SOILS OF THE Semporna Peninsula NORTH BORNEO

By T. R. PATON

HER MAJESTY'S STATIONERY OFFICE

This is a report of a reconnaissance survey of soils within heavily forested hilly country forming the Semporna Peninsula of North Borneo.

The area surveyed exceeds one thousand square miles, is almost unpopulated and has a complex pattern of sedimentary and volcanic rocks.

The aerial photographs were difficult to interpret but by cutting traverses through the forest, the author was able to identify the soils and has set them in a two-way classification based on geological age and geomorphological situation.

Colonial Research Study No. 36

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DEPARTMENT OF TECHNICAL CO-OPERATION

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A Reconnaissance Soil Survey of THE SEMPORNA PENINSULA NORTH BORNEO

By
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Department of Agriculture
North Borneo
1961

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CONTENTS

INTRODUCTION

The survey presented in this memoir, was carried out in the period 1953-1959, while the author was a member of the Department of Agriculture, North Borneo. It was financed from Colonial and Development Welfare funds and its purpose was to arrive at an appreciation of the agricultural potential of the Semporna peninsula.

The area to be surveyed was just over one million acres, covered, for the greater part, in high primary jungle. The topographic data available were meagre, as was the geological knowledge. It is only now that soil analyses are coming forward. Therefore the survey was necessarily a reconnaissance one being dependent for interpretation on the physical appearance of the soil, together with its geological and geomorphological background and the type of natural vegetation growing upon it.

This survey would never have been completed without the help of both the Colonial Development Corporation and Darvel Plantations. Thanks are also due for the help and encouragement received from both Mr. J. L. Greig and Mr. E. J. H. Berwick as Directors of Agriculture, North Borneo.

The following members of the staff of the Agricultural Department were responsible for the production of the field maps, Lee Dong Yong, Noordin bin Lassim and Wong Kuin Thin.

It is a pleasure to thank the Directorate of Overseas Surveys for undertaking the publication of the maps and diagrams to accompany this memoir. Mr. C. L. Bascomb of the Pedology Department of Rothamsted Experimental Station is to be thanked for carrying out the analyses quoted in this survey.

This memoir would never have been completed without the help given by Dr. H. Greene.

PHYSIOGRAPHY

The Semporna peninsula lies in the extreme south east of North Borneo. It is 70 miles long from west to east and 35 miles wide, at its broadest north to south part. The area is slightly over 1,000,000 acres in extent and is covered by eight quarter degree sheets on a scale of 1:50,000, as issued by the Directorate of Overseas Surveys. They are numbered, 4/117/8, 4/117/12, 4/118/5, 4/118/6, 4/118/7, 4/118/9, 4/118/10 and 4/118/11.

The peninsula gradually tapers from west to east and consists of numerous isolated hills and mountains, most of them representing the sites of extinct volcanoes. The highest mountain rises to over 4,200 feet (Magdalena) and the longest river is the Kalumpang, just over 100 miles.

The main features of the physiography are shown in figure 1.

The main mountain areas are:

(a) Magdalena and Lucia (4,200 feet)

(b) Maria (3,400 feet)

(c) Andrassy (2,400 feet)

(d) Wullersdorf (2,400 feet)

(e) Mostyn hills (1,800 feet)

(f) Hewett (1,300 feet)

(g) Sigalong-Pock-Siagal (2,000 feet)

(h) Timbun Mata hills (2,000 feet)

(j) The Semporna area, including the neighbouring islands, consists of numerous isolated hills rising to over 1,000 feet.

(k) The area between the upper Kalumpang and the Binuang which rises to over 2,000 feet.

(m) The area to the north west of the Binuang which has two or three peaks of over 2,000 feet.

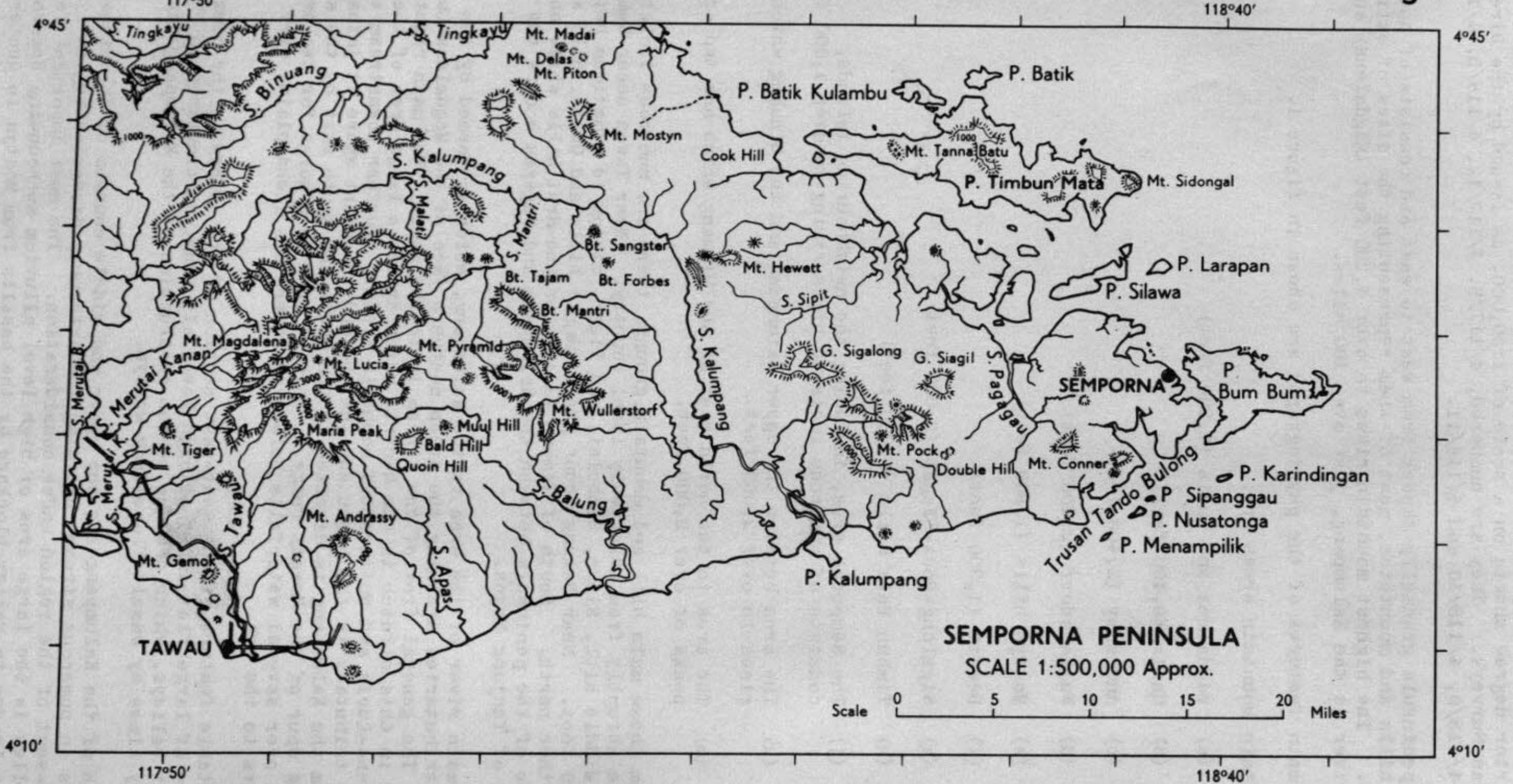
Apart from these main hill and mountain groups, there are numerous isolated hills which rise abruptly from relatively level country. Near Tawau occur Gemok, Kukusan, Middle hill, Sinon, Bombalai, and Tiger, rising to a maximum height of over 1,700 feet. Near Balung occur the Tinagat hills and Quoin, Bald and Muul hills further north. South of Timbun Mata occur the Brai hills while on the south side of the peninsula between the Kalumpang and Pagagau occurs the isolated hill mass of Tanjong Nagos.

The main river of the area is the Kalumpang, which is formed by the union of numerous tributaries draining the steep northern face of the Magdalena-Lucia massif. The general flow of the stream is to the east. The main right bank tributary in this stretch is the Mantri, which drains a large area of the junction of Magdalena-Lucia and Wullersdorf mountain areas. Further downstream the main left bank tributary is the Limau and just beyond the point where it joins the mainstream the Kalumpang is diverted to the south and south east by the southerly projecting spur of the Hewett range. Here it runs in a gorge for two or three miles and over several waterfalls before it enters its flood plain, over which it meanders to the sea.

A notable feature of the west-east section of its course is the common occurrence of large flat areas of high level alluvium, particularly in the Limau and Mantri valleys, which are due to the obstruction of the Kalumpang during Quaternary times by basalt flows from Mostyn.

North of the Kalumpang lie the upper and middle courses of the Binuang. This rises in numerous streams draining the extremely dissected region lying in the north-west of the region under consideration. The most important feature of its valley is the large area of high level alluvium surrounding Baturong hill. This again is due to valley blockage by the basalts from Mostyn in Quaternary times.

Fig 1


117°50′
118°40′
4°45′
4°10′
S. Tingkayu
Tingkayu
S. Binuang
Mt. Madai
Mt. Delas
Mt. Piton
Mt. Mostyn
P. Batik
P. Batik Kulambu
Cook Hill
Mt. Tanna Batu
P. Timbun Mata
Mt. Sidongal
S. Kalumpang
S. Malati
S. Mantri
Bt. Sangster
Bt. Forbes
Bt. Tajam
Bt. Mantri
Mt. Hewett
S. Sipit
P. Larapan
P. Silawa
Mt. Magdalena
Mt. Lucia
Mt. Pyramid
G. Sigalong
G. Siagil
S. Pagagau
SEMPORNA
P. Bum Bum
S. Merutai B.
S. Merutai Kanan
S. Merutai K.
Mt. Tiger
Maria Peak
Muul Hill
Bald Hill
Quoin Hill
Mt. Wullerstorf
Mt. Pock
Double Hill
Mt. Conner
Tando Bulong
Trusan
P. Karindingan
P. Sipanggau
P. Nusatonga
P. Menampilik
S. Tawau
Mt. Andrassy
S. Balung
S. Apas
Mt. Gemok
P. Kalumpang
TAWAU
1000
2000
3000
SEMPORNA PENINSULA
SCALE 1:500,000 Approx.
Scale
0
5
10
15
20
Miles

To the east of the Kalumpang the streams are small except for the Sipit Bulu, which drains eastward from the Mt. Hewett area and the Sipit, which drains north eastward from the Pock-Sigalong range. These streams have a common estuary opposite Timbun Mata island.

To the south and west of the Kalumpang the area is drained by numerous independent streams. The most important of these will be described in order from west to east.

Merutai Besar. This river drains the western and north western flanks of Mt. Magdalena and flows almost directly south into the head of Cowie Harbour. The watersheds between this stream and the Kalumpang and the Binuang are of low altitude. Its main tributary is the Merutai Kanan, which drains the south western slopes of Mt. Magdalena.

Merutai Kechil. This drains the southerly projecting spur of the Magdalena-Lucia mountain area. After a short torrent course it flows in a general westerly direction across an area of high level alluvium, caused by valley blockage due to basalt flows from Tiger hill. It then turns abruptly south through a gorge eroded in the basalt and, after crossing a very short flood plain, enters the sea a few miles east of the Merutai Besar estuary.

Tawau. This drains the south-eastern slopes of Lucia and the western slopes of Maria and flows almost due south to the sea. It skirts the basalt of Table estate on its eastern margin, where a gorge more than 300 feet deep has been eroded.

