overlie transition EB horizons or rest directly on the argillic B horizon. The EB horizon averages 8 cm (3 in) in thickness and comprises yellowish brown to strong brown, rarely yellowish red, sandy clay loam to clay loam with patchy cutans. The argillic B horizon is strong brown to yellowish red in colour with clay texture. Structures are strongly developed subangular or angular blocky and occasionally show a tendency to prismatic. Cutans are prominent. Transition BC horizons are composed of weathering tuffite with a strong brown to yellowish red clay matrix and the C horizons are formed of weathering tuffite. These soils are closely associated with soils in which the argillic B horizon has hues of 5YR with chromas of 4 or less or redder hues. They have shallow ochric A horizons overlying transition EB horizons which average 8-10 cm (3-4 in) in thickness and which are composed of brown to reddish brown clay loam to clay with moderately developed subangular blocky structures and cutans. The argillic B horizon is reddish brown to red in colour with clay texture, moderate to strongly developed subangular or angular blocky structures and cutans. Transition BC horizons contain many weathering tuffite fragments in a reddish brown to red clay matrix. C horizons are composed of weathering tuffite (Profile Ao 6).

Of comparatively rare occurrence are soils in which the argillic B horizon has hues of 10YR. Shallow ochric A horizons overlie EB horizons, which average 3 cm (8 in) in thickness and which are composed of yellowish brown to brownish yellow clay loam, with moderately developed subangular blocky structures and cutans. The underlying argillic B horizons are yellowish brown in colour with clay textures. Structures are strongly developed angular or subangular blocky and cutans are prominent. Transition BC horizons are composed largely of weathering tuffite fragments with a yellowish brown clay matrix and the C horizons are formed of weathering tuffite.

In all profiles, the ochric A horizon has low amounts of organic carbon and low C/N ratios. The A horizons have moderate to high amounts of exchangeable bases and moderate percentage base saturation values. The argillic B horizon, however, has low to very low contents of total exchangeable bases and percentage base saturation values.

Limitations to agricultural development

The Dagat Association is marginal in terms of suitability for agriculture; the main limitations are imposed by the short moderate to steep slopes.

GUMPAL ASSOCIATION

The Gumpal Association occurs east of the Sungai Tabin, where it extends from the foothills of Mount Hatton towards Dagat and also west of the Tabin extending towards the Sungai Tagas Tagas and the Sungai Segama at Tomanggong Estate. North of the Segama it is mapped at Bukit Kretam and in the headwaters of the Manalunan. It covers about 50 km^2 (19 mi^2).

Landforms consist of very narrow steep sided ridges with amplitudes up to 150 m (500 ft); slopes are greater than 25^{o} and often exceed 35^{o}; landslips are widespread.

Parent materials comprise sandstone, tuffite and minor mudstone. Dark grey, base rich sandstone and fine-grained tuffite are dominant in the Mount Hatton foothills. At Tomanggong sandstone forms the most prominent ridges; lower ridges are formed of white fine-grained tuffite and mudstone, with sporadic sandstone outcrops along crests. At Bukit Kretam the prominent ridges appear to be formed mostly of coarse-grained tuffite; less prominent ridges are formed of chert, sandstone and mudstone. Most soils are formed in deposits of stony colluvium with medium-to coarse-textured matrices.

Lowland Dipterocarp Forest covers most slopes, but regrowth of dense thicket with creepers and climbers occurs particularly on the steepest slopes where landslips have occurred. On some ridges at Tomanggong the forest has been felled and lower slopes have been planted with oil palm. Around Bukit Kretam the forest is now in an early stage of regeneration following logging.

The association includes Orthic Luvisols, Dystric and Eutric Cambisols and Lithosols on tuffite with Orthic Acrisols, Dystric Cambisols and Lithosols on sandstone (Figure 2-12). The soils on sandstone are described in the Lokan Association and the Luvisols on tuffite are described in the Dagat Association.

Dystric and Eutric Cambisols: Tenggara and Hatton Families

Dystric and Eutric Cambisols of the Tenggara and Hatton Families form on steep and very steep slopes. They are moderately deep to deep and well drained with A, B and C horizons. Ochric A horizons overlie cambic B horizons of yellowish brown clay loam with well developed subangular blocky structure, variable amounts of weathering tuffite and occasional thin cutans. C horizons comprise strongly weathered tuffite (Profile Bo 4 is an example of a soil of the Tenggara Family).

Lithosols

Lithosols occur sporadically on minor outcrops of tuffite on very steep slopes. They comprise shallow ochric A horizons resting directly on tuffite *in situ.*

Limitations to agricultural development

The severe slopes, rockiness and shallow soils make this association unsuitable for agriculture.

Soil associations on limestone

Limestone outcrops sporadically throughout the survey area and 2 soil associations are separated. The Semporna Association is restricted to low gently sloping land in the east of the Dent Peninsula and comprises Chromic Luvisols, Calcic Luvisols and Rendzinas. The Gomantong Association, which forms on isolated steep-sided limestone outcrops, comprises Calcic Luvisols and Rendzinas (Table 2-27).

SEMPORNA ASSOCIATION

The Semporna Association is restricted to the east of the Dent Peninsula (Stereogram 2-12); it covers about 25 km^2 (10 mi^2) of lowland with an amplitude of about 15 m (50 ft). Slopes are long and gentle and only exceed 5^o on the short slopes of minor hillocks. The area is weakly dissected by minor streams and sink holes occur sporadically.

The parent material is coralline limestone of the Togopi Formation. This outcrops on minor hillocks and valley sides and feagments also occur on the soil surface. The whole association is covered in Dipterocarp Forest in which *Parashorea tomentella* and *Dipterocarpus caudiferus* are dominant.

Well drained Chromic Luvisols occupy the long gentle slopes with Calcic Luvisols and Rendzinas on the inextensive minor hillocks (Figure 2-4).

Chromic Luvisols: Tegupi Family

Chromic Luvisols of the Tegupi Family occur on generally flat land with slopes ranging from 0-5^o.

They have A, argillic B and C horizons. Typically the shallow ochric A horizon overlies strong brown clay loam to clay argillic B horizons; blocky structures and cutans are well developed. Limestone occurs within 60-75 cm (24-30 in) of the surface; it is abruptly separated from the argillic horizon.

The pH values are neutral at the surface, but decrease with depth so that the argillic horizon is moderately acid. Cation exchange capacities are moderate to high; exchangeable calcium values are high to very high and percentage base saturation values are similarly high (Profile Lc 8).

Calcic Luvisols and Rendzinas: Semporna and Loc Sambuang Families

Calcic Luvisols and Rendzinas of the Semporna and Loc Sambuang Families occur in very close association as a result of the irregularity of the limestone surface. Soils of the Semporna Family have shallow mollic A horizons composed of dark brown clay loam, with granular structures; organic matter contents average 10%. They overlie shallow argillic B horizons of yellowish brown calcareous clay, with limestone fragments, strongly developed blocky structure and thin cutans. The boundary to the underlying limestone is sharp and irregular (Profile Lk 2).

Soils of the Loc Sambuang Family comprise shallow mollic A horizons, resting directly on limestone.

The soils of both families are moderately alkaline; they have very high cation exchange capacities and exchangeable calcium contents.

Limitations to agricultural development

The main limitations to the development of land in the Semporna Association are imposed by stoniness and shallowness of soil. Liability to drought would also be a minor limitation because of the shallowness of the soil and the porosity of the underlying limestone. None of these limitations, however, are severe and the land is considered to be suitable for agricultural development.

GOMANTONG ASSOCIATION

The Gomantong Association occurs in the Tabin valley, along the Kinabatangan at Tanjong Batu, Sukau, Batu Batangan and Batu Puteh, at Gomantong (Plate 2-29), Batu Timbang and in the Pinangah valley. It covers about 25 km^2 (10 mi^2) and is formed on isolated hills and ridges with steep, often sheer, slopes. Narrow flats also occur and in places the relief is terraced and distinctly karst-like. Apart from Batu Timbang, which exceeds 750 m (2 500 ft), the association occurs below 225 m (750 ft).

TABLE 2-22 **Soil association on limestone**

Association	Landforms	Vegetation	Parent material	Soil units	Soil families
Semporna	Hills of very low relief; slopes 0-5^{o}	Dipterocarp Forest	Limestone	Chromic Luvisol	Tegupi
				Calcic Luvisol	Semporna
				Rendzina	Loc Sambuang
Gomantong	Hills and ridges of high relief; slopes $>$ 25^{o}	Dipterocarp Forest	Limestone	Calcic Luvisol	Semporna
				Rendzina	Loc Sambuang

Predominantly crystalline limestone of the Gomantong Limestone and Labang Formations and partly crystallised foraminiferal limestone of the Sebahat Formation are the main parent materials. Shallow deposits of yellowish brown clay overlie limestone where slope permits, but in general the limestone is close to the surface and it often outcrops and forms sheer cliffs. In addition limestone boulders litter the surface and screes may also occur on lower slopes. At Batu Puteh and in the Tabin valley the limestone forms scarp slopes or hogs back ridges with sandstone and mudstone outcropping on the steep dipslopes.

Apart from small cleared areas at Sukau, where hill rice is grown between limestone outcrops, the association is under Dipterocarp Forest or poor forests dominated by Lauraceae.

The association includes bare rock, Rendzinas and Calcic Luvisols (see the Semporna Association). Bare rock and Rendzinas are dominant with Calcic Luvisols restricted to narrow flats and inextensive gentle slopes. Orthic Acrisols form on sporadic outcrops of sandstone and are described in the Lokan Association (Figure 2-13).

Limitations to agricultural development

In the Gomantong Association there are severe limitations of rockiness and steep slopes and the association is not recommended for agricultural development.

Soil associations on igneous rocks 1. Soil on basic igneous rocks

Three soil associations are described on basic igneous rocks and their derivatives. The Mentapok Association occurs on mountain ranges and isolated hills and comprises Orthic and Chromic Luvisols, Chromic and Eutric Cambisols, Lithosols and Orthic Acrisols. The Malubok Association also occurs on mountain ranges and isolated mountains formed largely from the Chert-Spilite Formation in which basic rocks are dominant; ultrabasic rocks, chert and sandstone also occur. The association includes a similar range of soils to those in the Mentapok Association with Ferralsols, Luvisols, Cambisols and Lithosols on ultrabasic rocks and Acrisols, Cambsols and Lithosols on sandstone and chert. Low hills, terraces and alluvial flats with Orthic Acrisols, Gleyic Luvisols, Eutric Gleysols and Dystric Histosols are included in the Tapang Association (Table 2-23).

MENTAPOK ASSOCIATION

The Mentapok Association occurs to the west of the Mananam Plain (Plate 2-23; Stereogram 2-4), in the Karamuak valley, in the Malua and Malubok catchments and on the watershed of the Kinabatangan and Segama extending west to the Kuamut valley. It covers about 520 km^2 (200 mi^2).

In general the association is formed on mountain ranges and also on isolated hills and mountains. To the west of the Mananam Plain, mountains extend from north-east to south-west with elevations generally in the 750-900 m (2 500-3 000 ft) range. Slopes are steep, sheer cliff faces are common and ridges and crests are narrow; there are also occasional gently sloping spurs. In the Malua and Malubok catchments isolated,

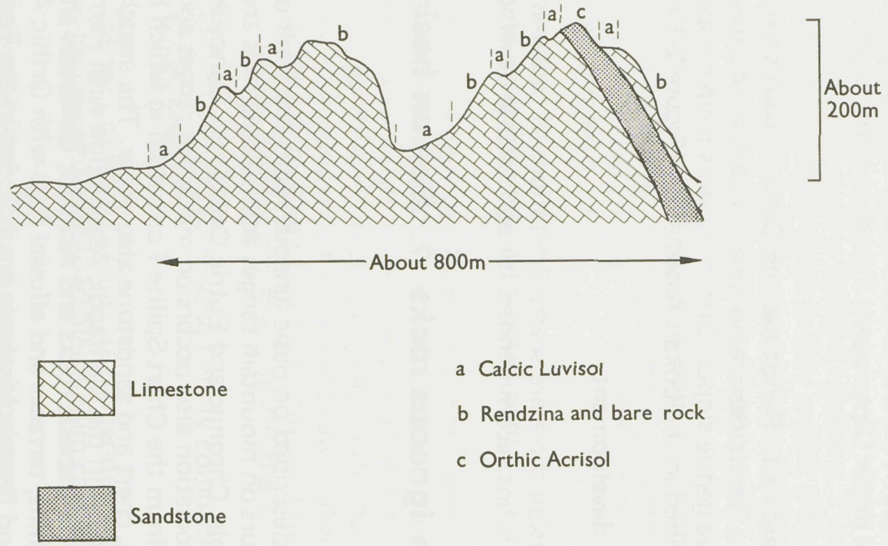

FIGURE 2-13 Theoretical cross-section of the Gomantong Association

FIGURE 2-13

Prepared by the Directorate of Overseas Surveys 1974

steepsided, domelike hills with ridges and peaks reaching up to 600 m (2 000 ft) are common, again with steep, often rocky slopes. Low hills with amplitudes of approximately 75 m (250 ft) are found adjacent to the ultrabasic hill masses bordering the Karamuak valley and Mananam Plain.