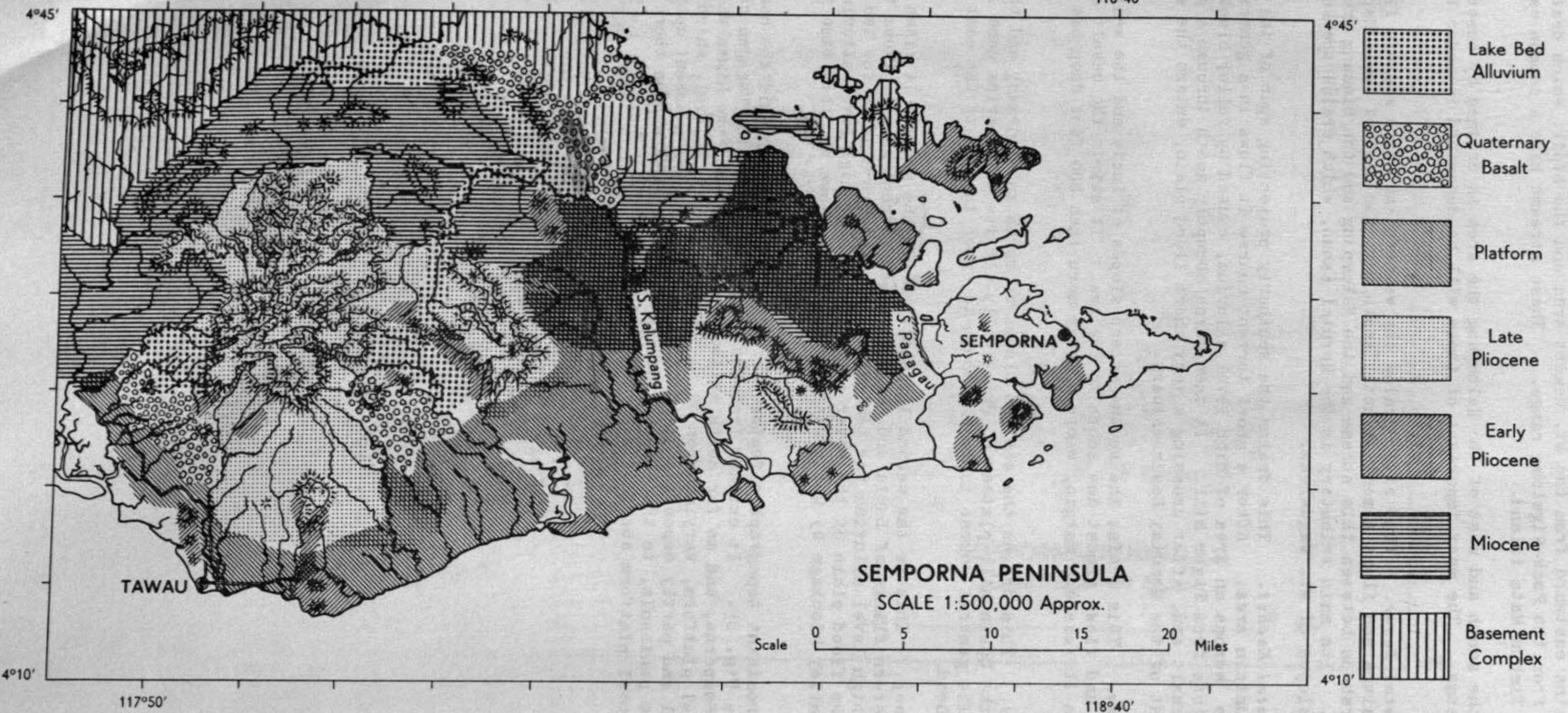
Apas. This drains the eastern slopes of Maria and Andrassy and the southern part of the Quoin hill plateau. Practically all its tributaries come from the west. Its general course is to the south to enter the sea to the east of Tinagat head.

Balung. This is the second largest river in the area. It rises on the south eastern flanks of Lucia and, after a short torrent course, flows through an area of high level alluvium for ten miles, then through a gorge for two miles, before the flood plain of the river is reached. The high level alluvium is again due to valley blockage by Quaternary basaltic lava-flows but this time from Quoin hill.

A prominant topographic feature throughout the peninsula is the coastal platform (see Fig. 2). It extends from the Merutai Besar to the Pagagau channel, west of Semporna, and as far north as the Mostyn hills and the Limau valley. It is a level platform, varying from 50 to 100 feet above sea level, which is partly erosional and partly depositional in origin. It suggests a recent uplift of the whole peninsula, to the west of the Pagagau. Round Semporna there is a raised coral platform about 8 to 10 feet above sea-level.

GEOLOGICAL MAP

Fig 2



CLIMATE

Lying within 5^{o} of the equator and with a maximum elevation of 4,200 feet the Semporna peninsula is very hot throughout the year and is, for the most part, continuously humid. As the area is under high primary jungle, or only recently cleared, there are few recording stations and those that have been established are peripheral to the main area, usually coastal, and hence cannot be regarded as being quite typical. Rainfall figures are few and not too reliable, figures for other climatic factors are practically non-existent.

The temperature is uniformly high but the only figures available are those from Table estate, which show a maximum of 91.2^{o}F and a minimum of 72.6^{o}F. No doubt maximum figures at sea-level will be rather higher due to the drier conditions which prevail there.

The few rainfall records available point to its extreme variability. Figures are available for Tawau, at sea-level, for 30 years: the average rainfall is 78 inches per annum, the minimum is 25 inches and the maximum 95 inches. Table estate, with figures for only five years, shows a minimum of 83 inches and a maximum of 104 inches. Mostyn estate, with figures for only 4 years, has a minimum of 79 inches and a maximum of 115 inches. For Semporna reliable records are available for 10 years. These show a variation from a minimum of 73 inches to a maximum of 103 inches.

It is difficult, at this point, to see any particular rhythm in the annual rainfall. Any month in any area within the peninsula, could be subject to a rainfall varying from 0 to 15 inches. From a study of the daily rainfall figures, it is apparent that most of the rain falling in the Semporna peninsula does so in the form of short but extremely intense downpours. A corollary of this is that there is a great deal of sunshine. Droughts of up to four months in duration have been known to occur three or four times in the last decade, in various places in the peninsula.

GEOLOGY

The geological formations of the Semporna peninsula probably range from Cretaceous to Recent in age. Those prior to the upper Eocene may be referred to as "basement complex" and cover a great range of sediments and igneous rocks, all of which have suffered a certain degree of metamorphism. They occur as a border along the northern boundary of the area and occupy a total of 200 square miles (see figure 2).

The MIOCENE occurs as a broad belt throughout the area immediately south of the "basement complex". It consists of two distinct facies, one of sandstone, shale and limestone and the other of andesitic and rhyolitic tuff and volcanic breccia. They occupy a total of some 400 square miles. Rocks of probable PLIOCENE age represent a wide range of igneous activity and are mainly volcanic. The older rocks, occupying some 110 square miles, consist of basaltic lava and tuff, andesitic tuff and breccia and doleritic, dioritic and acidic intrusive rocks. Younger, possibly Pliocene, rocks, (occupying about 460 square miles) are wholly volcanic and consist of andesitic, rhyolitic and dacitic lava and ash. The QUATERNARY covers about 150 square miles and includes large areas of high level alluvium and basalt lava. This alluvium has accumulated in several river valleys due to blockage by the basaltic lavas. RECENT sediments and coastal mangrove swamps make up the balance of the area, a total of over 225 square miles.

Only the Miocene of the Kalumpang and Sipit valleys and Quaternary sediments near Semporna have been dated by fossil evidence. A provisional stratigraphic sequence, described below, has been built up using such data as rock type correlation, degree and type of orogenesis suffered by rocks and their relationship to pediplanation and lateritisation. (see table 1).

No detailed study of the pre-upper Eocene rocks has been made and it is not proposed, in this account, to attempt a history of this "basement complex". It may, however, be said in passing, that the great range of igneous metamorphic and sedimentary rocks exposed in the area, which can be referred to this formation, necessitates a long and complex geosynclinal history to explain them.

MIOCENE

At the beginning of the Miocene a land mass consisting of the "basement complex" bordered the area to the north. Its southern boundary ran along what is now the position of the Binuang valley, then south of the Madai hills, along the north eastern boundary of Mostyn estate and terminated in the Mt. Cook area. A detached island of basement rocks occurred further to the east in what is now the central area of Timbun Mata island. Lying to the south of this was an area where marine and brackish water conditions occurred. In the north-west, where it was almost landlocked, estuarine conditions prevailed and thick bedded sandstones were deposited while, further to the east, where limestones are more common, more typically marine conditions were dominant. These general conditions occurred throughout the area from the opening of the Miocene onwards, interrupted from time to time by volcanic eruptions, uplift and orogenesis. The most outstanding characteristic of this period is the widespread volcanic activity. Centres of eruption extend from Mt. Hewett, through the Mt. Mostyn area, westwards into a considerable part of the area between the Binuang and Kalumpang rivers. There are two main types of volcanic activity, an acid type (rhyolitic) and a basic type (andesitic-basaltic).

Acid volcanic rocks occur as a fine-grained blue-green tuff and tuff-breccia in the steep range of hills, including Mt. Mostyn and Mankok, extending southwards in the Mostyn area towards the Kalumpang river. The fine grained tuff is uniform in certain exposures, but in others finely banded and spotted varieties occur. This tuff is interbedded with, or passes laterally into, tuff breccias, which have the characteristic green colour of the fine tuffs.

Basic volcanic rocks occur round Mt. Hewett and in the Kalumpang valley west of the Mostyn area. At the Mt. Hewett centre brecciated andesitic or basaltic crystal tuffs and volcanic breccias with lava fragments are exposed. West of Mostyn, andesitic or basaltic volcanic breccia, tuff and tuff breccia form the hilly area extending southwards from near the river Binuang to the Kalumpang valley and going as far as the area between the Mantri and Sangster and Forbes hills. The very coarse volcanic breccias which occur south of Kalumpang river contain fragments of purple slate which is not found *in situ* in the area.

(065087)

TABLE I

PROVISIONAL STRATIGRAPHIC SUCCESSION

PERIOD	GENERAL DESCRIPTION OF ROCKS	STRATIGRAPHIC BREAKS AND DIASTROPHISM
QUATERNARY	Low level alluvium, both riverine and coastal, including swamps, at present being formed	
		Slight break with no considerable earth movement.
	High level alluvium, now being eroded	
	Grey to white boulder beds and very fine grained tuffitic material, deposited by mudflows	
	Late stage hydrothermal alteration of basalt	
	Main basalt flows.	
		Considerable break, during which the older basalts were almost completely weathered.
	Older basalt flows	
		Great break, during which laterization occurred and uplift of the coastal platform took place.
TERTIARY	Dacitic lavas, ashes and agglomerates from Mt. Maria	
PLIOCENE	Rhyolitic lavas and plugs.	
	Andesitic lavas and ashes	
		Mid-Pliocene break with earth movements particularly faulting, a considerable time lapse, with profound erosion.
	Basalt lavas and tuffs, andesitic tuffs and agglomerates, acidic intermediate and basic intrusions.	
		Earth movements of considerable intensity. Strong folding of Miocene rocks, particularly near "basement complex"
MIOCENE	Rhyolitic and andesitic lavas, tuffs and volcanic breccias, sandstones, shales (carbonaceous in places) and limestones.	
		The major Oligocene break, during which the late Cretaceous - Eocene geosynclinal rocks were folded and metamorphosed.
PRE-UPPER EOCENE	Contains a variety of mainly igneous rocks including, banded diorites and ultrabasics, serpentines, peridotites, felsites. Sediments include, metamorphosed shales, sandstones, limestones and cherts.	

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The main outcrop of volcanic rock is small but beds of tuffite intercalated in the Miocene sediments are widespread over an area of about 40 miles across, extending from Mt. Siagal and the Sipit valley to the headwaters of the Kalumpang. West of Mostyn, tuffite and tuffite breccia bands occur in a succession of siltstones and mudstones. In the higher reaches of the Kalumpang the tuffite and tuffite breccia bands become less coarse and give way to grey and buff coarse sandstones interbedded with shales, generally containing clay-ironstone nodules. East and south east of Mostyn the strata remain finely bedded, tuffite bands are less common and sandstone is never dominant. Limestone generally occurs as lenses within a siltstone and shale succession. Occasionally it is massive as at Semarang and the Brai hills near the Sipit estuary. Fossil faunas from these limestones and from the tuff bands and shales between the Kalumpang and Sipit valleys show that they are of Te-f age.

The only other strata, which may be of Miocene age, are lamelli branch-bearing and carbonaceous mudstones found in the Apas-Balung area. No determinative fossils have been found in these rocks which are similar to the Miocene coal bearing sediments of the Serudong and Silimpopon basins further to the south west.

The Miocene period of deposition was brought to an end by strong earth movements. The degree of folding of the Miocene rocks varies and appears to depend on the distance from the stable block of the "basement complex" found to the north. Thus in the middle Kalumpang valley, the strata close to the block are strongly folded but in the upper reaches of the same river, further away from the block, strata of the same age are only gently folded. In the rhyolitic tuffs there is evidence of brecciation and calcitisation and also some quartz and manganese mineralisation, which may be referred to this period. Calcite veining is also common in the shales of the upper Kalumpang valley.

POST-MIOCENE FORMATIONS

After the Miocene three further periods of widespread volcanic activity have been recognised. They are described in turn below:-

FIRST VOLCANIC PERIOD (? EARLY PLIOCENE)

Volcanic rocks of this age extend in a belt from west of Tawau to Gaya island in Darvel Bay. It can be considered as a belt of igneous activity tending east north east with some intrusions along fractures complementary to this i.e. north north west.

Timbun Mata island. Intrusive rocks comprising hornblende diorite, granodiorite, microgranite and dolerite are associated with volcanic breccia containing blocks of Miocene limestone and sandstone. The prominant peak of Mt. Sidongal and the Grassy point peninsula are built of hornblende diorite. The relationship between the intrusive rocks and the volcanic breccias is uncertain. The Mt. Sidongal intrusion appears to be bounded on its western side by a north easterly trending fault. From the fact that no fragments of hornblende diorite are to be found in the volcanic breccia, it is probable that the breccia was formed first followed by faulting and intrusion of the hornblende diorite. Rocks of similar type occur on the mainland at Brai hill.

Semporna area. The volcanic rocks of the Semporna area probably belong to this period but are of a different character. Here volcanic breccias and basaltic lavas are very common. There is evidence on Tagasan hill south of Semporna of a sill-like intrusion of acidic material. The central intrusion of Sipangoa island is also of an acidic type. The volcanic breccias of this area differ from those of Timbun Mata in being generally more basic with less interstitial ash and in containing only volcanic rock fragments; no rock fragments derived from an underlying sedimentary formation are present. From the exposures in this area, particularly in the three islands to the south of Semporna (Sipangoa, Nusa Tonga and Menampili), a general sequence can be established of basic lavas and intrusives, a tuffitic explosive phase and a final acid intrusive phase.

The islands of Gaya, Bohidulong and Tetagan, which lie north east of Semporna, together form a semi-circular group enclosing a lagoon. The islands are precipitous and rise steeply from the lagoon to 800 to 900 feet. They are built of basic volcanic breccia similar to that in the Semporna area and probably of the same age.

The rocks building Mt. Siagil and the eastern end of the Mt. Pock area are similar to those of Eastern Timbun Mata island, volcanic breccia and ash being the main rock types.

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Balung-Tawau area. West of the Kalumpang river rocks of the first post-Miocene volcanic period are widespread. They are ascribed to this period mainly on their general character and appearance. At the mouth of the Balung river there is a good exposure on the foreshore of basaltic lavas cut by a basic dyke and, just above Balung estate, volcanic breccia is exposed in the river bed. At Tinagat, Membalua and Tiku hills the rock consists of volcanic agglomerate and breccia (plate 7), which extends up the valley of the Kinabutan Besar river. A mixture of basic tuff and volcanic breccia occurs on the south side of the Balung valley at Muul hill.

The remainder of the rocks are intrusive and are basic to intermediate in composition. Black fine-grained dolerite is widespread between Kawa and Pyramid hills, on the south western flanks of Mt. Wullersdorf; from the Kinabutan Besar river across the southern flanks on Mt. Andrassy; in the upper Tawau valley, particularly in the area between Glas hill and Bombalai; on the north east flank of Lucia in the Malatai valley, extending south into the upper valley of the Mantri.

Intermediate rocks are found as small intrusions which have generally given rise to steep sided prominent hills. Thus three microdiorite intrusions for Gemok, Middle and Kukusan hills to the north of Tawau. Further east a biotite-diorite intrusion forms Sinon hill. In the Kalumpang valley Sangster and Forbes hills are composed of intrusive diorite.

THE SECOND VOLCANIC PERIOD (? LATE PLIOCENE)

Early eruptions of andesitic lava and ash occurred from four main centres of vulcanicity, Magdalena-Lucia, Andrassy, Wullersdorf, Pock. The products of these eruptions now form the highest ground in the peninsula. Lavas occur near the sites of the volcanoes but ashes normally occur in the surrounding country. The lavas are light grey with micro-porphyritic crystals of hornblende and plagioclase. The ashes are recognised by their blue-green colour which becomes a dirty buff on weathering, they also have a distinctive greasy feel. Those earlier ashes may be differentiated from the subsequent ashes from Mt. Maria by the lack of crystalline quartz. The best exposures of lava so far discovered are round Magdalena and Lucia and on the northern face of Andrassy. The ash intermingled with dolerite boulders is exposed on Kinabutan Kechil hill and is seen lying directly on top of the dolerite on the Bombalai-Glas hill ridge on the south-eastern slope of Mt. Andrassy and on the southern slopes of Mt. Wullersdorf.

Further from these centres the ash appears to have been deposited in shallow water. These volcanic ashes contain large quantities of organic material including carbonised wood, leaf fragments and seeds. Exposures of this type can be seen in the deeply trenched tributary valleys of both the Apas and Gading rivers.

The andesitic eruptions were succeeded by the extrusion of highly viscous rhyolites, which are best exposed in the Mt. Wullersdorf area. The top 500 feet of this mountain is built of rhyolite, apparently in the form of a plug. The rhyolite, which has steeply dipping flow banding, is extensively silicified and is probably the eroded spine of a volcano. Round the base of the main hill there is an accumulation of huge boulders of rhyolite up to 30 feet across, which probably represent the remnants of a much bigger volcanic spine. The Andrassy volcano and Glas hill are two other centres of rhyolitic eruption.

Eruptions of dacite from Mt. Maria occurred at the end of this period of vulcanicity. The dacites consist of ashes and tuff-breccias rich in crystals. The field recognition of this material is dependent on the occurrence of crystalline quartz, which is found in every facies of the deposit. The tuffs are of two kinds grey and pink, and contain crystals of quartz, biotite, hornblende and plagioclase. The ashes are brown in colour and well-bedded.

The explosive eruption of a mass of lavas and ashes into an extremely wet environment has resulted in the occurrence of volcanic phenomena similar to those which have been recognised in Java. "Ladus" or "nuée ardente d'avalanche" which consist of avalanches of hot lava fragments, sand and dust, mixed with broken debris of the old summit of the volcano, carried material from the summit of the volcano to the base of the major cone where it was dumped in an unstable state. The many welded rhyolitic boulders were probably formed in this type of avalanche. When these unstable masses became saturated with water mudflows on a considerable scale occurred. They are called "lahars" in Indonesia, and are well exposed on Imam estate north of Tawau. This has given rise to an extremely confused pattern of deposits round the lower slopes of these volcanoes, well bedded ashes being interspersed with jumbled "lahar" deposits; detailed mapping would be required to differentiate them.

South of the area of "lahar" deposits fine grained volcanic material was deposited in shallow water lagoonal conditions.

This deposit probably marks the end of Tertiary deposition and during the interval before the third post-Miocene volcanic period a great deal of weathering and erosion took place which is of considerable importance from a pedological viewpoint. It was during this interval that the coastal platform, then at or near sea-level, was formed. In the Sipit, Kalumpang and Limau valleys the bevelling of the thinly bedded Miocene sediments occurred. The extent of the platform in this area, however, would appear to have reached a limit where all the easily eroded materials have been removed and the present boundary occurs where more massive volcanic rocks have resisted erosion. In the south of the area, extending from the Kalumpang to the Merutai Besar, the volcanic ash and debris from the late Pliocene volcanoes was quickly reduced to the level of the platform and it was gradually extended by pediplanation at the expense of the Pliocene materials. This was much easier against the incoherent late Pliocene ash and lavas as compared to the early Pliocene agglomerates and intrusives. The angle of junction between the pediplain and Tinagat hill, composed of early Pliocene andesitic agglomerate is well developed (plate 6).

This coastal platform was raised 50-100 feet above sea-level sometime before the final basaltic eruptions. This gave increased erosive power to streams in their lower courses and it was onto an extremely dissected area that the basaltic lavas were erupted.

THIRD VOLANIC PERIOD (? QUATERNARY-RECENT)

The final eruptions of lavas were basaltic and occurred in the Table-Tiger, Quoin hill and Mostyn areas at about the same time.

Table-Tiger basaltic lavas. There are three centres of eruption, Tiger hill, Bombalai hill and a smaller cone mid-way between them. Eruptions started from Tiger hill and remains of the oldest lavas are now found between the eastern boundary of Tiger estate and the Bombalai-Glas hill ridge and in some of the deeper valleys of Tiger estate itself. No basalt lavas have been found *in situ*. The deposit is now in the form of a yellowish brown soil which is considered to be the weathering product of this oldest series of basalt flows, because it has a unique crumb structure, which, apart from this example, occurs only in soils that are definitely derived from basalt and it is always closely associated with the younger basalts. No bedding or variation in texture or structure has been seen in pits dug in this material to a depth of 14 feet.

After this first eruption there was a considerable time lapse, which allowed deep weathering of the basalt, before the next and most important eruptions occurred. These lavas were extruded from both the Tiger and Bombalai cones and consist of a dark grey vesicular rock with xenolithic quartz. In the more northerly exposures it is seen to be resting on well bedded, late Pliocene dacitic ashes (plate 4), while further to the south it lies on the mottled clay of the upraised coastal platform.

Red basalts with a purplish tinge form the youngest lavas which were erupted from all three centres.

The Quoin hill basalt flows followed a similar sequence to the Table-Tiger eruptions and were erupted onto similar underlying materials but in this case there was only one volcanic cone and not three. Quoin hill lies on the lower south east slopes of Mt. Maria and the basalt flows from it followed the regional slope to the south and east.

The earlier flows were directed to the east where they impinged on the lower slopes of Kawa hill and only their weathering product, a yellowish brown soil previously referred to, remains. They do not produce such a marked topographic feature as the later basalts but their margins are visible on the ground. There is a considerable time break between them and the later, main basalt eruptions, which is marked by a major topographic break. These later basalts are dark grey vesicular rocks with xenolithic quartz. In the north west of the area the basalt can be seen resting on the very coarse dacitic deposits from Mt. Maria (probably a "ladu" deposit) at the Chisholm falls. In the south east at the Morris falls it overlies the mottled material of the uplifted coastal platform. A red basalt with a purplish tinge occurs in the immediate environs of Quoin hill.

The Mostyn basalt flows are due to a fissure type of eruption along a line of weakness at the junction of the Miocene and older formations. Before the

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eruptions the area had a highly dissected relief and the first lava flows followed the old Binuang-Tingkayu valley, which roughly followed the junction between the Miocene and older rocks from Baturong south of the Madai hills and into the sea near the estuary of the present Madai river. These first flows turned an area, roughly delineated by the present boundaries of the Mostyn Estates Ltd. concession, into an enclosed basin. This was gradually filled with subsequent basalt eruptions which were then able to escape in several directions.

(a) Both north east and north west along the former Binuang-Tingkayu valley.

(b) Across the original watershed northeastwards to the coast of Kunak.

(c) Southeastward through the Mostyn hills into the Limau valley. The lava is a vesicular microporphyritic basalt but, unlike the Table and Quoin hill areas, contains no xenolithic quartz and is weathered to only a shallow depth (about 2 feet). The absence of xenolithic quartz in the lava is due to lack of crystalline quartz in the underlying Miocene and older materials. The shallow depth of weathering of the lava is also due to the bedrock which is relatively non-porous when compared to the late Pliocene ashes and lavas which underlie the Table and Quoin hill lavas. A feature of the Mostyn basalt flows is the great abundance of rounded vesicular boulders of basalt on the surface of the soil. (plate 10).

The basalt flows from all three centres were erupted onto a land scape which had a well developed river system and so caused a great deal of drainage disruption. Each area will be discussed in turn.

1. The Table-Tiger area which lies north west of Tawau town is easier to observe than the other two as it is mostly cleared for estates. Figure 3 illustrates the way in which the drainage of this area is postulated to have evolved.

Prior to the eruption of the basalt across their lower flanks the controlling factors of drainage were the ash and lava piles making up Mt. Magdalena, Lucia, Maria and Glas. Being for the most part massive ash beds, particularly in the case of Maria, drainage tended to be radial from their centres, with each stream being separated from its neighbour by a well developed ridge.

The original drainage must have been something similar to that shown in the inset of figure 3.

I. The upper valley of the present Merutai Kanan and the lower valley of the present Merutai Kechil.

II. The upper valley of the present Merutai Kechil and a lower valley which is unnamed.

III. The upper valley of the present Tawau river which may have flowed down a valley in a similar position to the Burut river to the Merutai Kechil estuary.