The soils are formed on basic igneous rocks comprising basalt, gabbro, dolerite and spilite with less common occurrences of ultrabasic rocks such as periodotite. Large areas of stony colluvium derived from these rocks have accumulated both on steep mountain slopes and also on footslopes. Deposits of fine-textured stoneless colluvium are restricted to inextensive gentle slopes.

TABLE 2-23 Soil associations on basic igneous rocks

Association	Landforms	Vegetation	Parent material	Main soil units	Soil Families
Mentapok	Mountainous, with moderate to very steep hills with moderate to very steep slopes	Dipterocarp Forest	Basic igneous rocks	Orthic Luvisol	Kobovan
				Chromic Luvisol	Beeston
				Chromic Cambisol	Kawa
				Eutric Cambisol	Bombalai
				Orthic Acrisol	Kinabutan
				Lithosol	
Malubok	Mountain ranges with moderate to very steep slopes (> 25%)	Dipterocarp Forest	Basic igneous rocks	See Mentapok Association	
			Ultrabasic igneous rocks	See Bidu Bidu Association	
			Sandstone and mudstone	See Crocker Association	
			Chert	Chromic Cambisol	Juak
				Lithosol	
Tapang	Hills of low relief, slopes 0-15°; terraces and valley floors	Dipterocarp Forest	Alluvium	Xanthic Ferralsol Eutric Gleysol	Tungau Bangawat
			Alluvium derived from basic and ultrabasic rocks	Gleyic Luvisol	Nangoh
			Peat	Dystric Histosol	Klias
			Basic igneous rocks	Orthic Acrisol	Kinabutan

Lowland Dipterocarp Forest, which is well stocked with large trees, covers the slopes up to about 600 m (2 000 ft). On Gunong Gunatong the following species were observed: *Parashorea tomentella, Dryobalanops lanceolata, Lithocarpus* spp. *Shorea leptoclados, S. gibbosa, S. superba, S. guisio, S. maxwelliana, Hopea sangal, Parishia, Anisoptera costate* and *Dipterocarpus caudiferus.* Much smaller trees occur above 600 m (2 000 ft) and rarely exceed 18 m (60 ft) in height. Species include *Hopea argentea, Shorea macroptera, S. asahi, S. andulensis, S. atrinervosa, S. ovalis, S. guisio, S. parvifolia, Dipterocarpus acutangulus, D. gracilis, D. caudiferus, Vatica* sp. and *Drypetes sp.* Above 900 m (3 000 ft) the following species were seen: *Shorea venulosa, S. squamata, S. nebulosa, S. acuminatissima, Vatica dulitensis* and *Lithocarpus sp.* On the inextensive summit at 1 050 m (3 500 ft) mossy forest with *Tristania, Casuarina* and orchid occurs.

Orthic and Chromic Luvisols are the dominant soils. They form on the majority of steep slopes but give way to Chromic and Eutric Cambisols with rock outcrops and Lithosols on very steep slopes. Orthic Acrisols develop on the gentle slopes of ridge crests (Figure 2-14).

Orthic Luvisols: Kobovan Family

Orthic Luvisols of the Kobovan Family are the most widespread soils in the association. They develop on deposits of stony colluvium on the majority of steep slopes in close association with Cambisols, Lithosols and rock outcrops. Boulders of basic rocks are widespread on the surface.

The soils are shallow to moderately deep and well drained; they are predominantly stony and have A, weak, but generally absent EB, B and C horizons. The A horizon is

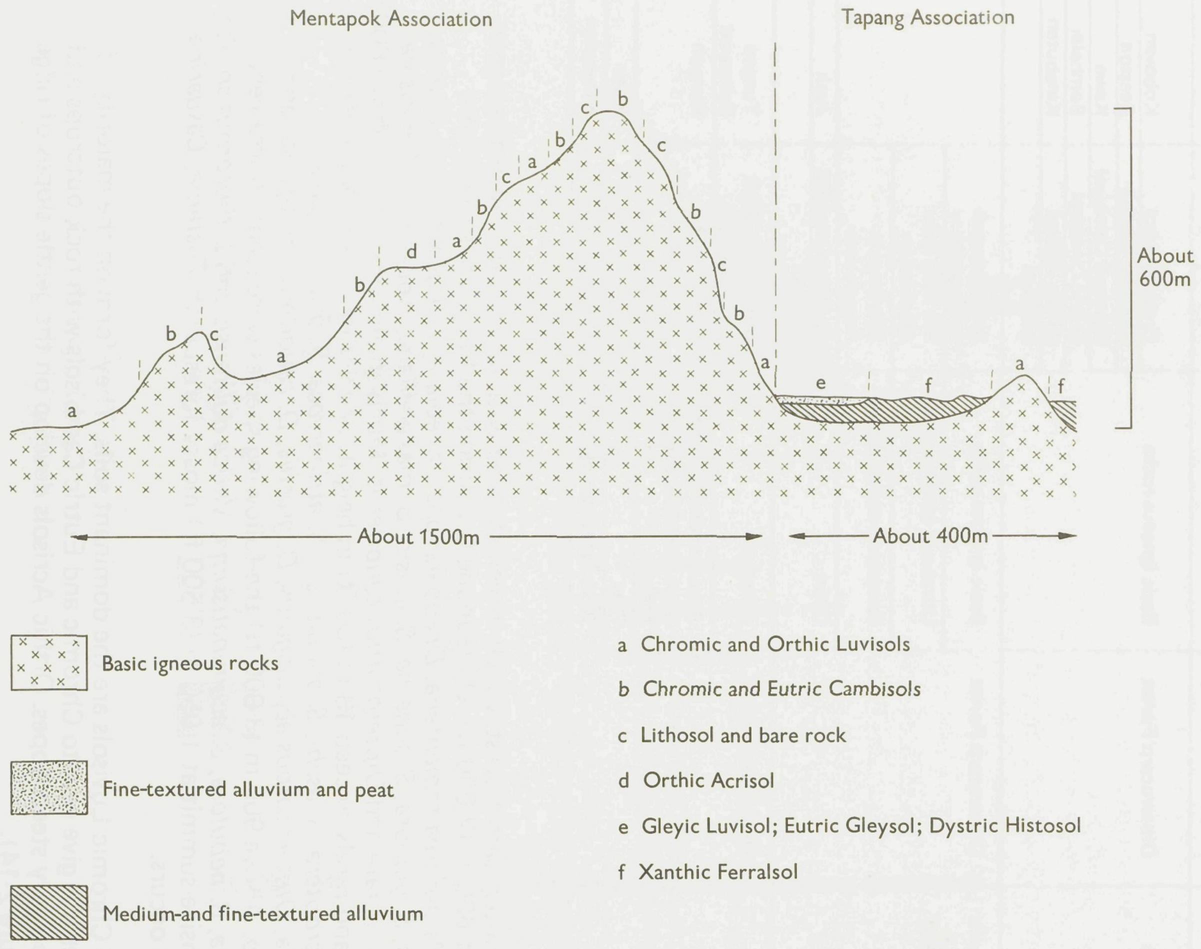

FIGURE 2-14 Theoretical cross-section of the Mentapok and Tapang Associations

FIGURE 2-14

Prepared by the Directorate of Overseas Surveys 1974

ochric and is normally about 3 cm (1 in) in thickness although occasionally it is 8-15 cm (3-6 in) thick presumably as a result of the accumulation of material eroded from upslope. It has loam to clay loam textures and is often stony. Where present, shallow EB horizons comprise yellowish brown stony and concretionary loams. These merge into the argillic B horizons, which range from pale yellow through olive yellow, yellowish brown, dark yellowish brown, to dark brown in colour. Textures range from loam to clay loam, structures are moderately to strongly developed subangular blocky and cutans are prominent.

They are sometimes concretionary and contain many angular and subangular fragments and boulders of basic rocks, which are often hard and less strongly weathered than the underlying C horizons which are composed largely of rotten rock.

The ochric A horizons have medium to low percentages of organic carbon and are slightly acid in reaction. Both the ochric A and argillic B horizons have high amounts of both exchangeable calcium and magnesium and very high base saturation values. (Profiles Lo 5, 6 and 7).

Chromic Luvisols: Beeston Family

Chromic Luvisols of the Beeston Family occur on similar sites to the Kobovan Family on deposits of stony colluvium. The soils are mainly moderately deep, rarely shallow and have A, weak or absent EB, and C horizons. They are identical in almost all respects to the soils of the Kobovan Family, but have redder colours and somewhat finer textures. Colours are normally reddish brown occasionally strong brown and textures range from clay loam to clay.

Both the ochric A and argillic B horizons have high amounts of exchangeable calcium and magnesium and high percentage base saturation values.

Chromic and Eutric Cambisols: Kawa and Bombalai Families

Cambisols of the Kawa and Bombalai Families occur on deposits of stony colluvium on very steep slopes in close association with Luvisols, Lithosols and rock outcrops. They are shallow to moderately deep well drained soils which are predominantly stony and have A, B or BC and C horizon sequences. They differ little from the Kobovan and Beeston Families but show insignificant changes in clay content with depth and cutans are absent or only weakly developed; the B horizons are therefore defined as cambic horizons. Soils of the Kawa Family (Profile Bc 4) have strong brown to red cambic B horizons and those of the Bombalai Family have cambic B horizons ranging from olive yellow through yellowish brown to dark brown in colour. Both families have cambic B horizons with base saturation values greater than 50%.

Orthic Acrisols: Kinabutan Family

Deep well drained Orthic Acrisols of the Kinabutan Family are formed on fine-textured colluvium on inextensive gentle slopes associated with convex crests and spurs. They have A, B and C horizons. The shallow ochric A horizon overlies deep argillic B horizons composed of yellowish red, rarely strong brown, clay loam to clay with moderate to strong subangular blocky structures, prominent cutans and infrequent concretions. Where C horizons occur they are formed in strongly weathered basic rocks.

The argillic B horizons are strongly acid with very low amounts of total exchangeable bases, moderate cation exchange capacities and very low percentage base saturation values. They are transitional to oxic horizons, and the soils are similar, in many respects to the deep, well drained and stoneless Xanthic Ferralsols of the Tungau Family described in the Tapang Formation.

Moderately deep to deep well drained soils also develop on deposits of somewhat stony colluvium on moderate to steep slopes. They have A, B, BC and C horizons. Shallow ochric A horizons overlie strong brown sandy clay loam transitional EB horizons with moderately developed subangular blocky structures and thin cutans. The underlying argillic B horizons are strong brown to yellowish red in colour with sandy clay loam to clay loam textures, moderate to strong angular or subangular blocky, often tending to prismatic, structures, prominent cutans and variable amounts of basic rock fragments. Basic rock fragments are more common in the transitional BC horizons where iron concretions may also occur. C horizons are formed of rotten basic rocks and normally occur below 125 cm (50 in).

The somewhat stony profiles are less strongly leached than the deep stoneless profiles and have moderate amounts of exchangeable magnesium. Contents of total exchangeable bases are, however, very low and percentage base saturation values are low to very low. In profiles with common rock fragments, however, percentages of exchangeable magnesium increase and percentage base saturation values are only marginally less than 50% in the B horizon. (Profile Ao 5).

Lithosols

Lithosols occur in close association with rock outcrops on narrow crests and cliff faces. They have A and C horizons. The ochric A horizons are shallow loams to silt loams and similar material is intersticial to basic rock fragments in shallow transitional AC horizons. Coherent hard basic rocks occur within 10 cm (4 in) of the surface.