IV. An alternative to the above the lower valley following the Table stream through to the Bombalai estuary.

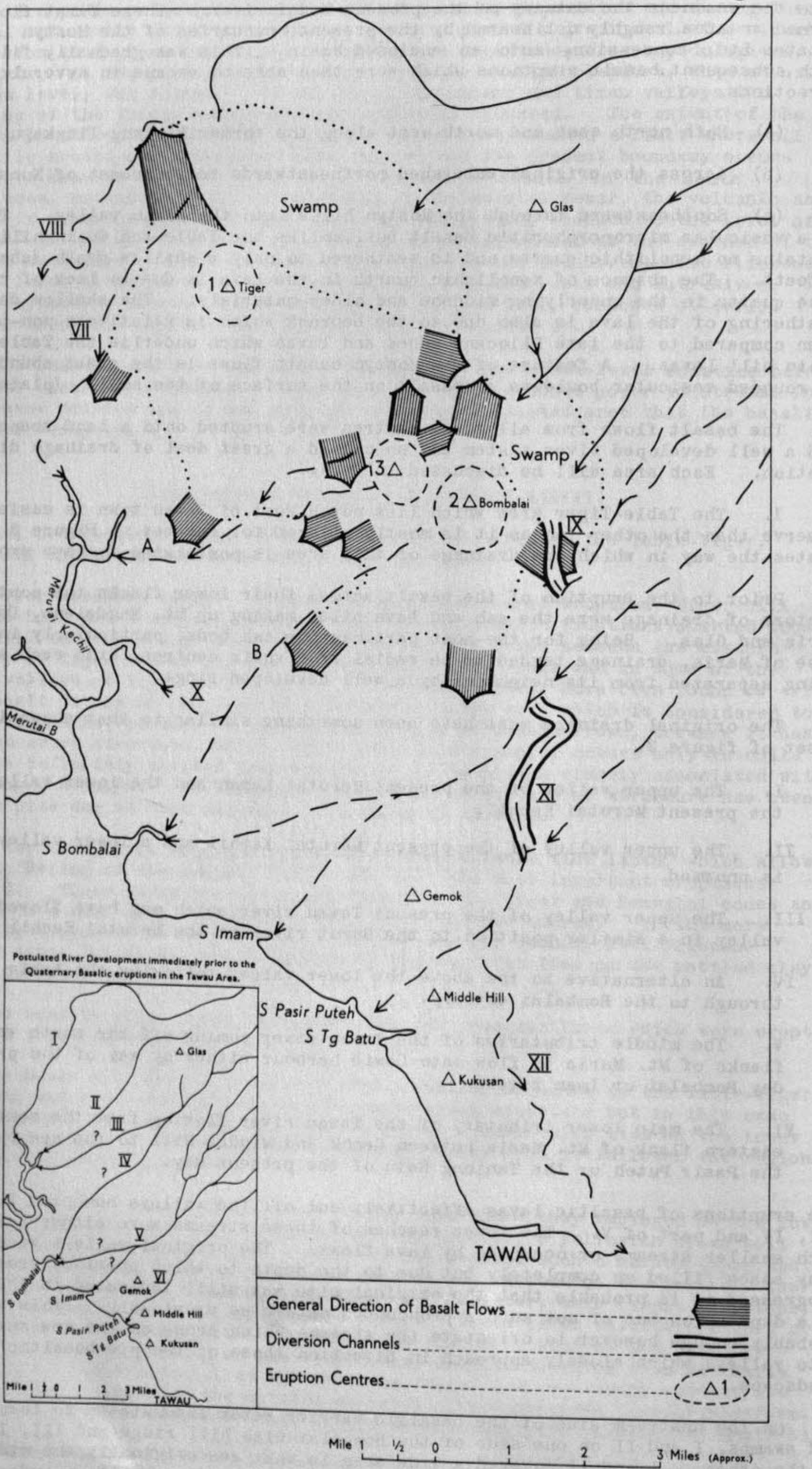
V. The middle tributaries of the Tawau river coming off the south western flanks of Mt. Maria to flow into Cowie harbour either by way of the present day Bombalai or Imam rivers.

VI. The main lower tributary of the Tawau river flowing from the south-eastern flank of Mt. Maria between Gemok and Middle Hill to the sea by either the Pasir Puteh or the Tanjong Batu of the present day.

The eruptions of basaltic lavas effectively cut off the valleys numbered I, II, III, IV and part of V. The lower reaches of these streams were either left with much smaller streams or occupied by lava flows. The original valleys were in many cases filled up completely but due to the depth to which previous erosion had progressed it is probable that the original site was still indicated in the lavas by a depression but of not such a pronounced nature as previously. This was probably enough however to orientate the streams which arose on the new surface into valleys which closely approach in direction those of the pre-basaltic landscape.

On the upstream side of the basaltic barrier water accumulated to form lakes and swamps, I and II on one side of the Bombalai-Glas hill ridge and III, IV and V on the other. I and II covered a wide area in what was originally the middle valleys of the Merutai Kechil and Merutai Kanan. The water built up and

READJUSTMENTS TO DRAINAGE RESULTING FROM QUATERNARY BASALTIC ERUPTIONS IN THE TAWAU AREA Fig 3



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eventually found an outlet over the lowest point of the basaltic barrier. Any other direction would have been impossible as on all the other sides there were extremely high ridges rising within a few miles to heights of over 4,000 feet. This lowest point, for reasons given above, probably coincided with the old lower valley of the Merutai Kanan and some of the dammed up water was drained along this channel, VII on figure 3, which is now marked by a gorge through the basalt. Later headward erosion by a stream tributary to the Merutai Besar working round the north-western corner of the basalt flow abstracted the Merutai Kanan, VIII on figure 3. This will eventually capture the present day Merutai Kechil as it is eroding into the high level alluvium on which the Merutai Kechil is flowing.

The second lake area involves a more complicated story. The waters were here ponded back into an area of very steep topography. The only possible line of escape was over the lowest point in the ridge lying towards the south-east. (IX on figure 3). When this was achieved there was a very large head of water and the result was a catastrophic flood of water, mud and boulders down the stream marked V on figure 3 and spreading out over the Bombalai-Imam area. Thus there was laid down in this area a white to buff-coloured, well bedded material which varies in grain size from fine clay to a coarse conglomerate (see plate 14). In certain places it contains large quantities of well preserved dicotyledonous leaves. The boulders are of a varied nature including examples of all the Pliocene volcanic rocks but dominated by the pink and grey dacites from Mt. Maria. It occurs as a valley filling and also spreads over the coastal platform, where it directly overlies strongly mottled and weathered material, i.e. proof that it was deposited on the uplifted coastal platform. Just north of the Bombalai estuary this material filled the lower valley of the Table stream, B, on figure 3, and diverted the stream to the north-west, X, on figure 3.

When these catastrophic floods of debris ceased the stream which was transporting this material found itself unable to maintain its course and in turn built up a head of water until a passage to the next stream, XI figure 3, was made. Again an overloaded stream deposited buff coloured mud and slightly weathered ash into this new stream. This was in general much finer material than is found in the Imam Bombalai area but it was enough to divert the stream to the south east, XII on figure 3, into something like its present course.

2. The second area of basaltic eruptions occurs at Quoin hill on the eastern flank of Mt. Maria. This is only an eruption from a single centre and hence it is not such a complex story but here again the main basalt flows were erupted across the drainage lines of the country. The map, figure 4, will illustrate the two examples of river diversion that have been noted. The most important one is the diversion of the Balung river. Prior to the basalt eruptions the lower course of the Balung was along the present Jarangan valley, which is now occupied by a small underfit stream. The basalts spread eastwards from Quoin hill and reached as far as the southerly projecting ridge from Wullersdorf known as Kawa hill. This blocked the whole of the Balung valley above this point. The water backed up until a low col on the north side of Kawa hill was overtopped, through which the Balung now runs, before reaching the low level alluvium on which Balung estate occurs.

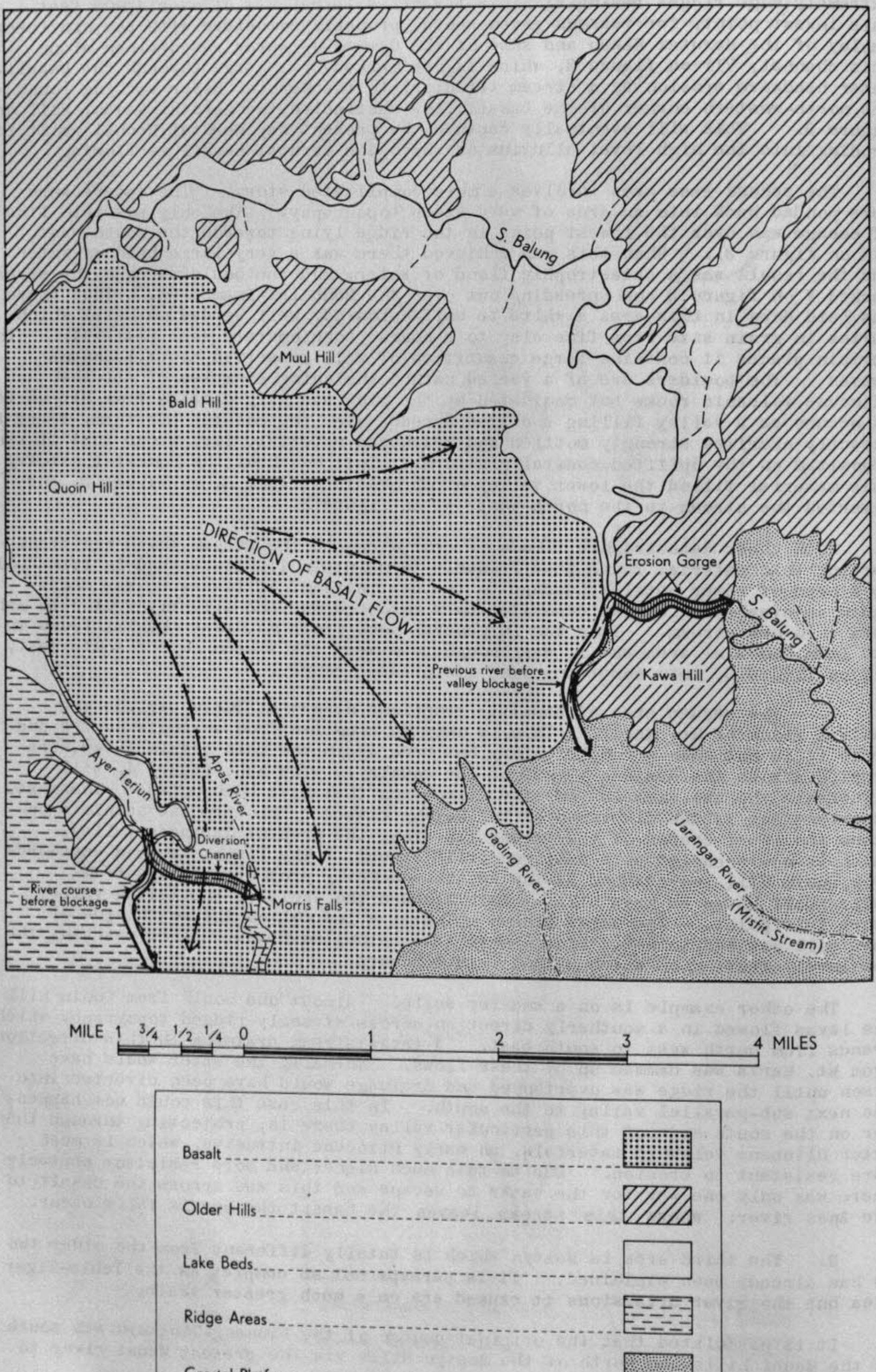
The other example is on a smaller scale. Almost due south from Quoin hill the lavas flowed in a southerly direction across strongly ridged topography which trends from north west to south east. A large stream draining in this direction from Mt. Maria was dammed up by these flows. Normally the water would have risen until the ridge was overtopped and drainage would have been diverted into the next sub-parallel valley to the south. In this case this could not happen for on the south side of this particular valley there is, projecting through the later Pliocene volcanic materials, an early Pliocene intrusive, which is much more resistant to erosion. Due to this much higher and more resistant obstacle there was only one way for the water to escape and this was across the basalt to the Apas river: **where this stream leaves** the basalt the Morris falls occur.

3. The third area is Mostyn which is totally different from the other two as has already been explained. **It is perhaps not so complex as the Table-Tiger area but the river diversions it caused are on a much greater scale.**