Limitations to agricultural development

The severe limitations of steep slopes, rockiness and shallow stony soils rule out agriculture in the Mentapok Association.

MALUBOK ASSOCIATION

This association covers about 505 km^2 (195 mi^2) in the middle and upper reaches of the Malua and Malubok, from where it extends to the watersheds of the Danum and Imbak drainage systems. It occurs both as isolated, steep-sided dome-like mountains and as mountain ranges with prominent peaks at altitudes up to about 1 050 m (3 500 ft) (Stereogram 2-9).

It is formed on the Kuamut and Chert-Spilite Formations in which basic rocks such as gabbro, spilite and basalt are dominant; chert is locally dominant and sandstone and ultrabasic rocks also occur.

Dipterocarp Forest covers the majority of the association except where rock outcrops are extensive and where ultrabasic rocks give rise to dense low forests with bamboo thickets.

The association includes the range of soils described in the Mentapok Association; Ferralsols, Cambisols, Luvisols and Lithosols on ultrabasic rocks (see the Bidu Bidu Association): Acrisols, Cambisols, and Lithosols on sandstone (see the Crocker Association) and Lithosols and Chromic Cambisols on chert.

Chromic Cambisols: Juak Family, and Lithosols

Chert outcrops sporadically as rocky knolls, on ridge crests and on some upper slopes with Lithosols and Chromic Cambisols in close association with actual rock outcrops.

Shallow stony Lithosols comprise shallow ochric A horizons and red chert within 10 cm (4 in) of the surface.

Shallow and moderately deep well drained Chromic Cambisols of the Juak family have A, B and C horizons. The A horizons are shallow and ochric and the cambic B horizons consist of reddish brown clay loam with many to dominant chert fragments; C horizons comprise weathering red chert.

The soils of the Juak Family have very high contents of exchangeable magnesium and high base saturation values. (Profile Bc 6).

Limitations to agricultural development

The Malubok Association is unsuited to agricultural development because of steep slopes, rockiness and shallow stony soils.

TAPANG ASSOCIATION

The Tapang Association covers 25 km^2 (10 mi^2) and is restricted to the northern end of the Mananam Plain and the upper Karamuak valley, but it may occur on other small areas adjoining the Gunong Gunatong range. It is formed on terraces, which have been weakly dissected into low hills and flats with an amplitude of less than 30 m (100 ft) and slopes of less than 15^o; they are often less than 5^o. Narrow, often swampy, alluvial flats also occur.

Parent materials are considered to be old alluvia derived mainly from basic and ultra-basic rocks which form the surrounding hills; these deposits are fine textured and stoneless. Outcrops of basic rocks are confined to incised lower slopes and to low hills above the general terrace level. Lowland Dipterocarp Forest is widespread and species to the north of the Karamuak at Enteleben include *Shorea argentifolia, S. ovalis, S. parvifolia, S. macroptera, S. gysbertsiana, S. smithiana, Dipterocarpus caudiferus, D. confertus, Dryobalanops lanceolata, D. beccariana* and *Pometia pinnata.*

Xanthic Ferralsols are the dominant soils in the association. Orthic Acrisols occur sporadically on the low hills with Gleyic Luvisols (see the Binalik Association), Eutric Gleysols and Dystric Histosols on alluvial flats (Figure 2-14).

Xanthic Ferralsols: Tungau Family

Deep well drained Xanthic Ferralsols of the Tungau Family occur on deposits of old stoneless alluvium on low gently undulating land where slopes are less than 5^o. They have A and B horizons; E horizons are lacking. The ochric A horizons are rarely more than 3 cm (1 in) in thickness and overlie deep oxic B horizons. These are strong brown to reddish yellow in colour with clay textures, moderate to strong subangular blocky structures and thin cutans. Profiles are stoneless but concretionary layers may occur at depth.

These soils are strongly to extremely acid in reaction with very low total exchangeable bases and percentage base saturation values in the argillic B horizon.

Orthic Acrisols: Kinabutan Family

Orthic Acrisols of the Kinabutan Family occur on the moderate slopes of low hills. The soils are formed on stony colluvium derived from basic igneous rocks and are moderately deep to deep and well drained. They are fully described in the Mentapok Association.

Eutric Gleysols: Bangawat Family

Eutric Gleysols of the Bangawat Family occur on inextensive deposits of fine-textured alluvium which are confined to ill drained, often swampy, narrow valley floors. They have Ag and Cg horizons. The shallow Ag horizon is composed of rust mottled greyish brown silt loam and this overlies gleyic C horizons comprising light grey silty clay with variegated mottling and manganese concretions. These soils are very poorly drained and water tables are commonly close to the surface.

Dystric Histosols: Klias Family

Dystric Histosols of the Klias Family occur in close association with the Bangawat Family. They have O and Cg horizons. The histic O horizon is composed of slightly decomposed peat derived largely from sedge and wood fragments; it overlies gleyic C horizons composed of light grey silty clay.

Limitations to agricultural development

In the Tapang Association there are minor limitations of slope and the soils are inherently infertile with low reserves of exchangeable cations. Soils on the alluvial flats have limitations imposed by drainage and minor flooding. In spite of these limitations much of the Tapang Association is considered to be suitable for agricultural development.

Soil associations on igneous rocks 2. Ultrabasic igneous rocks

Three soil associations are described on ultrabasic rocks and their derivatives. The Bidu Bidu Association is the most extensive and is formed for example on the impressive mountain range extending from near Telupid, south to Gunong Rara. The soils included in the association comprise Orthic and Rhodic Ferralsols, Orthic Luvisols, Eutric Cambisols and Lithosols. The Tawai Association comprises Dystric Cambisols, Dystric and Humic Gleysols and Dystric Histosols. It is restricted to the Tawai Plateau, which is an upland plateau situated centrally in the Tawai mountain range. Alluvial fans and valley floors emanating from the mountains are mapped in the Binalik Association which comprises Orthic Ferralsols. Orthic, Gleyic and Ferric Luvisols and Ferric Acrisols (Table 2-24).

BIDU BIDU ASSOCIATION

The Bidu Bidu Association is most extensive on mountain masses extending northwards from Gunong Rara to Bulud Tawai and on the mountains forming the watersheds between the Malubok, Malua, Sangitan and Segama rivers. Gunong Rara 1 470 m (4 900 ft), Bulud Tawai 1 290 m (4 300 ft), Gunong Moritok 1 098 m (3 661 ft) and Bukit Tinkar 810 m (2 694 ft) are the main summits of these mountains which in general have a relief amplitude of 300 to 600 m (1 000-2 000 ft) with very narrow ridges, minor peaks, and very steep slopes liable to landslides (Plate 2-30; Stereogram 2-17). Elsewhere the association occurs as isolated low hills rarely exceeding 150 m (500 ft) at for example Bukit Lawa Lawa (Plate 2-31) and in the catchments of the Malua, Malubok and Koyah rivers (Stereogram 2-7). Collectively the association covers about 545 km^2 (210 mi^2).

The soils are formed on ultrabasic rocks and derivatives in the form of bouldery colluvium and notably as strongly weathered, generally stoneless, reddish brown, fine-textured colluvium. Peridotite, which is invariably serpentinised predominates in the Gunong Rara and Tawai areas. (Collenette, 1965b; Kirk, 1965). Serpentinite is more common to the east of the Kuamut, where it often occurs in close association with gabbro. The chemical composition of some ultrabasic rocks is shown in Table 2-13. Large areas are clothed with low dense xerophytic forest with species including *Dipterocarpus lowii, Shorea laxa, S. andulensis, S. atrinervosa, S. venulosa, S. geniculata, Eugenia sp., Tristania grandifolia, Podocarpus sp.* and *Casuarina sumatrana.* Most of the larger trees do not exceed 120 cm (48 in) in girth or 12 m (40 ft) in height and the forest is notable for its dense understorey of rotan, bamboo, *Mapania,* stemless spiny palm, orchids and pitcher plants. Lower slopes of the mountains carry stands of taller trees up to 210 cm (7 ft) in girth and 36 to 42 m (120-140 ft) in height. Species include *Dipterocarpus lowii, Heritiera borneensis, Shorea venulosa, S. scabrida, S. andulensis* and *S. multiflora.* Here, too, *Casuarina sumatrana* and *Eugenia sp.* occur on exposed rocky ridges and Fagaceae 12 to 18 m (40-60 ft) in height were also noted. Bukit Lawa Lawa has a unique oak forest dominated by *Lithocarpus* species with a canopy height at 18 to 21 m (60-70 ft). Other species include *Diospyros sp., Eugenia, Pternandra canarium* and *Macaranga.*

TABLE 2-24 **Soil associations on ultrabasic igneous rocks**

Association	Landforms	Vegetation	Parent material	Main soil units	Soil families
Bidu Bidu	Mountainous with moderate to very steep slopes (25°) and isolated hills of moderate relief and moderate to steep slopes	Forest on Ultrabasic Rocks	Ultrabasic igneous rocks	Rhodic Ferralsol	Pinianakan
				Orthic Ferralsol	Ambun
				Eutric Cambisol	Binuang
				Orthic Luvisol	Tingkayu
				Lithosol	
Tawai	Upland plateau with level to gently undulating surface	Heath Forest	Ironstone	Dystric Cambisol	Meliau
				Dystric Histosol	Kaintano
			Alluvium	Dystric Gleysol	Koyah
				Humic Gleysol	Guan
			Peat	Dystric Histosol	Klias
Binalik	Alluvial fans, valley floors and terraces	Forest on Ultrabasic Rocks	Alluvium derived from ultrabasic rocks	Orthic Ferralsol	Nobusu
				Orthic Luvisol	Numaroi
				Ferric Luvisol	Pantagaluang
				Gleyic Luvisol	Nangoh
				Ferric Acrisol	Lumisir

The association is dominated by Rhodic and Orthic Ferralsols which form on strongly weathered colluvium. In contrast Lithosols, Eutric Cambisols and Orthic Luvisols form in close association on areas of rock outcrop and little weathered stony colluvium (Figure 2-15).

Rhodic and Orthic Ferralsols: Pinianakan and Ambun Families

Deep well drained Rhodic and Orthic Ferralsols of the Pinianakan and Ambun Families occur on sites ranging from crests, at heights up to at least 900 m (3 000 ft), to lower slopes. They are identical in all respects except colour, the Pinianakan Family being distinguished by having oxic horizons with red to dusky red colours. Both families have ochric A and oxic B horizons. The ochric A horizon is a very shallow brown to reddish brown silt loam. It overlies deep oxic B horizons which may extend to depths of 6 m (20 ft) or more. The oxic horizons show little or only gradual colour and textural variation, but a thin B1 horizon averaging 15 cm (6 in) in thickness can be separated by its somewhat paler colour, its distinctive strong medium and fine subangular blocky structure and the suggestion of thin patchy cutans. Below this the oxic horizon varies in colour from dark reddish brown to yellowish red but there is normally a distinctive purple lustre on ped faces and in pores.

Textures are described in the field as silty clay to silty clay loam. Laboratory analyses, however, often show high percentages of fine sand and coarse sandy loam textures. This is considered to be due to the problems of dispersion of materials rich in iron oxides for values of more than 50% total iron are common in the oxic horizons. Structures of the oxic horizon are moderately to weakly developed subangular blocky; they are so friable that they break to strong fine granular on deformation. Serpentinite fragments rarely occur but around the edge of the Tawai Plateau pisolithic concretions derived from ironstone are sometimes found (see the Tawai Association). Thin section studies of one profile revealed the presence of cutans in many of the pores; the nature of the cutans has yet to be determined but they are presumably composed largely of iron oxides.