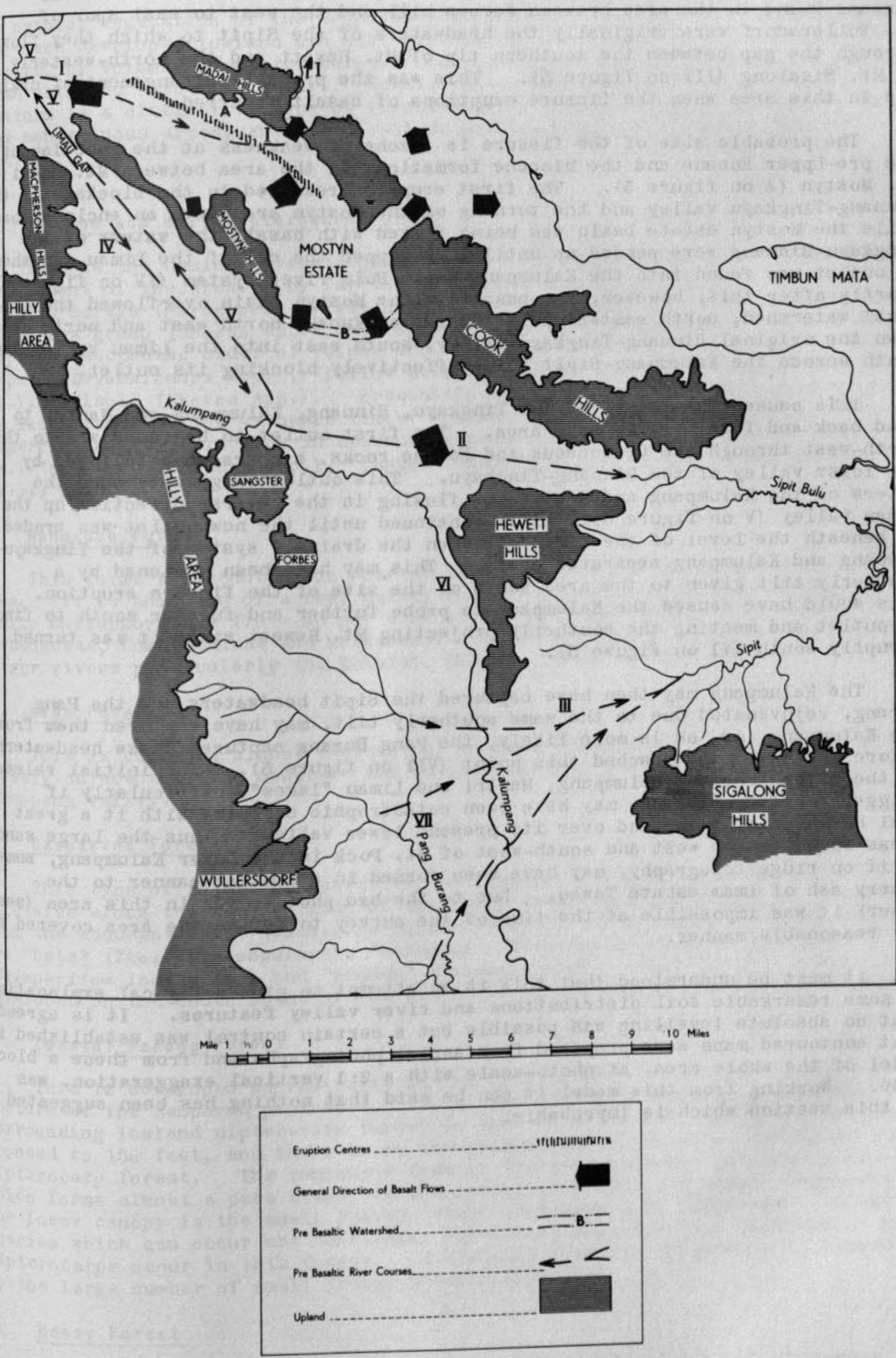
It is postulated that the original course of the Binuang-Tingkayu was south of the Madai hills and north of the Mostyn Hills via the present Madai river to the coast (I on figure 5).

The Mostyn estate area was deeply dissected and if any stream occurred in this area it would be tributary to the Binuang-**Tingkayu**. The watershed between it and the Kalumpang would have been the line of hills running between Mostyn estate and Limau-Kalumpang drainage as it is at present. (B on figure 5).

LAKE BEDS & RIVER DIVERSIONS BALUNG Fig 4



LAKE BEDS & RIVER DIVERSION IN THE MOSTYN AREA — Figure 5



The Kalumpang instead of turning south continued to flow east-south-east between Cook hill and Mt. Hewett along what is now the lower valley of the Sipit Bulu to the sea opposite Timbun Mata island (II on figure 5). The numerous small streams found in the area between Forbes hill and the west to east spur of Mt. Wullersdorf were originally the headwaters of the Sipit to which they flowed through the gap between the southern tip of Mt. Hewett and the north-westerly tip of Mt. Sigalong (III on figure 5). This was the probable arrangement of drainage in this area when the fissure eruptions of basalt occurred.

The probable site of the fissure is a zone of weakness at the junction of the pre-Upper Eocene and the Miocene formations in the area between Mt. Madai and Mt. Mostyn (A on figure 5). The first eruption resulted in the blockage of the Binuang-Tingkayu valley and the turning of the Mostyn area into an enclosed basin. While the Mostyn estate basin was being filled with basalt the waters of the Tingkayu-Binuang were ponded up until they topped the col of the Limau gap when an outlet was found into the Kalumpang-Sipit Bulu river system (IV on figure 5). Shortly after this, however, the basalt in the Mostyn basin overflowed the original watershed, north eastwards to the sea at Kunak, north east and north west down the original Binuang-Tingkayu valley, south east into the Limau valley and south across the Kalumpang-Sipit Bulu, effectively blocking its outlet.

This caused the waters of the Tingkayu, Binuang, Kalumpang and Mantri to pond back and form a large lake area. The first outlet to be found was to the north-east through the Cretaceous and Eocene rocks, a course now followed by the lower valley of the Binuang-Tingkayu. This outlet originally took the waters of the Kalumpang and Mantri, now flowing in the reverse direction, up the Limau valley (V on figure 5). This continued until the new outlet was eroded to beneath the level of the Limau col when the drainage system of the Tingkayu-Binuang and Kalumpang separated again. This may have been hastened by a southerly tilt given to the area south of the site of the fissure eruption. This would have caused the Kalumpang to probe further and further south to find an outlet and meeting the southerly projecting Mt. Hewett ridge it was turned abruptly south (VI on figure 5).

The Kalumpang may then have captured the Sipit headwaters and the Pang Burang, rejuvenated due to the same southerly tilt, may have captured them from the Kalumpang, or, as is more likely, the Pang Burang captured these headwaters before the Kalumpang reached this point (VII on figure 5). The initial release of the water from the Kalumpang, Mantri and Limau "lakes", particularly if triggered off by tilting, may have been catastrophic carrying with it a great deal of material to spread over its present lower valley. Thus the large sandy areas found to the west and south-west of Mt. Pock in the lower Kalumpang, some of it on ridge topography, may have been formed in a similar manner to the Quarry ash of Imam estate Tawau. Due to the bad photo-cover in this area (see later) it was impossible at the time of the survey to define the area covered in any reasonable manner.

It must be understood that this is an attempt to give a logical explanation to some remarkable soil distributions and river valley features. It is agreed that no absolute levelling was possible but a certain control was established in that contoured maps were prepared from aerial photographs and from these a block model of the whole area, at photo-scale with a 2:1 vertical exaggeration, was made. Working from this model it can be said that nothing has been suggested in this section which is improbable.

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NATURAL VEGETATION

The natural vegetation of the Semporna peninsula is rain forest. On inland areas there are developed lowland and hill dipterocarp forests, containing 60 per cent, or more, by volume, of dipterocarps. In coastal regions areas of mangrove swamp, nipah palm and casuarina occur. Scattered sporadically over an upraised coastal platform is a distinctive type of forest locally called "coastal padang". On some mountainous areas, where the soil is particularly poor, "mossy forest" occurs.

1. Lowland and Hill Dipterocarp Forest

This is the dominant vegetational type of the peninsula, covering more than 75 per cent of the area. By far the most important single species is "urat mata" or white seraya (*Parashorea melaanonan*) which is exceeded in volume only by the red seraya group (*Shorea* spp.) and "keruing" (*Dipterocarpus* spp.). Other dipterocarps in descending order of volume are "selangan batu" (*Shorea* and *Hopea* spp.), "kapur" (*Dryobalanops* spp.), "yellow seraya" (*Shorea* spp.), "selangan" (*Hopea* spp.), "melapi" (*Shorea* spp.). Frequently associated with these dipterocarps are rich stands of the valuable timber "belian" (*Eusideroxylon zwageri*). Other commercial non-dipterocarps in descending order of volume are "nyatoh" (*Palaquium* spp.) "sepetir" (*Sindora* spp.), "ranggu" (*Koordersiodendron pinatum*) and "merbau" (*Intzia palembanica*).

2. Mangrove Forest

This forms a discontinuous coastal fringe covering about 6 per cent of the area. It is composed of a few, mainly woody, species belonging primarily to the family Rhizophoraceae (70 - 90 per cent of the growing stock), with some Verbenaceae, Combretaceae and Meliaceae. It is developed at the mouths of the larger rivers particularly the Merutai, Balung, Kalumpang and Sipit.

3. Nipa Forest

This is composed almost exclusively of *Nipa fructicans*. It occupies areas closely adjacent to the mangrove and is particularly well developed in the Lower Kalumpang valley.

4. Casuarina Forest

This type of forest is restricted to a narrow belt, up to a quarter of a mile wide along the seaward side of shallowly shelving sandy beaches. Apart from the abundant "aru" (*Casuarina equisetifolia*), other common wood associates are "bata" (*Thespesia populnea*), "ketapang" (*Terminalia catappa*) "penaga" (*Calophyllum inophyllum*) and "pandam" (*Pandanus* spp). This forest is well developed on the south coast of the peninsula from Tawau to the Pagagau channel.

5. Coastal Padang Forest

This is developed sporadically on the coastal platform, which is such a feature of the Semporna peninsula. This type of forest contrasts with the surrounding lowland dipterocarp forest in that it has a low canopy, 60 feet as opposed to 150 feet, and there is no stratification, which is so marked in the dipterocarp forest. The commonest tree is "palawan-palawan" (*Tristania obovata*) which forms almost a pure stand, in the canopy at least. A common component of the lower canopy is the small leaved "obah" (*Syzygium* c.f. *zelanica*). Other species which can occur are *Pentaceae, Anonaceae, Mangifera* and *Canarium*. No dipterocarps occur in this forest. A strongly vertical appearance is caused by the large number of small trees, chiefly *Tristania*.

6. Mossy Forest

This is a very restricted development and occurs at altitudes in excess of 2,000 if encouraged by poor soil. The only occurrences in the Semporna peninsula is at the summit of Mt. Wullersdorf and at Glas hill where the soil has been derived from a late Pliocene rhyolite. It is a distinctive type of open forest, composed of low trees with gnarled boles and crooked branches. All the trees are festooned with mosses and this forms a covering, 6 in. thick, on the ground.

More detailed work was carried out by the late G. H. S. Wood on one area of lowland and hill dipterocarp forest in the Quoin hill area. Two or three half acre plots were totally enumerated on each major soil type and it was found that there was a close relationship between the forest and the type of soil. This can be seen most clearly when the differences are considered between forest developed on soils belonging to the Gading family (coastal platform) and Table family (high level plateau). There are well defined differences in the species as well as in the size and number of trees.

(a) **Gading Family**

Four half acre plots were totally enumerated on soils of this family. The commonest commercial species were red seraya, keruing, yellow seraya, selangan batu and oba suluk. In places keruing is almost pure. The trees are usually of good form but mainly of small to medium size. Also frequently found was a species of *Parashorea* (white seraya) with a heavy wood. ***Parashorea melaanonan*** and its varieties were almost absent. On the average there were 197 trees to the acre over 4 in. diameter. This figure was fairly constant on the four plots studied, varying from 188-214.

Table 2 shows the distribution of numbers and basal areas by girth classes. It can be seen that even though the number of Dipterocarpaceae is small they make up nearly one half of the total basal area, since many of them are large trees, and nearly two thirds of the number and basal area of trees of over six feet in girth. As there was no measurement of clear bole, figures for merchantable volume cannot be given, but they would, on the average, be proportional to the basal area.

Table 3 gives the numbers of the various genera of dipterocarps that were present.

(b) **Table Family**

This is confined to the high level plateau. One notable feature of the forest on these soils is its irregularity, the volume being exceptionally high in places while other patches, up to one acre in extent, have practically no merchantable timber.

The most noticeable difference from the previous group is the abundance of "majau". It was noted that this species was totally absent from the areas with Gading soils. Also occurring was the true "white seraya" (*Parashorea malaanonan*) which was also rare on soils of the Gading family. Another feature is the large size of many of the trees. In the plots assessed the largest size was the 18 foot girth class but many other larger trees were seen. The largest recorded was a 32 foot girth at 14 feet and 250 feet high, with a clear bole length of 90 feet. This is a relatively short bole and in general this would seem to be the case with many of the trees of the high level plateau. This would fit in with the general observation that there seemed to be a lack of competing main storey, thus allowing shorter boles to develop.

The figures in table 4 were taken from 10 plots covering 5 acres. Comparing these figures with those of the forest on the Gading soils there are a number of points of difference. Firstly, the mean number of trees over 4 in. in diameter is very much lower. Almost all these differences occur in the first three girth classes, that is to say, there are fewer trees with a girth of less than 4 feet on the Table than on the Gading soils. Another striking feature is the larger size attained by some of the trees. This is probably a direct consequence of the more fertile soil and it is probably due to the presence of these larger trees that there are fewer smaller ones. Of more importance is the higher basal areas of dipterocarps of merchantable size, nearly 73 per cent of the total basal area over 6 feet in girth being made up of this family.

Table 5 gives the numbers of the various genera of dipterocarps that were present.

Some idea of the variation in numbers and basal areas of trees on the Table soil can be seen from the figures of the individual plots. The number per acre varied from 100 to 188, while the basal area varied from 113 to 238 square feet. Enumeration of three two-acre strips showed a high merchantable volume of 3,690 cubic feet to the acre.

Plates 1, 2 and 3 give some idea of the forest.

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Table 2

NUMBERS AND BASAL AREAS OF TREES ON GADING FAMILY SOILS

Girth class (centre)	No/Acre All trees	No/Acre Dipts	BA/acre All trees	BA/acre Dipts
1 ft. 6 ins.	113	22.5	20.2	4.0
2 6	34	5.0	16.8	2.5
3 6	18.5	6.0	18.0	5.9
4 6	6.5	1.5	10.5	2.4
5 6	8.5	4.0	20.5	9.6
6 6	5.0	1.5	19.8	5.0
7 6	5.5	4.0	24.6	17.9
8 6	1.0	0.5	5.8	2.9
9 6	0.5	0.5	3.6	3.6
10 6	1.5	1.0	13.2	8.8
11 6	2.0	1.5	21.0	15.8
12 6	1.0	1.0	12.4	12.4
Total	197.0	49.0	186.4	90.8
Total over 6 ft.	16.5	10.0	100.4	66.4

Table 3

GENERA IN DIPTERO CARP FOREST ON GADING FAMILY SOILS

	No/Acre	No/acre over 6 feet in girth
Dipterocarpus	5.5	1.0
Dryobalanops	0.5	0.5
Hopea	0.5	0.0
Parashorea	2.5	1.0
Shorea	30.0	6.5
Vatica	10.0	0.0

Other species to reach a girth of 6 feet were belian (2), berangan (0.5), mengaris (1.5) and obah (2.5).

(Data of the late G. H. S. Wood)

Table 4

NUMBERS AND BASAL AREAS OF TREES ON TABLE FAMILY SOILS

Girth class (centre)	*No/acre all trees*	*No/acre Dipts*	*BA/acre all trees*	*BA/acre Dipts*
1 ft. 6 ins.	77.1	9.5	13.8	1.7
2 6	25.6	4.5	12.7	2.2
3 6	13.3	3.6	12.8	3.5
4 6	8.4	2.9	13.5	4.7
5 6	6.2	1.5	14.9	3.6
6 6	3.8	1.3	12.8	4.4
7 6	2.4	1.1	10.6	4.9
8 6	1.6	0.5	9.4	2.9
9 6	2.9	2.5	21.3	18.0
10 6	0.9	0.5	8.0	4.4
11 6	1.5	1.5	15.3	15.3
12 6	0.5	0.5	6.8	6.8
13 6	0.4	0.4	5.3	5.3
14 6	-	-	-	-
15 6	-	-	-	-
16 6	0.4	0.4	7.9	7.9
17 6	-	-	-	-
18 6	0.2	0.2	5.0	5.0
Total	145.2	30.9	170.1	90.6
Total over 6 ft.	14.6	8.9	102.2	74.7

Table 5

GENERA IN DIPTEROCARP FOREST ON TABLE FAMILY SOILS

	No/acre	No/acre *over 6 feet in girth*
Dipterocarpus	1.3	0.0
Dryobalonops	3.3	0.5
Hopea	0.4	0.0
Parashorea	5.1	1.3
Shorea	18.7	6.9
Vatica	2.0	0.2

There were 14 other species to reach 6 feet in girth but the number per acre was very low (6 species at 0.4 and 7 at 0.2 per acre), except in the case of belian which averaged 1.5 trees per acre.

(Data of the late G. H. S. Wood)

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AGRICULTURE AND INDUSTRY

The largest block of developed estates in the colony is to be found near Tawau, while at Mostyn there is one of the largest mechanised logging units. There is in addition a considerable development of Chinese smallholdings in and around Tawau, while native smallholdings are found mainly at Kunak and around Semporna. Logging on a smaller scale is also carried out round Semporna.

Agriculture

Quite a large variety of tropical crops is grown of which the most important is rubber. It is grown on four estates belonging to Borneo Abaca Limited (Merutai Kechil, Burut, Imam and Tawau) and in addition some is grown on the Chinese smallholdings nearer Tawau. Most of this is unimproved seedling rubber but new planting and replanting with high yielding materials is being carried out on the estates.

Within the colony of North Borneo the cultivation of Manila hemp is confined to the Semporna peninsula. Table estate of Borneo Abaca Limited is reserved for its cultivation and in addition, 600 acres are planted on Balung estate and 900 acres on Mostyn. Expansion of the growth of this crop has been seriously impeded by the occurrence of "bunchy top" virus disease. However, control measures have now been evolved which are compatible with an economic return from the crop.

The coconut is the most important crop for the Chinese smallholders. There is a considerable acreage in the immediate vicinity of Tawau and this extends, as a coastal strip, as far east as the mouth of the Gading river. There is also a considerable area near Semporna on soils derived from coral.

The growth of oil palms and cocoa is not yet beyond the experimental stage but within a few years should be of considerable importance.

The cultivation of rubber and hemp on a large scale by Borneo Abaca Limited has given rise to the only considerable industry in the peninsula. In the Bombalai area of Imam estate is situated the mechanical decorticator for the production of hemp and the central rubber factory. The manufacture of copra by the smallholders is all by crude methods of sun-drying without any grading.

The smallholdings in the Tawau area are mostly owned by Chinese. They are generally based on the growth of coconuts, bananas, maize and, if they are near enough to Tawau, vegetables and fruits. Pigs and poultry are raised and occasionally a little seedling rubber has been grown. The association of cattle and coconuts is becoming more common in the area. The general level of agriculture is low and could be raised considerably by extension work (this will be seen to be essential when prevention of soil erosion is considered). A similar type of mixed cash crops and subsistence agriculture is found in the area of Semporna, again due to the Chinese.

Immediately south of Semporna is an area settled by Bajaus. They depend for the most part on fishing and only grow crops as a sideline. Their main crops are maize and cassava, which are grown continuously for several years. Maize is generally grown on the flat land of the coral platform (Semporna soils) and cassava on the neighbouring steeper hillsides (Conner soils). On the flat areas there is a peculiar type of land settlement. Taking a large tree as a centre point they clear outward from it leaving it as a marker. The end product is a cleared circle with a large tree in the centre, individual holdings being a segment radiating from the central tree.

Numerous hillsides in this area are covered with a "fire climax" of lallang (plate 12) which indicates a former considerable spread of dry padi cultivation. There is no known reason for the abandonment of these large holdings. It may have been due to unsatisfactory water conditions or the depredations of pirates.

Another area which is being actively developed by smallholdings is Kunak (Mostyn). As in the Semporna area the main crops are maize and cassava: concentration on these two crops is probably due to ignorance of how to grow any others. It will be impossible to remedy this state of affairs and also the bad effects on this valuable soil without a demonstration farm in the area.

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Logging

The British Borneo Timbers Company Limited block II concession covers over 900 square miles in the northern part of the peninsula. It is being actively exploited wholly by mechanical means. After felling, logs are skidded from the stump to the loading area by means of tractors. They are then loaded onto trucks and transported by road to Kunak wharf. From here they are rafted across to Bohian island where they are loaded directly into ocean going ships. A track loader was introduced by the firm in 1958. This is a mobile unit which drags logs, by means of wire ropes, from the stump to the loading areas and also loads the logs onto trucks at this point. When logging is finished in any particular area the machine moves under its own power to a new one. The advantages of using this machine, as opposed to tractors, is the greater speed of operations, the ease of setting up a loading point and the much steeper slopes that can be worked. No timber is sawn by this company in the Mostyn area. A sawmill is operated at Semporna by Chinese, who extract logs by tractor and rail. It is to be noted that with the use of larger machines for logging the risks of accelerated soil erosion are much increased and evidence in 1959 was that the amount of destruction of the forest and of the soil had been much increased by their use.

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METHODS OF WORK

Prior to the start of this survey, in 1953, no systematic pedological work had been attempted in North Borneo. In addition, in the Semporna peninsula, both geological and topographic maps were lacking or were of very little value. The various methods used to carry out the survey will now be outlined.

The Directorate of Overseas Surveys had published preliminary plot sheets of the Semporna peninsula on a scale of 1:50,000. It was found impossible to use these as a base for the survey because the scale was too small and the topographic data were too scanty. The positions of the principal points of the aerial photographs were, however, taken from these sheets. A scale of 1:25,000, or photo-scale, was found to be of more value for use in the field, transferring back to a scale of 1:50,000 for the final maps. These scales were not conditioned by the pedological details which were available but it was found, when working in high primary jungle, that the 1:25,000 scale enabled points to be located with comparative ease while the 1:50,000 was of little value.

The scheme for the preparation of field maps as finally evolved was:

1. Aerial photographs were marked with principal points and tie points. A pricker was used for the actual point and this was circled in poster paint. The principal points were connected by straight lines again drawn in poster paint.

2. The centre points of photographs as shown on the 1:50,000 preliminary plot sheets were transferred to a transparency on which the 1:25,000 field map is to be made.

3. Using a Universal and a lens stereoscope the coast line and drainage (in blue) and watersheds (dashed white line) are marked in. It was found in this high forest that every depression carried a stream and the photographs were marked accordingly.

4. The photographs were then form-lined at a vertical interval of 100 feet. Spot heights of easily recognisable peaks were obtained from marine charts. Relative differences of height were obtained by the use of the stereometer bar. Form lines were put on as solid yellow lines.

5. All details that were on the photographs were transferred to the transparency, each photograph being accurately located vis-a-vis its principal points, by means of a radial line plotter.

6. This gives a topographic map transparency which was reproduced by sun-printing to give a field map.

For the purpose of organising field work the region was divided into eight areas coincident with the limits of the 1:50,000 sheets. In addition to the D.O.S. number each area was given a regional name, for instance, Tawau, Balung, Kuala Kalumpang.

All rocks collected were given a Geological Survey number and forwarded to their headquarters for registration and sectioning together with a map showing their location.

All soil samples were collected from pits which were 6 feet deep or to parent rock if at a shallower depth. Within a particular map sheet all profiles were named after the sheet head and consecutively numbered. As a cross check each soil horizon was given a registered number and fully described under that number. Thus every profile was described as a whole and as individual horizons. In addition the soil sample number, profile number, horizon and location were recorded in a soil sample register. Locations of all soil profiles were recorded on a separate map. Soil descriptions were all made according to handbook number 18 of the United States Department of Agriculture.

In the high primary forest, such as makes up the greater part of the Semporna peninsula, it is practically impossible, even with the help of a reasonable topographic map, to pinpoint a position accurately without additional help. It was necessary to cut tracks on a compass bearing from a fixed starting point and to measure distances from this point. The frequency of these traces is dependent on the complexity of the soil pattern and also on the topography. In a fairly flat area they are cut on a grid a mile square. In strongly rolling to hilly country this becomes less. When mountainous country is encountered it is practically impossible to proceed in a straight line and recourse must be made to a ridge track, with occasional transects on either side to give some idea of soil variation. All tracks were numbered, even ones in one direction and odd numbered ones at right angles and measured in chains from their origin. Every 10 chain point was marked by a numbered post (small forest saplings were found to be ideal for this purpose). No account was taken of the effect of slope, all distances measured were those actually occurring on the ground. Map distances could be arrived at by measuring on the aerial photograph between two recognisable points such as hilltops or river crossings.

When the tracks have been cut and marked it is possible to begin the soil survey. This was carried out by making an auger boring at every 10 chain post to a depth of 4 ft. 6 ins. As every six-inch bite of the auger was removed it was described for colour, texture, structure, consistence, mottling and rocks (a post-hole auger of 6 in. diameter was used). In addition a general description of the topography and any interesting exposures in the previous 10 chains was given. Rock samples were collected throughout the traverse. Using this method it was possible to cover a mile every 2 hours irrespective of topography. Naturally at this rate the soil surveyor did not have time to cover all the tracks that have been cut. Assistants, however, were trained to cover some of the area so that the surveyor could extrapolate with a fair degree of confidence from the main tracks, which he has personally examined. Topographic notes were made and rock samples collected by the assistant. At every 10 chain post auger samples were taken as previously but they were sent back to the soil surveyor for examination.

When this was completed the soil surveyor had a general idea of the soil pattern.

At the same time as the ground survey was being carried out an analysis of land forms and tree growth was being made from aerial photographs. By combining these observations with the ground data it was possible to map the boundaries of some of the major soil families on aerial photographs. This was only possible in this particular case because of the geomorphological youth of the area and it was found that a particular family of soils was generally confined to a particular geomorphological unit. This was confirmed over a period of three years before any extrapolation was attempted and a trial extrapolation was confirmed in the field before this method was finally adopted. In no case has any completely uncontrolled extrapolation been attempted, at least one track crosses every soil family that is found on any particular map.

The following divisions were recognised on aerial photographs:

1. *The coastal plain* was differentiated by having no topographic break at the shoreline but a very abrupt change on the landward limit. The natural vegetation is varied and the following divisions may be made, nipah, casuarina, mangrove and mixed coastal forest.

2. *The riverine plain* is a continuation of the coastal plain but occurs as strips along the lower course of rivers. It is differentiated from anything on the coastal plain by its natural vegetation, which consists of very well grown lowland dipterocarp forest.

3. *The high level plains* occur as extensive level areas in the middle and upper valleys of the Merutai Kechil, Balung, Mantri, Kalumpang, and Binuang. There is a distinct break between the lowland riverine plain and this feature of perhaps 50-100 feet. These areas are recognised by being elevated, extensive, adjacent to rivers, slightly dissected with a much poorer vegetation than is found on the low riverine alluvium.