FIGURE 2-15

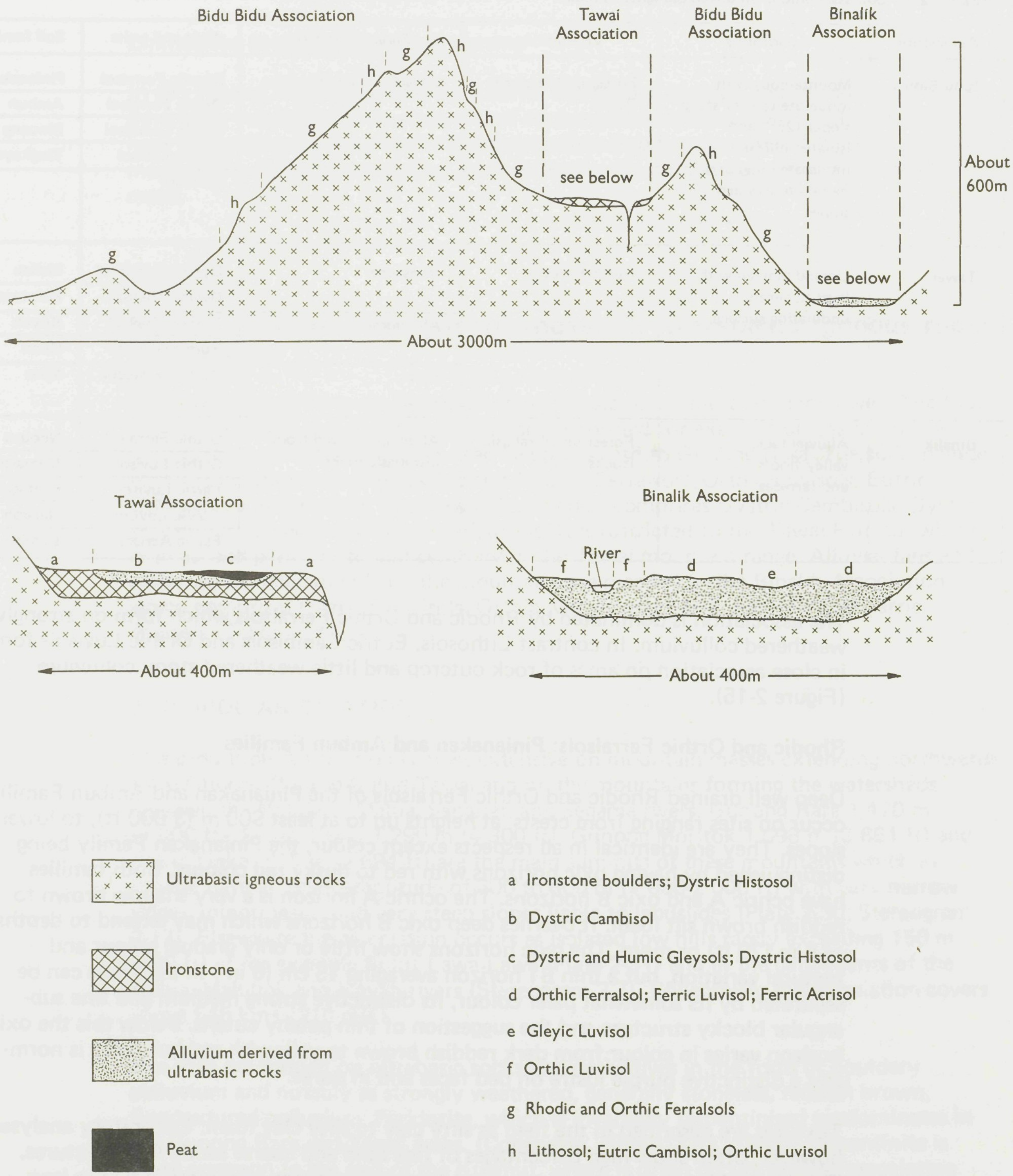

FIGURE 2-15 Theoretical cross-sections of the Bidu Bidu, Tawai and Binalik Associations

Prepared by the Directorate of Overseas Surveys 1974

The cation exchange capacity of the oxic B horizon is usually very low; exchangeable magnesium and calcium levels are also very low but percentage base saturation values are extremely variable. Analyses for trace elements on similar soils undertaken in the Labuk Valley (Hooper and Ives, 1964) showed manganese to be present in quantities of up to 3 000 ppm., titanium up to 5 000 ppm., copper 300 ppm., nickel 3 000 ppm., chromium 3 000 ppm., and zinc 100 ppm. Values for copper ranging from 500-600 ppm with peaks of 2 000 ppm have been reported in tributaries of the Karamuak (Lewis, 1964; Walker and Toms, 1963). (Profile Fo 1 is an example of a soil of the Ambun Family).

Eutric Cambisols: Binuang Family

Shallow Eutric Cambisols of the Binuang Family occur in close association with Lithosols on ridge crests and near rock outcrops. They are similar to the Lithosols, but have shallow cambic B horizons composed of greyish brown stony clay to clay loam.

Deep and moderately deep soils develop on deposits of stony colluvium on steep slopes below rock outcrops; their cambic B horizons are composed of dark greyish brown gritty loam with moderate subangular blocky structures; they become granular on deformation. Stones are common and become dominant below 60 cm (24 in).

The soils are slightly acid to near neutral in reaction. They have moderate to high cation exchange capacities with very high contents of exchangeable magnesium and base saturation values. (Profile Be 2).

Lithosols

Lithosols occur on ridge crests and near rock outcrops. They consist of ochric A horizons composed of black loam and transitional AC horizons of greyish brown gritty loam with dominant serpentinite fragments overlying rock within 10 cm (4 in) of the surface.

Orthic Luvisols: Tingkayu Family

Moderately deep and shallow, well drained Orthic Luvisols of the Tingkayu family occur on steep upper slopes immediately below the crests of narrow ridges. They have A, B and C horizons. The ochric A horizon comprises dark greyish brown silt loam and overlies argillic B horizons of yellowish brown clay loam to clay with strong subangular blocky structures and continuous cutans. Fragments of ultrabasic rocks increase with depth and transition BC horizons of stony clay loam overlie rock *in situ.*

Chemically these soils are similar to the Binuang family with moderate to high cation exchange capacities, very high amounts of exchangeable magnesium and very high base saturation values. (Profile Lo 3).

Limitations to agricultural development

The Bidu Bidu Association is unsuitable for agricultural development because it occurs on mainly mountainous land. In addition the Ferralsols have probable trace element toxicities and the Lithosols, Cambisols and Luvisols are limited by depth and rockiness.

TAWAI ASSOCIATION

This association is restricted to the Tawai Plateau, a broad shallow plateau bordered to the south and west by low minor peaks of the Tawai range and on the north-east by major peaks and ridges which culminate in Bulud Tawai itself (Stereogram 2-17). It is divided into 2 parts with a total area of 10.5 km^2 (5 mi^2); the larger part, to the north, lies between 390 to 420 m (1 300-1 400 ft) and the smaller at 330 to 360 m (1 100-1 200 ft). The plateau is level to gently sloping and apart from the perimeter, much is swampy. Minor streams which drain the swamps have carved trench-like valleys with narrow terraces. The Meliau drains the northern part and descends by a spectacular waterfall over the sheer northern edge. The major part, however, is drained in an easterly direction by the Sungai Tangkulap.

The plateau is underlain by hard impervious pisolithic ironstone described as 'hard and cellular massive fine grained goethite in the form of pellets or concretions up to 10 mm diameter cemented by more clayey limonite' (Wilford, 1968b) (Table 2-13). The ironstone is often weathered to form deposits of loose concretions at the surface. The massive deposit forms boulder covered flats around the perimeter of the plateau and boulders also occur in stream banks, but over much of the plateau it is overlain by deposits of fine-textured concretionary alluvium. Mohr and van Baren (1959) refer to similar iron concretionary masses which occur as weathering residues on ultrabasic rocks in the south-east of Borneo; they regard these as fossil remnants of concretionary layers, which resulted from the oscillation of ground water and which hardened on exposure.

The boulder-covered flats support a low mossy forest with abundant orchids and pitcher plants. *Casuarina sumatrana* is dominant with *Tristania grandifolia, Hopea pentanervia* and *Shorea venulosa* amongst dipterocarps present. In addition the swamps support several species of conifer, including *Podocarpus.*

The association includes Dystric Cambisols, Dystric Histosols and Humic and Dystric Gleysols (Figure 2-15).

Dystric Histosols: Kaintano Family

Shallow well drained Dystric Histosols of the Kaintano family occur on the boulder flats and comprise histic O horizons of moss, leaf fragments and roots over loose concretions and boulders.

Dystric Cambisols: Meliau Family

Dystric Cambisols of the Meliau family occur in intermediate positions between boulder flats and swamps. They are all subject to fluctuations of groundwater and have O, A, B and C horizon sequences. Shallow O horizons composed of mixed leaves and roots overlie ochric A horizons of greyish brown concretionary silt loam. The shallow cambic horizon is dominated by small concretions, but has a yellowish brown silt loam matrix. The C horizon is composed of concretions and boulders. These soils do not show the typical grey colours associated with gleying although they occur in sites with high water tables.

Similar soils form on deeper deposits of fine-textured concretionary alluvium adjoining narrow streams, but the cambic B horizon is deeper; it comprises dark yellowish brown to dark brown silty clay loam with many concretions.

The soils are extremely acid with very low contents of exchangeable bases and percentage base saturation values.

Dystric Gleysols, Humic Gleysols and Dystric Histosols: Koyah, Guan and Klias Families

The Koyah, Guan and Klias families occur in close association in the swamps. The swamp surfaces are very uneven and gullied and many of the small trees grow on low peaty hummocks. The soils are formed on fine-textured concretionary alluvium overlain in places by variable depths of peat.

Dystric Gleysols of the Koyah family have shallow ochric A horizons which overlie gleyic horizons of yellowish brown silty clay loam. In common with the soils of the Meliau family these soils do not show the typical colours associated with gleying although they are under water for long periods.

Humic Gleysols of the Guan family contrast with the Koyah family in that they have shallow histic surface horizons instead of ochric horizons, where the histic horizon exceeds 40 cm (16 in) the soils become Dystric Histosols.

Dystric Histosols of the Klias family are best developed around tree roots where decomposed woody peat overlies the concretionary alluvium. The peat depth averages 45 to 60 cm (18-24 in) but depths of up to 120 cm (48 in) have been recorded (Lewis, 1964). The watertable is at, or close to, the surface throughout the year.

Because of the lack of analyses the Gleysols have been included with the Koyah and Guan Families as soils formed from undifferentiated alluvium.

Limitations to agricultural development

There are severe limitations of soil depth, stoniness and drainage in the Tawai Association so that the land is of no agricultural value.

BINALIK ASSOCIATION

This association occurs adjacent to the Gunong Rara and Tawai ranges and in particular fringes the Karamuak valley (Stereogram 2-17). Individual occurrences are usually small in extent but collectively these soils cover about 25 km^2 (10 mi^2).

The association is formed on alluvial fans associated with streams draining the mountains; these are mostly level to gently undulating and in the broader valleys occasionally comprise series of low terraces. There is usually a slight decrease in height and a corresponding deterioration in drainage conditions away from the streams; all are liable to short term flash floods.

Parent materials comprise mixed alluvia derived predominantly from ultrabasic and basic rocks with some admixture of sedimentary rocks. These are dominantly fine-textured; they are rarely stony, but contain hard concretions which are either discrete or cemented into blocks.

Much of the association is covered by poor quality Dipterocarp Forest often with bamboo thicket and climber tangle. Swampy areas with *Alstonia sp., Eugenia sp.* and *Pandanus* occur sporadically.

The association is dominated by Orthic Ferralsols. Orthic Luvisols, Ferric Luvisols and Ferric Acrisols are also common with Gleyic Luvisols restricted to poorly drained depressions (Figure 2-15).

Orthic Ferralsols: Nobusu Family

Orthic Ferralsols of the Nobusu Family are formed on deposits of alluvium derived almost wholly from ultrabasic rocks. On the east bank of the Karamuak, for example, coalescent fans now form a weakly dissected terrace derived from colluvial deposits on the footslopes of the Tawai mountains. The soils are identical to those described on footslopes comprising deep, well drained, reddish brown silty clay loams with fine subangular blocky and granular structures and distinctive purple lustre on ped faces (see the Bidu Bidu Association).

Orthic Luvisols: Numatoi Family

Moderately well to well drained Orthic Luvisols of the Numatoi family are found near the main streams and on low terraces. They have A, transition AB and B horizons. The A and AB horizons are composed of brown to dark brown loam and these grade into the argillic B horizon, which comprises strong brown silty clay loam or clay loam with strong fine and medium subangular blocky structures and moderately thick continuous cutans. This horizon is often mottled with brown to dark brown colours and soft, black manganese concretions may also occur.

The soils are moderately acid with argillic horizons in which cation exchange capacities are moderate and base saturation values are high, largely as a result of very high contents of exchangeable magnesium. (Profile Lo 1).