4. *The coastal platform* stands 50 to 100 feet above the coastal and riverine plain. It is a very extensive feature spreading from the Merutai to the Kalumpang and north to Mostyn and the Sipit. Its inland junction with either ridges or mountains or high level plateaux is abrupt and easily recognisable. It is a level feature which is slightly dissected, cut through by streams which are in narrow entrenched valleys. There are two major divisions which may be recognised

   (a) A moderate to poor type of lowland dipterocarp forest with an even canopy is confined to the area of the depositional coastal platform with Gading soils.

   (b) A rather better growth of jungle but with not such an even canopy. This is confined to the erosional coastal platform and the Sipit family of soils.

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This difference can be related to the greater depth of soil on the depositional coastal platform, which is relatively poor as compared to the shallow but richer soils of the Sipit family.

Another division which can be recognised is the *coastal padang*. This may occur on either of the two types described above but is more commonly associated with the Gading soils. It is seen as extremely stunted areas of growth within areas of more normal lowland dipterocarp forest. It is associated with sand deposits on the coastal platform.

5. *The ridge country* was recognised by its extremely dissected nature, consisting of sub-parallel ridges separated by narrow valleys up to 100-150 feet deep. There is generally a quarter of a mile between adjacent ridges. The growth is in general good dipterocarp forest. It is, however, only possible to differentiate the types of ridge country on the ground.

6. *The high level plateaux* were recognised by being level areas at heights varying from sea-level to 800 feet (but generally nearer the latter) totally out of context with the surrounding landscape. They overlie both ridge country and coastal platform and the junction is abrupt, generally a break of about 100 feet. This break is emphasised by the fact that the forest on these plateaux consists of extremely large crowned trees which are much bigger than those found elsewhere.

7. *Mountains* - four main groups were differentiated:

(a) Mountains showing a fine grained type of dissection with a moderate but evenly spaced forest cover. These areas carry soils of the Cook family

(b) Mountains showing distinct strike ridges with a moderate to good growth of forest but with an uneven canopy. These areas carry soils of the Malatai family

(c) Large strongly dissected mountain areas with no distinct lineation and where forest growth is in general good. This includes soils of both the Besar and Tajong families and differentiation must be done on the ground.

(d) Small isolated hill masses are of two distinct types. Those which are connected with the extrusion of the Quaternary basaltic lavas which now form the high level plateaux. They can be differentiated from the numerous others which carry soils of the Besar family.

The combined data from this land form and vegetation analysis and from the ground survey was put onto the aerial photographs. The previous topographic data was confined to one and this information was confined to the other of a photo pair. To make the soils map transfer was done as before to the topographic map transparency, using the radial line plotter. The photographs were filed for permanent reference. If any revision becomes necessary this will be easily done on the photographs for the poster paint lines are easily erased.

SOIL MAPPING

As a result of the work carried out as described in the previous section it was found in general that the major soil groups were confined to certain parent materials within certain geomorphic units.

From this point of view the most important aspect of the parent material is its age, for this was found to be directly related to the topography on which any soil was developing. The actual composition of the parent materials is used as a differential factor within these major divisions.

Seven age groups of parent materials were differentiated:

(a) Pre-Upper Eocene

(b) Miocene

(c) Early Pliocene

(d) Late Pliocene

(e) Late Pliocene-Quaternary

(f) Quaternary

(g) Recent

Eight main geomorphological units are differentiated:

(a) Hills and mountains

(b) High level plateaux

(c) Ridge country

(d) Erosional coastal platform

(e) Depositional coastal platform

(f) High level plains or "lake beds"

(g) Riverine plain

(h) Coastal plain

If these two divisions are plotted against one another it is possible to define the major soil families found in the Semporna peninsula. (Table 6).

Soils developed on hills and mountains

(a) From pre-upper Eocene rocks - the COOK family

Sub-families according to the composition of the parent material

BINUANG - developed from serpentines

MADAI - developed from limestones

COOK - developed from sandstones and shales

(b) From Miocene rocks - the MALATAI family

Sub-families according to the composition of the parent material

HEWETT - developed from andesitic agglomerate

MANKOK - developed from rhyolitic tuff

MALATAI - developed from sandstones and shales

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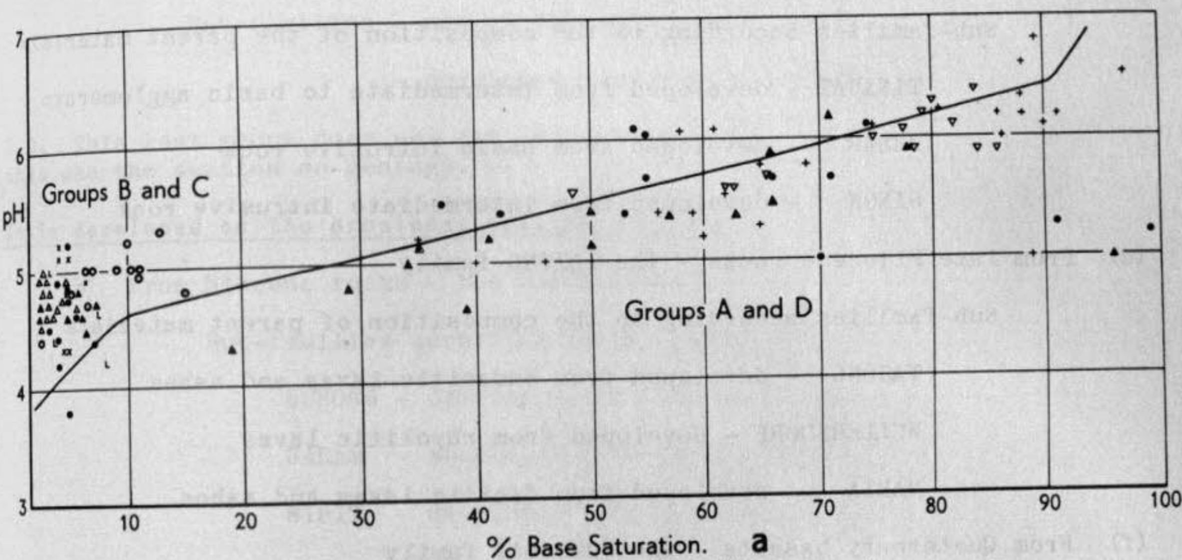
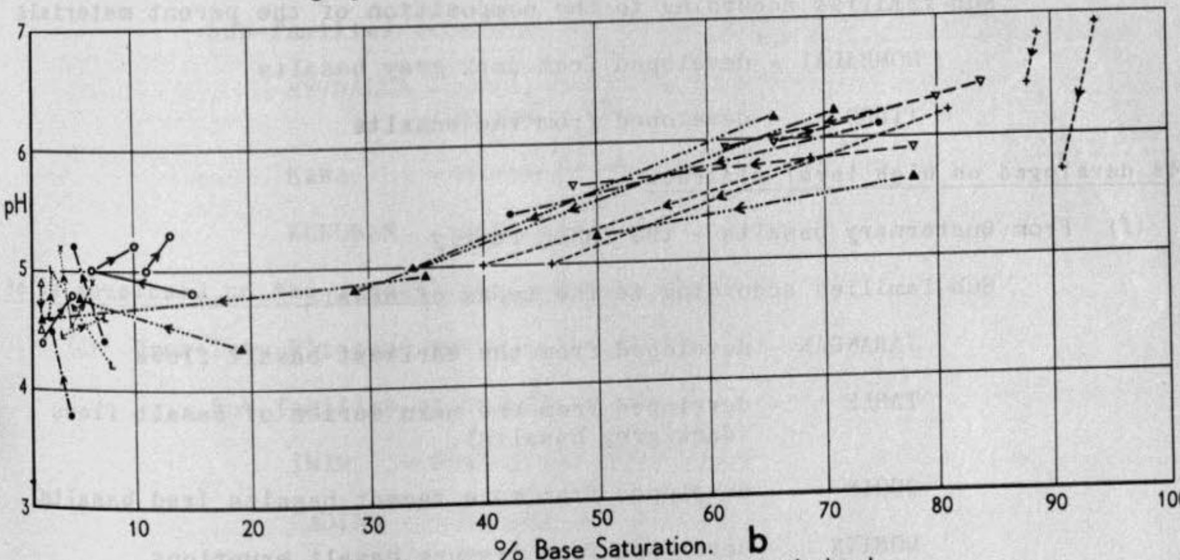
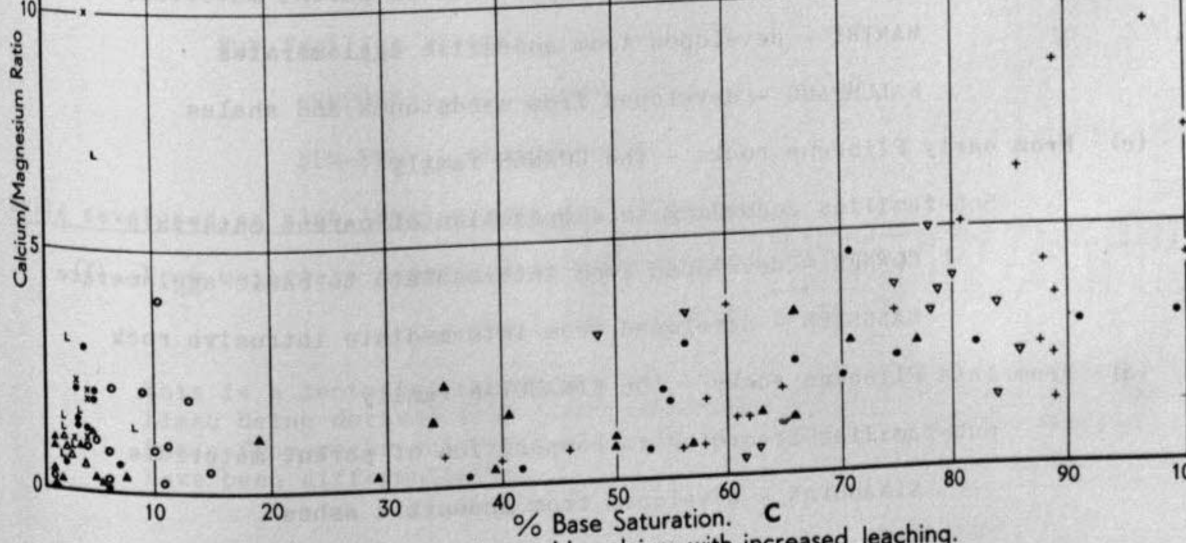
Fig 6



Segregation of soil families by pH and base saturation



Oxysol/Ochrosol segregation ; change with depth.



Decrease in exchangeable calcium with increased leaching.

(c) From early Pliocene rocks - the BESAR family

Sub-families according to the composition of the parent materials

TINAGAT - developed from intermediate to basic agglomerate

BESAR - developed from basic intrusive rock

SINON - developed from intermediate intrusive rock

(d) From late Pliocene rocks - the TAJONG family

Sub-families according to the composition of parent materials

TAJONG - developed from andesitic lavas and ashes

WULLERSDORF - developed from rhyolitic lavas

MARIA - developed from dacitic lavas and ashes

(f) From Quaternary basalts - the BOMBALAI family

Sub-families according to the composition of the parent materials

BOMBALAI - developed from dark grey basalts

TIGER - developed from red basalts

Soils developed on high level plateaux

(f) From Quaternary basalts - the TABLE family

Sub-families according to the types of basalt

JARANGAN - developed from the earliest basalt flows

TABLE - developed from the main series of basalt flows (dark grey basalts).

QUOIN - developed from more recent basalts (red basalts)

MOSTYN - developed from fissure basalt eruptions

Soils developed on ridges

(a) From pre-upper Eocene rocks - the TINGKAYU family

Sub-families - one of the same name - developed from serpentine

(b) From Miocene rocks - the KALUMPANG family

Sub-families according to composition of parent materials

MANTRI - developed from andesitic agglomerates

KALUMPANG - developed from sandstones and shales

(c) From early Pliocene rocks - the CONNER family

Sub-families according to composition of parent materials

CONNER - developed from intermediate to basic agglomerate

SANGSTER - developed from intermediate intrusive rock

(d) From late Pliocene rocks - the KINABUTAN family

Sub-families according to composition of parent materials

KINABUTAN - developed from andesitic ashes

APAS - developed from dacitic ashes

(e) From late Pliocene-Quaternary rocks - the QUARRY family

Sub-families - one of the same name

- developed from mud-flow deposits

N.B. This last group does not fit into the general pattern, for a discussion on this see the section on geology.

Soils developed on the erosional coastal platform

(b) From Miocene rocks - the SIPIT family

Sub-families according to the composition of the parent materials

BURONG - developed from andesitic ashes

GARAM - developed from rhyolitic ashes

SIPIT - developed from sandstones and shales

(c) From early Pliocene rocks - the KAWA family

Sub-families according to the composition of the parent materials

MEMBALUA - developed from intermediate and basic lavas and ashes

KAWA - developed from basic intrusives

KUKUSAN - developed from intermediate intrusives

Soils developed on the depositional coastal platform

(d) From late Pliocene rocks - the GADING family

Sub-families according to the general colouring of the profile

IMAM - weakly coloured soils

GADING - strongly coloured soils

(e) Late Pliocene-Quaternary rocks - the KUBOTA family

Sub-families - one of the same name

- developed from beach sand deposits

Soils developed on the raised coral platform (this is localised in the Semporna area and is not included in the general classification of land-forms).