Ferric Luvisols: Pantagaluang Family

Deep moderately well drained Ferric Luvisols of the Pantagaluang Family have A, transition AB and B horizons. The A and AB horizons are dark brown with yellowish brown mottles and sandy loam textures. The underlying argillic B horizon is dark yellowish brown with strong brown and greyish brown mottles, sandy clay loam texture and thin cutans. Concretions of iron and manganese are common throughout the argillic horizon and increase in content with depth.

These soils are chemically very similar to the soils of the Numatoi Family with argillic horizons containing high amounts of exchangeable magnesium and having high to very high base saturation values. (Profiles Lf 1 and 2).

Gleyic Luvisols: Nangoh Family

Poorly drained Gleyic Luvisols of the Nangoh Family occupy depressions and sites distant from main streams. They have A, EB and B horizons. The ochric A horizon comprises dark greyish brown sandy loam and overlies a transition EB horizon of brownish grey, sandy loam with some iron and manganese concretions. The argillic B horizon, which is also gleyic within 50 cm (20 in) of the surface, is olive grey in colour with yellowish brown mottles, sandy clay loam texture, moderately thick cutans and many concretions.

These poorly drained soils are chemically very similar to the Numatoi family with argillic horizons containing high amounts of exchangeable magnesium and having high to very high base saturation values. (Profile Lg 1).

Ferric Acrisols: Lumisir Family

Ferric Acrisols of the Lumisir Family occur on well drained sites often on terraces composed of medium- tofine-textured concretionary alluvium. They have A and B horizons. Shallow ochric A horizons overlie transition AB horizons of brown to dark brown sandy clay loam with few concretions. The underlying argillic horizon is strong brown to yellowish red or reddish brown in colour with silty clay loam to silty clay textures, moderately thick cutans and common to dominant concretions of iron and manganese, which may be sufficient to impede root development.

These are strongly to extremely acid soils with very low cation exchange capacities and percentage base saturation values.

Limitations to agricultural development

The Binalik Association which contains Ferralsols with toxicity problems, and Gleyic Luvisols with drainage limitations and which is also liable to flash floods is not recommended for agricultural development.

Part 4

Agriculture and soil suitability

AGRICULTURE

Introduction

The economic history of the Sandakan and Kinabatangan Districts is closely related to the history of land use in which village communities derived a living from agricultural and forest produce and Sandakan developed as the export centre for these products. In the Kinabatangan District shifting cultivation is still practised by tribal communities, who still collect and trade in rattan and damar resin. On the coast and lower reaches the Orang Sungai and Suluk communities have for long lived by fishing and planting sufficient rice or tapioca to meet their needs.

In its early years the Chartered Company derived its revenue from leases and taxes on the collection and export of forest produce (Tregonning, 1958). During the 1880's shops were opened at strategic points along the Kinabatangan for the collection of commodities such as rattan, gutta percha, damar, crocodile skins and ivory and the export trade in birds nests, hampered by pirates, was revived. Meanwhile the Administration encouraged planters so that accessible land around Sandakan Harbour was acquired and many tropical crops, notably tobacco, were planted. In 1884 a company at Suan Lamba sent a sample of tobacco leaf to the London market; this received such a warm reception that the company promoted a rush to acquire land and a boom in tobacco followed. From one company growing tobacco in 1884 there were 21 in 1890 with land applications for a total of about 71 000 ha (175 000 ac). Large estates were set up in the Segaliud, Sapagaya and Suan Lamba Valleys and from Melapi to Pintasan along the Kinabatangan. Exports increased from a value of M $822 in 1885 to over M $2 000 000 in 1902; exports were mostly to the USA. A decline followed due to the introduction of a protective tariff in the USA and due also to local factors including periodic drought, untimely floods and disease. The Batu Puteh Company survived until 1929, but by then all estates on the floodplain had been abandoned.

By 1907 interest had turned to rubber and the earliest ventures were at the Bode and Sekong Estates. Rubber was planted at Melapi, Bilit, extensively on the Lamag Estate and as far upstream as Tangkulap along the Sungai Kinabatangan.

It was the most important crop in the Sandakan Peninsula and between the wars there was considerable planting along the Labuk Road. Like tobacco, rubber was sensitive to price fluctuations and was seriously hit by the slump of 1931. Today few rubber estates are still producing on a commercial basis and the large areas of derelict rubber are witness to yet another era of former prosperity.

The coconut, however, has survived the vicissitudes of the markets, but it has never been a very profitable crop; it is mostly grown by smallholders or on small estates whose owners are not solely dependent on it as a source of income. Coconuts have been planted extensively around the coast, near Sandakan and around Sandakan

Harbour and the sale of copra has been, until recently, a steady source of income to both the growers and the merchants in Sandakan.

A number of other attempts have been made to produce commercial crops on a large scale. In 1918 a Japanese company bought the Kinatan rubber estate at Bilit (Rutter, 1922) and after experimenting with tobacco and cotton, invested in jute; this lasted until after the war. In 1959 the River Estates Company planted about 240 ha (600 ac) of cocoa at Deramakot but this was devastated by flooding in 1963 and the estate was abandoned (Barrett, 1972). In 1962 the Tongod Anglican Mission started an agricultural project in an attempt to encourage the shifting cultivators to adopt a more settled existence. A demonstration farm was started with rubber, oil palm, coffee and cocoa together with fruit trees, pineapples, fish ponds and livestock, but although initially successful has not been maintained.

Oil palm, rubber, coconuts, rice, vegetables and fruit crops are the main crops grown today. It is estimated that crops are grown on about 26 700 ha (65 900 ac) which is just 1.3% of the total survey area (Table 2-25) (Sabah, Department of Agriculture, 1971).

Oil palm

In recent years the oil palm has become the leading crop and its area has increased at the rate of about 1 600 ha (4 000 ac) a year since 1967. There is no sign of any reduction in this rate, but it must clearly slow down as estates complete their planting. Oil palm is grown on settlement schemes and private estates and by co-operative land development societies and smallholders.

Table 2-25 Estimated area of main crops in the Sandakan (S) and Kinabatangan (K) Districts in hectares and acres; 1970

	Area	Oil palm		Rubber		Coconut		Wet rice		Hill rice		Other crops		Total
		S	K	S	K	S	K	S	K	S	K	S	K	
Settlement schemes	ha	3 691	–	–	–	–	49	–	61	–	–	–	30	3 831
	ac	9 120	–	–	–	–	120	–	150	–	–	–	75	9 465
Cooperative Land Development Societies	ha	1 294	–	278	105	759	–	–	–	–	–	1	–	2 437
	ac	3 198	–	691	260	1 873	–	–	–	–	–	3	–	6 025
Small-holders	ha	61	–	3 102	8	2 644	202	20	–	20	834	867	166	7 924
	ac	150	–	7 664	20	6 534	500	50	–	50	2 060	2 142	410	19 580
Private estates	ha	4 689	2 069	4 548	665	523	–	–	–	–	–	–	–	12 494
	ac	11 581	5 112	11 238	1 644	1 293	–	–	–	–	–	–	–	30 868
Total	ha	9 735	2 069	7 928	778	3 926	251	20	61	20	834	868	196	26 686
	ac	24 049	5 112	19 593	1 924	9 700	620	50	150	50	2 060	2 145	485	65 938

There are 3 major settlement schemes administered by the Sabah Land Development Board totalling 7 690 ha (19 000 ac) in the Sandakan District. These are the Sungai Manila (Plate 2-32 and 2-26), Ulu Dusun and Suan Lamba schemes and in mid 1971 oil palm acreages totalled 2 420 ha (5 970 ac), 490 ha (1 214 ac) and 590 ha (1 451 ac) respectively. At Ulu Dusun there is also a minor settlement scheme which is administered by the Department of Agriculture. Here it is proposed to plant 200 ha (500 ac) of oil palm and at the end of 1971 about 60 ha (150 ac) had been planted.

There are 34 co-operative land development societies in the Sandakan and Kinabatangan Districts, of which only 2 are in the latter. Six are based on the cultivation of oil palm and at the end of 1971 about 1 295 ha (3 200 ac) had been planted. These societies are groups of individuals who have pooled their resources, usually derived from the timber industry, to develop land. In general, however, it can be said that the aim of the societies obtaining land is not for the development of the land, but the quick profits that can be obtained from timber. As a result little effort is spent in ensuring proper maintenance and management of planted areas and large areas have not been planted, but have reverted to secondary forest following removal of timber. There are few permanent residents on the land, so that there are severe problems of, for example, damage to growing palms by wild pigs and elephants.

There are few smallholders engaged in oil palm production and the acreage involved is estimated at only 60 ha (150 ac).

The transport of fresh fruit to large central mills and the subsequent transport of palm oil to bulk installations will require a considerable programme of work notably in road construction. In addition palm oil bulking installations prior to shipment are an essential feature of the industry. In 1971 the bulk installation facilities at Sandakan became operational and superceded the previous arrangements whereby oil was transferred to ships by coastal lighters.

Coconuts

The area under coconuts in the Sandakan and Kinabatangan Districts totalled about 4 060 ha (10 300 ac) at the end of 1971. Coconuts have been planted mainly on coastal beaches extending from Tambisan to Tanjong Pisau (Plate 2-13) and in addition occur near Sandakan and on the Kinabatangan floodplain at Pintasan.

The diminishing importance of coconuts on the east coast can be assessed from the exports of copra. Exports from Sandakan fell from 9 495 lgt in 1961 to 1 471 lgt in 1963 and 729 lgt in 1971. However, coconuts are popular among smallholders because they are easily planted and because no complicated processing facilities are involved. Approval has been granted for the development of coconut plantations by cooperative land development societies and recent plantings total about 800 ha (2 000 ac); these are in general badly maintained for reasons discussed in the section on oil palm.

There are 3 minor settlement schemes administered by the Department of Agriculture on the Kinabatangan at Karamuak, Kuamut and Kuala Lokan. Acreages of coconuts planted at the end of 1971 totalled 8 ha (20 ac) at Karamuak and 38 ha (95 ac) at Kuamut; an additional problem here is the high cost of transport to Sandakan.

Rubber

The total area of rubber in the Sandakan and Kinabatangan Districts at the end of 1971 was about 8 700 ha (21 500 ac), but it is estimated that less than 20% of this area is being tapped. Large areas are derelict and some plantations of young rubber are not properly maintained. Most of the rubber is on estates; of these only the Friendly Estate and the Bode Estate in the Sandakan District are known to be operating. In the Kinabatangan District, Litang Estate on the Sungai Segama is the oldest and largest estate with about 665 ha (1 640 ac), but rubber has not been tapped since 1971. Rubber is tapped by smallholders in the Sandakan Peninsula notably around the airport and along the Labuk road. The low price of rubber up to 1973 and the shortage of labour have been the main factors in the decline of production and have discouraged new planting, but about 320 ha (800 ac) have recently been planted by cooperative societies. Exports from Sandakan reached a record low level in 1967 with only 640 lgt, but had risen again to 1 070 lgt in 1970.

Rice

About 80 ha (200 ac) of wet rice are grown in the survey area. Of this most is grown on the Kinabatangan at Bukit Garam and Sukau. Bukit Garam (Plates 2-18 and 2-34) was selected in 1968 as the site for a pilot project in the mechanised cultivation of wet rice. This was in anticipation that large areas of the Kinabatangan floodplain would prove suitable for the purpose. The project has met with many severe problems including labour shortage, poor communications, severe flooding and the use of heavy machinery on poorly drained land (Plate 2-34), but will provide valuable information essential in the formulation of proposals for future development. At Sukau, wet rice is grown on a small settlement scheme administered by the Department of Agriculture. There have also been attempts to grow wet rice at Bilit and in the Labau valley.

Most of the rice grown is hill rice and almost all of this is in the Kinabatangan District. It is grown largely by shifting cultivators notably in the Labau valley, Mananam Plain, Karamuak valley and Inarat Lowlands, and along the Sungai Milian downstream from Pinangah, the Kinabatangan between Kuamut (Plate 2-33) and Abai and the Segama downstream from Litang. In the Labau valley, Mananam Plain, Karamuak valley and Inarat Lowlands rice is grown mainly on communal plots up to about 20 ha (50 ac) in size. An area of forest is felled and burnt and rice is grown during one year, after which parts of the plot are used for tapioca before it reverts to secondary forest. Along the Milian, Kinabatangan and Segama rice is generally grown by individuals on much smaller plots. Estimates of area under hill rice vary from about 800 ha (2 000 ac) to 2 225 ha (5 500 ac) (Sandilands, 1969); its importance is far greater than the area would indicate, since it is the staple crop for about 10% of the population.

Other crops

It is estimated that there are about 850 ha (2 100 ac) of other crops in the Sandakan District and about 200 ha (500 ac) in the Kinabatangan District. These comprise food crops such as maize, tapioca and vegetables, fruit crops including bananas, citrus and pineapple and cash crops such as coffee. Most of these crops are grown by smallholders close to Sandakan for the Sandakan market. Mumiang (Plate 2-14) and Bungon are notable centres producing a wide range of vegetables and fruit crops, melons being a seasonal speciality.

Livestock

Livestock farming is concentrated near Sandakan where marketing facilities are available. Outside Sandakan there is no commercial livestock farming, but pigs and poultry are common in the interior villages. Cattle, however, comprise just two small herds on the Kinabatangan near Bilit and Tongod and there are a few buffalo in the Labau valley.

About 500 cattle are kept on 12 farms in the Sandakan District but these are badly maintained. Improperly managed pastures are heavily overgrazed and weed infested and rotational grazing is not practised because of the insufficient numbers of paddocks. In addition there is high incidence of disease, mortality and inbreeding. Local butchers are reluctant to purchase local cattle because there is a regular supply of both cattle and buffalo from Kudat. There are only about 150 buffalo and about 1 000 goats in the Sandakan District, but the number of goats is increasing because of the large demand for goat meat.

Pig production in Sandakan has apparently reached a peak; about 18 000 pigs are reared by commercial farmers and back-yard gardeners. There are 9 commercial pig farms which produce about 1 000 pigs monthly for slaughter. The animals are housed in well designed buildings with adequate water supplies and drainage. Imported breeds include Landrace, Berkshires and Tamworths. Backyard farms account for about two thirds of the pigs slaughtered at the Sandakan abbattoir and a conservative estimate of the number of pigs reared in these farms is about 10 000. Breeds of pigs include Chinese Swaybacks, Berkshire crosses and some Large White crosses, but the standard of management is poor and disease is prevalent.

The poultry industry has made rapid progress and Sandakan has become more or less self-sufficient in table eggs. There are 8 commercial poultry farms with about 18 000 layers producing about 14 000 eggs daily. Seven of these farms rear broiler chicks, the total monthly production being about 7 000 broilers. The layers are mainly White Leghorns and New Hampshire Reds and they are reared in batteries on imported foodstuffs. Broilers are mainly New Hampshire crosses and Red Cornish crosses reared in battery cages, on wire mesh floor houses or on free range. Backyard poultry farms are very common around Sandakan with up to about 500 birds on any one farm. Ducks are also reared in backyard gardens but there are no commercial duck farms in the District.

SOIL SUITABILITY

Soil suitability classification

Soil suitability classification is an attempt to interpret the characteristics of soils in terms of their suitability for agricultural use, but this is in part determined by the detail of the survey and the existing knowledge on crop response. At the reconnaissance level of soil survey where maps show broad mapping units the interpretation can only emphasise the salient features of each mapping unit. It cannot show the information that is needed for locating and planning specific projects for which detailed surveys are required. Planting experience has until recently been the only criterion for development in Sabah and, while there has been nearly 100 years of trial and error, the lessons have often been negative and there are few records available for examination.

Three broad categories of land are recognised in the survey area

1. Suitable land. Suitable land has no more than minor limitations and is suited to a wide range of crops.
2. Marginal land. Marginal land has limitations that restrict the range of crops that can be grown and requires improvement or soil conservation measures.
3. Unsuitable land. Unsuitable land has severe limitations which preclude its use for agriculture.

Table 2-26 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 2-26 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 *Sabah Land Capability Classification* issued by the Sabah State Development Planning Committee (1973).

In the survey area as a whole about 13% is considered to be suitable for agricultural development, 21% is marginal and 66% is unsuitable.

Land unsuitable for agricultural development

Land which is considered unsuitable for agricultural development includes land with very severe slope limitations, land with severe drainage and flooding limitations and land with severe nutrient imbalance.

Land with very severe slope limitations

Large areas of the interior of the Kinabatangan District have very severe slope limitations (Text Map 2-6). They have unstable slopes on which landslides occur and which would be liable to severe erosion if the existing forest were removed. The Lokan, Crocker, Maliau, Serudong and Trusmadi Associations are all formed on sandstone and mudstone on steeply sloping, often mountainous land and are not suitable for agriculture; in addition many soils are shallow and stony and rocks outcrop sporadically. The Mentapok, Malubok and Bidu Bidu Associations are formed largely on basic and ultrabasic igneous rocks and are also unsuited to agriculture because of slope factors. In addition both the Mentapok and Malubok Associations have considerable areas of rock outcrop and shallow stony soils are commonplace. The deep Orthic and Rhodic Ferralsols which are the dominant soils in the Bidu Bidu Association are believed to have trace element toxicities and even were slopes favourable, could not be recommended for agriculture. The Gomantong and Gumpal Associations are formed on limestone and tuffite respectively and have short, steep, often precipitous slopes with extensive rock outcrops and shallow stony soils. In the latter the soft unstable rocks are prone to severe landslides and experience at Tomanggong indicates their unsuitability for tree crops.

While these areas with severe slope limitations cannot be recommended for agricultural development, it has to be recognised that some areas have long been used for agriculture. In the upper Tongod, Labau and Milian valleys and in the Mananam Plain steeply sloping land included in the Lokan and Crocker Associations is used for shifting cultivation. At Sandakan vegetables are grown on a small scale on steeply sloping land included in the Maliau Association. Here however, by terracing and the intensive use of manures on raised beds, the naturally unfavourable soil conditions have been overcome. Possibly the strongest argument against any large scale use of these areas is the certainty that the removal of the forest cover would cause increased flooding. These associations comprise the catchment areas of the main rivers which are already liable to severe flooding in their lower reaches and the destruction of the forest would undoubtedly further increase the severity of this flooding.

Land with severe drainage limitations and flood hazard (Text Map 2-7)

The floodplains and deltas of the Kinabatangan and Segama rivers together with their tributaries have high watertables, widespread swamp conditions and are subject to periodic severe flooding. Flooding occurs on the Segama and Kinabatangan floodplains sufficiently frequently and with sufficient severity to constitute a major hazard to agriculture. Flood measurements and flood warnings began as recently as 1969, but records are available that supplement the experience of major floods in 1968 and 1971 which make it possible to assess the degree and severity of flooding.

Along the Sungai Segama severe flooding was experienced in 1963, 1965, 1968 and 1971. At the Tomanggong Estate young oil palms and cocoa trees were destroyed and this led to the abandonment of the floodplain for tree crops. In addition trials to grow annual crops using machines to overcome labour shortages were hampered by drainage problems and were discontinued. On the Kinabatangan records of floods date back to the 1880's; the earliest mention is in Hatton's diary of 1883 when he abandoned any attempt to cross over to the Sungai Segama via the Sungai Tenegang owing to floods. In 1886, Von Donop noted that the river flooded badly 1 year in 7 and Guillemard (1886) referred to evidence of driftwood stuck in branches high above the Sungai Segaliud.

There were frequent references to the Kinabatangan in the North Borneo Herald between 1886 and 1910. These records show that in 1892, 1898, 1902, 1910, 1913

TEXT MAP 2-6

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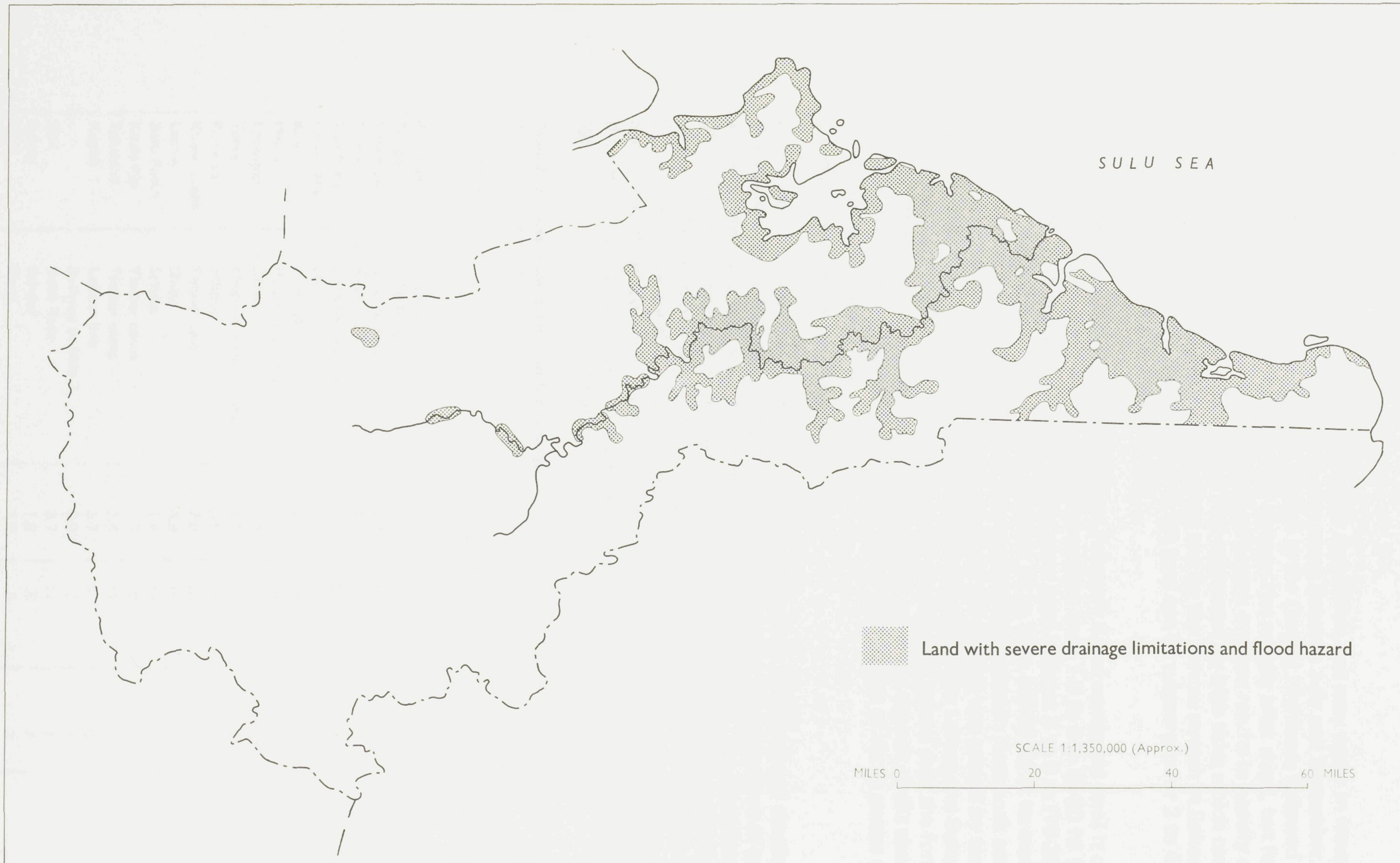

TEXT MAP 2-7

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and 1918 severe floods occurred on the scale of those experienced recently in 1963, 1968 and 1971. Eye witness accounts are given of those in 1902 and 1910 and the former is generally referred to as the worst ever. Major floods also occurred in 1917, 1927, 1928, 1934 and 1940.

Flooding occurs mainly between December and March, but may occur in November and extend into April. Minor flooding can also occur between July and September. The cause appears to be unusually heavy rainfall in the Central Highlands followed by rapid runoff. In the Kuamut catchment minor streams rise rapidly after short, but heavy, showers and prolonged rain over a period of a week or more results in heavily swollen rivers. Flooding on the Kinabatangan is also aggravated by high tides which cause a backing-up effect as far upstream as Lamag and by the narrow stretch at Sukau which restricts outflow. Evidence indicates that the land can be submerged for 2 to 4 weeks below Pintasan and up to a week above.

In 1971 the Kinabatangan began to rise on February 6 and continued until it overflowed its banks and inundated the plain to depths varying from 1.5 to 9 m (5-30 ft) (Table 2-27) (Plates 2-35 and 2-36). As the normal river level is about 3 to 6 m (10-20 ft) below the banks this represents a rise of about 12 to 15 m (40-50 ft) at its maximum. The depth of flooding and the rate of flow was greatest between Karamuak and Kuamut causing the greatest damage to housing. Much of the damage was caused by large logs carried by the floodwaters. The duration of flooding between Lamag and Sukau was 3 to 4 weeks, but the force was dissipated as the floodwaters spread over the forest covered floodplain. The floodplain was covered in a shallow deposit of silt about 5 cm (3 in) in thickness. In places, notably close to the river, layers of silt in excess of 30 cm (12 in) were deposited.

Land with severe nutrient imbalance

In addition to flooding itself, the other severe limitations to agricultural development of the meander belts, floodplains, backswamps and deltas are the occurrence of potential acid sulphate soils, high watertables and extensive peat deposits. The most severe problems other than flooding are encountered in the Weston, Klias and Sapi Associations. Because of daily tidal flooding the soils of the Weston Association have severe limitations imposed by salinity. There are also extensive areas of potential acid sulphate soils. The Klias and Sapi Associations comprise swamps with watertables at or above the surface throughout the year. In addition the peat in the Klias Association would present problems of shrinkage, instability and nutrient deficiency should development be attempted.

Table 2-27 Depth and duration of Kinabatangan floodwaters in 1971

Location	Site	Height of water above ground		Duration (days)
		m	ft	
Pinangah	Teacher's house	0.9	3	4
Tongod	Balai Raya	2.7	9	4
Karamuak	Shop on low terrace	5.2	17	10
Tamoi	River bank	9.5	31	?
Tangkulap	Shop on low terrace	7.3	24	?
Karis Karis	Shop	7.6	25	14
Kuamut	Hospital	4.6	15	?
Malua	House on terrace	2.7	9	7
Latangan	Office	4.3	14	15-18
Tedog	Shop on raised ground	1.5	5	?
Pintasan	School	5.5	18	21
Kuala Lokan	Timber camp	7.0	23	?
Lamag	Shop	4.9	16	?
Batu Puteh	School	3.4	11	?
Kuala Pin	Timber camp	3.7	12	22
Takala II	Timber camp	3.4	11	?
Koyah	Labour line	3.7	12	30
	Railway at Mile 7	0.9	3	?
Bilit	Balai Raya	3.7	12	?
Sukau	School	1.8	6	?
Abai	Shop	1.5	5	?

The Kinabatangan Association consists of generally poorly drained soils with sporadic swamp conditions and the Tuaran Association comprises a range of soils where additional minor limitations include those of excessive drainage. It is on land included in these two associations that the local people subsist on annual crops, but none of these associations can be recommended for agricultural development in the foreseeable future. However if measures are taken to control flooding and large-scale drainage systems are installed then areas covered by the Tuaran and Kinabatangan Associations could be made available for agriculture; a total of about 135 575 ha (335 000 ac) would be suited for wet rice, grassland or tree crops. In countries facing problems of severe land shortage tidal swamps with potential acid sulphate soils, similar to those contained in the Weston Association, have been reclaimed and used for various forms of agriculture. However, because acid sulphate soils are problem soils requiring high inputs for improvement and because there is currently no population pressure in Sabah they are not recommended for reclamation.

There are 4 other inextensive associations, the Binalik, Kepayan, Tawai and Sook Associations, which cannot be recommended for development. The Binalik Association contains Ferralsols with trace element toxicity problems and Gleysols with drainage limitations; its valley floors are also liable to short term flash floods. The Kepayan Association, although occurring on flat land, is of no agricultural value largely because of the inherent nutrient deficiencies and extreme acidity of the Gleyic Podzols which are its dominant soils. These soils are also subject to fluctuations of watertables, have periods of extreme surface drying when the watertable is at depth and have compact albic and spodic horizons. Although market gardening is practised on these soils around Sandakan airport, crops are dependent on the use of manure on raised beds. Young oil palms planted on these soils at the Sungai Manila settlement scheme show signs of acute nutrient deficiencies. The Tawai Association is restricted to an inaccessible part of the Tawai mountain range; it is of no agricultural value because of the severe limitations of poor drainage in the swamps and extremely shallow stony profiles elsewhere. The soils of the Sook Association have very low to low levels of plant nutrients, particulary in the Gleyic Acrisols and Podzols. Some are coarse-textured, and both poorly and excessively drained soils occur.

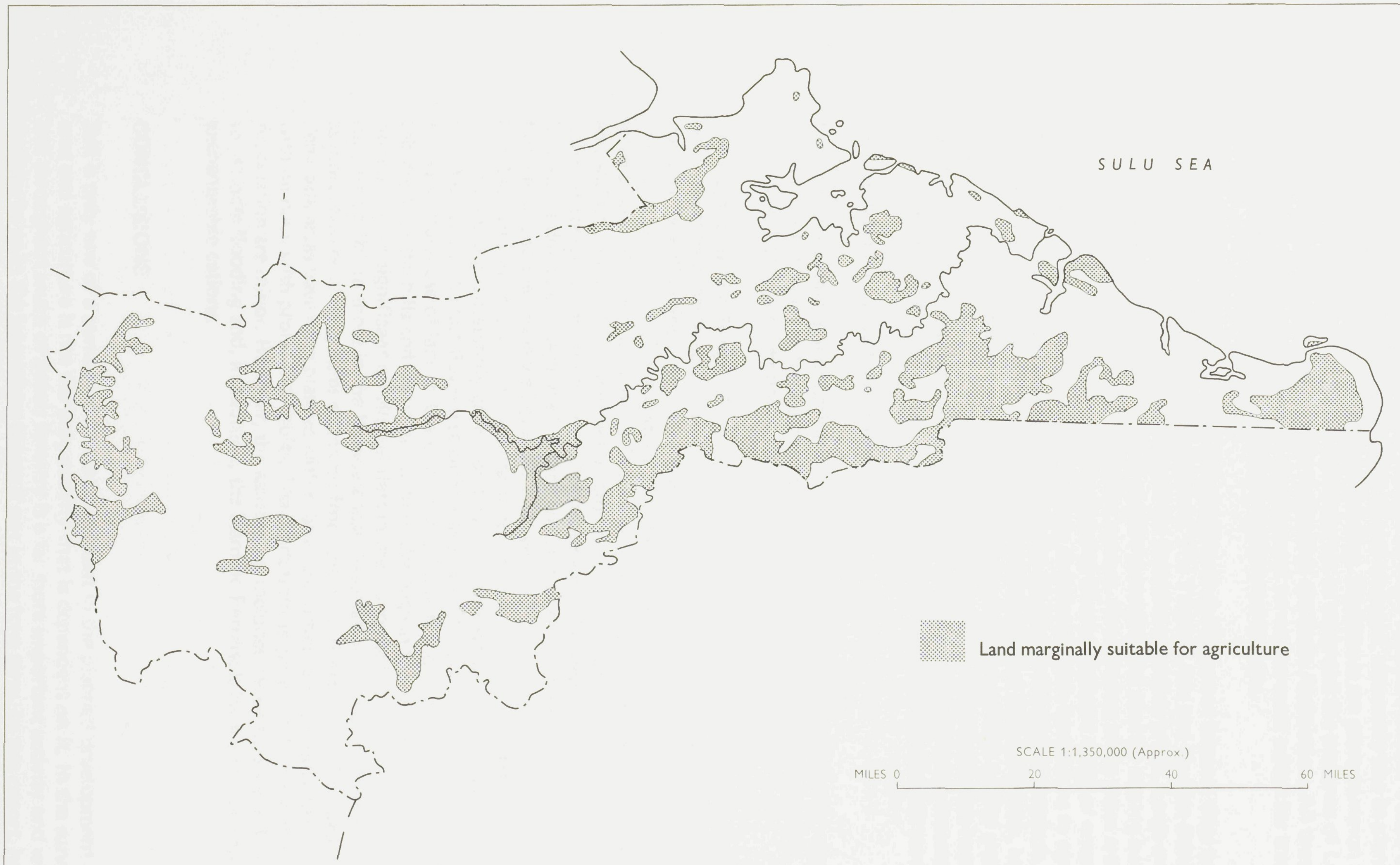
Land marginally suitable for agricultural development

Large areas of the Kinabatangan District consist of land which is marginal in terms of suitability for agricultural development (Text Map 2-8), but as in the case of land which has very severe limitations some of these marginal areas are already being used for agriculture. Eight soil associations are marginal for agricultural development because they have slope limitations.

The Brantian Association is formed on terraces in varying stages of dissection with moderate to steep slopes on terrace edges. The terrace tops are generally level and only where Gleyic Podzols occur is the land quite unsuitable for development; minor limitations common to all sites result from the strongly leached and acid Acrisols with additional limitations of stoniness where pebble deposits occur. The Sinarun Association has similar limitations to the Brantian Association, but is generally more dissected with rounded hill summits and often steeper slopes. Much of the association occurs in remote areas between Pinangah and Lanas and access would be a further problem. In the Labau valley, however, considerable areas have been used for shifting cultivation.

The Kretam, Tengah Nipah, Kalabakan, Dalit and Dagat Associations have short moderate to steep slopes and additional minor limitations. The Kretam Association has stony soils and large boulders are common in some areas; a further hazard to development is the unstable nature of the parent material which is prone to slumping when disturbed, for example, during road construction. Oil palm has been planted, however, at Tomanggong and Ulu Dusun and while growth is good, problems of erosion are being experienced on steeper slopes at Ulu Dusun. In the Tengah Nipah Association the hills which form part of Pulau Tambisan and which fringe the Dent Peninsula have been planted with coconuts, and fruit trees. Slope, however, must be considered a limiting factor for landslides are common under Dipterocarp Forest and

TEXT MAP 2-8



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in addition the association contains valley floors with mainly fine-textured, poorly drained soils which are liable to flooding. Most hills of the Dalit Association have a regular pattern of dissection with moderate upper and middle slopes, but frequently steep lower slopes. The majority of soils are strongly leached Acrisols. Valley bottoms contain Gleyic Acrisols which are often coarse-textured, extremely low in plant nutrients, poorly drained and liable to flooding. Mudstones are more common in the Kalabakan Association, but slopes are moderate to steep and the presence of Luvisols is only a marginal advantage over the Acrisols of the Dalit Association. All these Associations, which are marginal in development terms, are most suited for tree crops and both rubber and oil palm are already established in parts.

Two soil associations are marginal for agricultural development because they comprise land with drainage and nutrient limitations. The Tanjong Aru and Usukan Associations are both formed on beaches used in part for fruit and vegetable crops. Large areas have been planted to coconuts and there is market gardening and poultry rearing between Sandakan and Mumiang for the Sandakan market. Nevertheless while these areas have long been used for agriculture they are suited to a very restricted range of crops and must be considered marginal. In the Tanjong Aru Association limitations to agricultural development are imposed by excessive drainage leading to drought in Regosols, Arenosols and some Fluvisols, poor drainage in Gleysols and Gleyic Podzols, indurated horizons in Gleyic Podzols together with general conditions of high acidity and nutrient deficiences, so that some areas are quite unsuited to agriculture and others have limited use. The soils of the Usukan Association differ in that they are generally coarser in texture and more liable to drought; in addition they have strongly alkaline reactions.

Land suitable for agricultural development

Land which has only minor limitations and which is eminently suitable for agricultural development is found in the Tungku, Silabukan, Rumidi, Tepang, Lungmanis, Karamuak, Labau and Semporna Associations (Text Map 2-9).

The majority of the Tungku Association is composed of high quality agricultural land which must be considered the best within the survey area. It is both level and predominantly well drained but minor flooding occurs near the rivers which drain the hills to the west; only on the eastern edge do drainage limitations occur due to high watertables. Adjacent land in the Semporna Association has minor slope limitations and additional limitations imposed by stoniness and shallow soils. The Karamuak and Labau Associations occur on series of low terraces. The lower terraces have minor limitations due to drainage, flash floods and stony layers. Upper terraces are above flood level and they have well drained soils, which in the Karamuak Association have high base saturation and are very suitable for agriculture. In parts of the Labau valley wet rice is being successfully grown on lower terraces where water can be controlled, but in other valleys fast-flowing streams make this difficult. The minor limitations to the agricultural use of land in the Lungmanis, Rumidi and Silabukan Associations are the slopes of the hills and imperfect to poor drainage in the valleys. Drainage limitations are more significant on alluvial flats in the Lungmanis Association, but while soils are similar to those in the Kinabatangan Association the risk of flooding is less as most areas occur at greater distances from the main rivers. In the Sandakan Peninsula areas have been planted with rubber and others are currently being planted with oil palm with promising results. The limitations imposed by slope in the Tapang Association are minor. However, the association includes valley floors which are liable to periodic flooding and, in addition, the Xanthic Ferralsols have very low reserves of exchangeable cations.

CONCLUSIONS

Soil is only one of a number of factors important in the planned development of an area and agriculture is not the only activity that is dependent on it. In the survey area and throughout much of Sabah forestry is a far more important activity and will continue to be so in the immediate future if not in the long term. In this report, however, soil suitability is assessed only for future agricultural development.

Short term development comes within the scope of Development Plans now being carried out and yet to be formulated. The Sabah Development Plan 1965-70, incorporated into the First Malaysia Plan (Malaysia, 1965), stated the aims of agricultural policy and these are substantially the same for the Second Malaysia Plan for the period 1971-75 (Malaysia, 1970a). They can be summarised as:

1. To raise the living standard of the rural population and enlarge holdings to an economic size
2. To increase productivity and efficiency through education
3. To diversify smallholders crops
4. To raise nutritional standards of the rural population by more varied agricultural production
5. To foster smallholder production

The Second Malaysia Plan emphasises the need to open up more new land to settle families, the need to improve marketing and to stabilise prices and incomes and to establish Farmers Associations. These aims are directly relevant to the farmers of the Sandakan and Kinabatangan Districts in terms of land needed for immediate development and the distribution of land suitable for development. The 4 main categories of farmers involved are the smallholders of the Sandakan Peninsula, the fishermen of the coastal villages, the shifting cultivators along the rivers and the shifting cultivators in the upper Kinabatangan.

Any increase in the numbers of smallholders on the Sandakan Peninsula will be dependent on new roads giving access to new areas, because most land within reach of roads has now been developed under the Sandakan Peninsula scheme. The construction of the road from Ulu Dusun to Bukit Garam, however, will provide an immediate opening to large areas of suitable agricultural land.

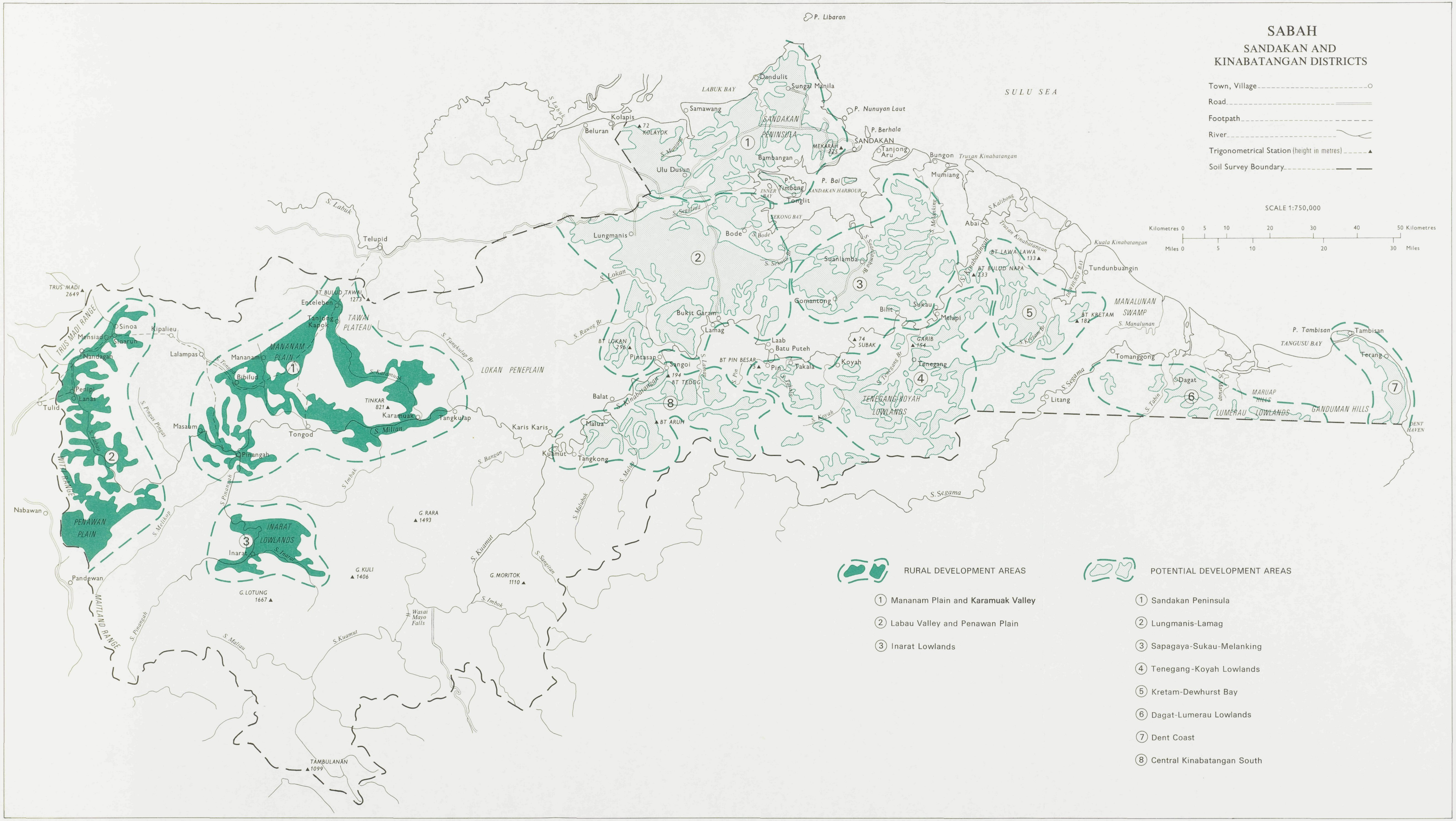
Neither the fishermen of the coastal villages nor the subsistence farmers along rivers have shown any interest in improved methods, crop diversification or enlarged holdings since the inception of the first plan in 1965. A survey of their requirements conducted by the Agricultural Department excited very little reaction. Vegetable crops are, however, being grown for sale both to timber camps and the Sandakan market and there is no shortage of land for an extension of this enterprise.

There have been two recent developments along the Segama and the Kinabatangan. Random land applications have been made for the expressed purpose of practising agriculture although it is clear that the applications are merely a subterfuge to obtain timber concessions. Many of the areas selected are totally unsuitable, extremely remote or too large and many have not been visited by the applicants. Some of the areas for which approval has been granted have not been developed because there was never any serious intention to do so. In other cases funds from timber sales have been exhausted at an early stage and development abandoned. These methods achieve nothing for agricultural development. The second development has been the implementation of minor schemes by the Department of Agriculture as a form of flood relief by encouraging people to move from the river banks to higher ground. It has encountered 3 main difficulties; the choice of suitable crops, the formidable costs of transporting planting and building materials and the lack of genuine interest. A sign of genuine interest for example would be a move to the Suan Lamba settlement scheme which is intended for people from the Kinabatangan. The fact that few people have yet moved to Suan Lamba presumably indicates a lack of desire for change.

Development Plans have yet to affect the shifting cultivators of the upper Kinabatangan, where the most formidable barrier to any development is inaccessibility. A report on shifting cultivation (Sabah, Department of Agriculture, 1951) recommended that people should be encouraged to move out to other areas; however, where there was reluctance to move it was recommended that sufficient suitable land should be

LAND RECOMMENDED FOR AGRICULTURAL DEVELOPMENT

TEXT MAP 2-9



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selected within the area for these independent people to engage in more settled forms of agriculture, in particular the production of wet rice. There is now a keen interest in planting wet rice and cash crops and settlements have become more nucleated. A danger of this is that the land surrounding the villagers will be used more frequently thereby shortening the rotation cycle and leading to increased erosion. Should this happen people are likely to move on again and the opportunity of establishing settled agriculture will be lost.

Rural Development Areas

Land with potential for development in the upper Kinabatangan occurs in 3 main areas, namely the Labau valley, the Mananam Plain and the Inarat Lowlands; these are referred to here as Rural Development Areas (Table 2-28; Text Map 2-9). Most of the land is considered marginal for agriculture, the main limitation being moderate to steep stopes which would limit the choice of crops. The crops that could be considered are wet rice on the valley floors and lower terraces, coffee and cocoa on upper terraces and low hills and rubber on more hilly terrain.

Table 2-28 Rural Development Areas

	Suitable land		Marginal land		Total	
	ha	ac	ha	ac	ha	ac
Mananam Plain and Karamuak Valley	6 120	15 150	32 510	80 480	38 630	95 630
Labau Valley and Penawan Plain	300	740	34 950	86 500	35 250	87 240
Inarat Lowlands	1 575	3 900	10 990	27 210	12 565	31 110
Total	7 995	19 790	78 450	194 190	86 445	213 980

Potential Development Areas

There are about 266 000 ha (660 000 ac) of land in the Sandakan and Kinabatangan Districts which are considered to be suitable for agriculture in the long term. Of this about 26 000 ha (65 000 ac) only are estimated to be under cultivation, so that there is a large reserve of undeveloped land. Much of this land is contained within Forest Reserves and should remain so until long-term plans have been formulated for the development of all the resources of the region.

Areas of land suitable for agriculture have been grouped into 8 Potential Development Areas. In addition there are other smaller areas which are isolated and cannot be conveniently grouped on a regional basis (Text Map 2-9).

1. Sandakan Peninsula. 43 100 ha (106 800 ac). Most of this land is either already under cultivation or approval has been granted for development. However, about 9 300 ha (23 000 ac) south of the Labuk Road between the Gum Gum and Segaliud rivers have not yet been developed.

2. Lungmanis — Lamag. 70 300 ha (174 000 ac). The road presently being built to link Lamag with Sandakan will give immediate access to this area and the construction of feeder roads will facilitate clearing and encourage settlement.

3. Sapagaya — Sukau — Melanking. 34 700 ha (85 900 ac). Agricultural development has begun in this area with the opening of the Suan Lamba Settlement Scheme. Already several timber extraction roads have been constructed, which could form the basis of a road network and a link could be established with areas south of the Kinabatangan by using Sukau as a bridging point.

4. Tenegang – Koyah Lowlands. 36 400 ha (90 000 ac). This area of low hills and broad valleys extends south of the Kinabatangan to the low watershed with the Segama. The upper reaches of the Koyah and Tenegang although affected by flooding are unlikely to be inundated for long periods and could also be considered suitable.

5. Kretam – Dewhurst Bay. 12 800 ha (31 700 ac). This area is accessible from Dewhurst Bay and the Kretam and could be linked to the Tenegang – Koyah Lowlands through the valley of the Simpang Kiri.

6. Dagat – Lumerau Lowlands. 8 800 ha (21 900 ac). The Lumerau Lowlands are at present very remote wity narrow tidal creeks making access by river difficult. Access would be most feasible from Dagat to the west or from the south. To the east of Dagat there is broad area of low hills which is already under consideration for large scale private development.

7. Dent Coast. 7 200 ha (17 800 ac). The coastal plain has immediate potential for agriculture, but access is difficult. A coral reef fringes the coast and there is swamp inland from the beaches. A road south from Tambisan, however, would be possible.

8. Central Kinabatangan South. 21 300 ha (52 800 ac). This area lies south of the Kinabatangan between the Sungai Pin in the east and the Sungai Deramakot in the west. It includes the upper catchment of the Sungai Pin and the middle reaches of the Sungai Lamag; it also extends into the Latangan and Malua Valleys.

RECOMMENDATIONS

1. A Regional Master Plan should be designed to consider the phased development of all natural resources of the Sandakan and Kinabatangan Districts. Priority for agricultural development should be given to Potential Development Areas and communications should be planned to give access to them.

2. Random land applications for agricultural development should be discouraged. They should instead be channelled into the potential development areas and permitted if there is sufficient guarantee of genuine interest and likelihood of development taking place.

3. Development should be discouraged on the floodplains of the Kinabatangan and Segama, except to meet the immediate requirements of the local inhabitants, until further investigations have analysed the problems of flooding and drainage. However, research at Bukit Garam should be broadened to include crops other than wet rice that could be grown on the floodplains.

4. Hydrological studies should be started in the catchment of the Kinabatangan with particular reference to the causes of flooding and the feasibility of flood control.

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