(e) Late Pliocene-Quaternary coral limestone - the SEMPORNA family

Sub-families according to the depth of soil

SEMPORNA - moderately deep soils

BUM-BUM - shallow soils

Soils developed on high level plains or "lake beds"

(f) From materials deposited in Quaternary times

- the LIMAU and LUCIA families

This is a tentative division based on the origin of the alluvium, the Limau being derived from rocks which are Miocene and older and the Lucia from rocks which are Pliocene and younger. No sub-families have been differentiated.

Soils developed on riverine plains

(g) From recent alluvial deposits - the SAPANG and BALUNG families

Again this is a tentative division based on the same principles as above. Sapang being equivalent to Limau and Balung to Lucia. No sub-families have been differentiated in the Sapang family but well-drained (BALUNG) and poorly drained (TAWAU) sub-families have been differentiated within the Balung family.

Soils developed on the coastal plain

(g) Recent marine alluvial deposits - the TANJONG family

Sub-families according to topographic position

TANJONG - derived from sand dunes

HITAM - derived from inter-dune lagoonal sediments

All soils in the above list are named after localities in the Semporna peninsula. The family name has been derived from the most important sub-families.

This survey was carried out to determine the major groups of soils of the Semporna peninsula. On the scale used it was possible to recognise certain sub-families and yet not to differentiate them on the map; certain sub-families were easy to differentiate due to being connected with a definite geomorphic feature. Where possible these sub-families have been differentiated by symbols; where not, a complex of symbols has been used. The following symbols and combinations of symbols have been used on the maps.

C	For the Cook family - sub-families not differentiated or symbolised as Cook is overwhelmingly dominant.
H Mk Ma H-Ma	For the Malatai family. The Mankok (Mk) is very localised. Where possible the Hewett (H) and the Malatai (Ma) are differentiated where not they are mapped as a complex.
Tt Br Sn Tt-Br	For the Besar family. The Sinon(Sn) is localised. Where possible the Tinaget (Tt) and Besar (Br) are differentiated where not they are mapped as a complex.
Tg W Mia Tg-W	For the Tajong family. The Maria (Mia) is localised. Where possible the Tajong (Tg) and Wullersdorf (W) are differentiated. Where not they are mapped as a complex.
Tr Bi	For the Bombalai family. The sub-families are differentiated.
Qn Myn Te J	For the Table family. Mostyn (Myn) is localised. The other 3 are differentiated where possible or mapped as a complex of any two of them.
Tu	For the Tingkayu family.
Kg Mi Mi-Kg	For the Kalumpang family. Where possible sub-families are differentiated, where not they are mapped as a complex.
Kan A A-Kan	For the Kinabutan family. Where possible the sub-families are differentiated, where not they are mapped as a complex.
Q-A-Kan Q-G	The Quarry family mapped as a complex with either the Kinabutan or Gading families.
B-St	For the Sipit family. Always mapped as a complex. The Garam is very localised and has not a symbol.

Kn K M	The Kawa family is mapped as sub-families where possible
G	Gading family undifferentiated
Kta	Kubota " "
Sa	Semporna " "
L	Limau " "
La	Lucia " "
S	Sapang " "
Bg	Balung " "
T	Tanjong " "

In the actual mapping there are three difficulties to be taken into account.

1. The unevenness of the ground cover, for instance, the areas derived from Quaternary basaltic lavas received much more attention than the lower valley of the Kalumpang or the mountainous area of the upper Binuang.

2. The gaps in the photography and the cloud cover on the aerial photographs made it extremely difficult to maintain the same degree of differentiation over the whole region. The worst obscured area for this is the Cook and Pock mountain areas and it is made even worse by occurring at the junction of four map sheets. During the survey it was difficult to locate oneself with any accuracy in this area.

3. There was great difficulty in laying down a boundary to differentiate certain families by making use of the aerial photographs. There is no topographic break between the Besar and Conner families and hence differentiation is not possible at the present time. In the case of the Kawa family it is impossible to differentiate it from the Gading soils as there is no break on the platform visible on the aerial photographs. Their occurrence has been symbolised where possible.

In using the maps the extent of these three difficulties must be kept in mind, for as more clearings are made and better maps prepared the necessary differentiation and increased accuracy can be achieved.

SOIL DESCRIPTIONS

Soils Developed on Hills and Mountains

(a) ***Pre-upper Eocene parent materials*** - The COOK family, including the BINUANG, MADAI and COOK sub-families.

All the soils in this division are developed on slopes in excess of 30° and they are, for the most part, skeletal. There is a wide variety of soils depending on the composition of the parent material. As a result of the present reconnaissance it has been possible to map the COOK family but not the sub-families. The region is complex and the number of sub-families is not exhaustive though the main ones are differentiated.

(i) **THE BINUANG SUB-FAMILY**, consists of skeletal brown earths, developed on serpentine. Merutai-Binuang profile 1, at 560 chains north on the Tingkayu rentis, on a 30° slope, under high primary forest, is typical

3549	0 - 6"	Dark greyish brown 10 YR 4/2*; sandy loam; moderate, fine to medium sub-angular blocky; hard (brittle), non-sticky; much weathering serpentine; many roots merging to
3550	6 - 24"	Brown, 10 YR 4/3; clay; interstitial to serpentine.

(For analyses see I). *All soil colours are recorded in the moist state.

(ii) **THE MADAI SUB-FAMILY**, consists of shallow red soils, developed from resistant limestones. It is found as pockets in depressions due to karst type weathering of the limestone. The site of the type profile, Mostyn number 32, is almost flat, perhaps an acre in extent, surrounded by perpendicular limestone cliffs 50 to 100 feet high. The forest is primary but of a very stunted nature.

1183	0 - 3"	Dark reddish brown, 5 YR 3/3; clay loam; moderate, medium sub-angular to angular blocky; too wet for consistence, slightly sticky; roots common; merging to
1184	3 - 12"	Reddish brown, 5 YR 4/4; clay; poor to moderate, medium to large sub-angular blocky; too wet for consistence, slightly sticky; roots common; merging to
1185	12 - 24"	Reddish brown, 5 YR 4/4; clay; poor to moderate, medium to large (massive) sub-angular blocky; too wet for consistence, slightly sticky; many large, fresh limestone boulders; few roots. Lies abruptly on fresh limestone.

(For analyses see II).

(iii) **THE COOK SUB-FAMILY**, consists of light coloured yellowish-brown to reddish-yellow soils, developed from interbedded sandstones and shales. The dominant soil is one derived from sandstone though soils derived from shales do occur. The type profile is located mid-way down a long 30° slope, under primary forest, at 1600 chains on the Tingkayu rentis. It is Merutai-Binuang Profile 14.

3602	0 - 6"	Very pale brown, 10 YR 7/4; loam; moderate, fine to medium sub-angular blocky; friable, non-sticky; weathering sandstone; slightly mottled and gleyed; roots common; merging to
3603	6 - 24"	Yellow, 10 YR 7/6; sandy clay loam; interstitial to weathering sandstone; merging to
3604	24 - 36"	Slightly variecoloured, otherwise same as above.
3605	36 - 48"	Same as above.
3606	48 - 72"	Same as above.

(For analyses see III).

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(b) *Miocene materials* - the MALATAI family, including the HEWETT the MANKOK and MALATAI sub-families.

All the soils in this division are developed on slopes in excess of 30° and they are, for the most part skeletal. There is a wide variety of soil depending on the type of parent material.

(i) **THE HEWETT SUB-FAMILY**, consist of skeletal brown earths derived from a Miocene andesitic agglomerate. The type profile is taken from just below Macpherson peak, south of mile 20 on the Baturong road, at a height of 1,300 feet, under high primary forest, on a slope of 32°.

1789	0 - 3"	Dark brown, 7.5 YR 3/2; loam; moderate to strong, medium sub-angular blocky; friable non-sticky; many roots; some rocks; merging to
1790	3 - 12"	Brown, 10 YR 5/3; clay loam; moderate, medium sub-angular blocky; sticky; abundant angular pebbles of green volcanic agglomerate; some roots, abrupt and undulating to
1791	12 - 24"	Brown, 10 YR 5/3; clay; poor, moderate to large sub-angular blocky; firm, sticky; some weathered rocks; roots common; merging to
1792	24 - 30"	Brown, 10 YR 5/3; sandy clay loam; intersticial to weathering rock.

(For analyses see IV).

(ii) **THE MANKOK SUB-FAMILY**, are skeletal yellowish brown soils derived from a Miocene rhyolitic tuff. A typical profile is located on the precipitous (30°+) southern slope of the hill in the Darvel Tobacco Plantations area north of the Kalumpang

0 - 2"	Dark brown, 7.5 YR 3/2; sandy loam; moderate, medium, sub-angular blocky; friable, sticky; stones common; roots common; merging to
2 - 12"	Yellowish brown, 10 YR 5/4; sandy loam; weak to moderate, medium sub-angular to angular blocky; friable, non-sticky, many rocks; few roots; merging to
12 - 18"	Yellowish brown, 10 YR 5/4; sand to sandy loam; too wet for structure or consistence, non-sticky; much weathering parent material; few roots; merging to
18 - 60"	Weathering rhyolitic tuff.

There are no analyses available for this profile. (see plate 11).

(iii) **THE MALATAI SUB-FAMILY** are yellowish brown skeletal soils derived from Miocene sandstones and shales. As in the Eocene materials sandstones are dominant and a typical profile can be found on the southern flank of Forbes hill in the Kalumpang valley. The slope at the site is about 30° and is under high primary jungle.

1230	0 - 1"	Dark brown, 10 YR 3/3; silty loam; granular; friable, non-sticky; many roots; abrupt and undulating to
1231	1 - 10"	Yellowish brown, 10 YR 5/4; sandy clay; moderate, friable, non-sticky; medium sub-angular blocky; many roots; merging to
1232	10 - 24"	Light yellowish brown, 10 YR 6/4; sandy clay; weak, large, angular blocky; slightly massive, but very porous and friable; some roots; merging to
1233	24 - 36"	Weathering sandstone.

There are no analyses available for this profile.

(c) *Early Pliocene Parent Materials* - the BESAR family - including the TINAGAT, BESAR and SINON sub-families.

(i) **THE TINAGAT SUB-FAMILY**, are skeletal soils of brown or reddish brown colour, derived from intermediate to basic volcanic agglomerates. An example of each of the two main types will be given. The first is a reddish brown soil derived from a red tuff, from the summit of Mt. Siagil at a height of 1950 feet, on a 35° slope, under high primary jungle.

1796	0 - 12"	Reddish brown 2.5 YR 4/4; loam; moderate, medium to large sub-angular blocky; hard, non-sticky; weathering tuff common; many roots; abruptly
	12"+	Red tuff.

(For analyses see V.).

The second is derived from a basic volcanic agglomerate from the highest point of Menampili island with 20-30° slopes on either side. When the profile was described and sampled, in 1958, it had been cleared and planted to cassava, previously it was under dense *Eupatorium*.

1677	0 - 6"	Brown to dark brown, 7.5 YR 4/2; clay loam; strong, medium to large sub-angular blocky; very hard; many roots; merging to
1678	6 - 12"	Same as above but interstiCial to weathering agglomerate.

(For analyses see VI).

(ii) **THE BESAR SUB-FAMILY** differ in some cases from the other mountain soils. They are derived from intrusive dolerite and sometimes give rise to profiles very similar to those of the Tinagat soils but within the main mountainous regions are some more gently sloping areas associated with the occurrence of these intrusive dolerites. A typical example of such an area is that found on the saddle between the Mantri and Balung valleys. The slope at the pit site is 10° overlooking 30° slopes and under high primary jungle

1749	0 - 4"	Pale brown, 10 YR 6/3; silt loam; moderate, medium sub-angular blocky; friable, sticky; many roots; merging to
1750	4 - 15"	Light yellowish brown, 10 YR 6/4; silty clay loam, moderate, medium sub-angular blocky; sticky; roots; merging to
1751	15 - 60"	Varicoloured in red (10 R 5/8), reddish yellow (5 YR 6/8) and light yellowish brown (2.5 Y 6/4); clay; moderate to strong, medium sub-angular blocky; friable, sticky; weathering dolerite; some roots; merging to
1752	60 - 72"	Dolerite weathering in neutral light grey (7/0), yellow (10 YR 8/8) and strong brown (7.5 YR 5/6).

(For analyses see VII).

(iii) **SINON SUB-FAMILY** are skeletal brown soils derived from intermediate intrusive rocks. On the higher parts of the hills formed from these rocks the soil is apparently non-existent. The trees root in among the boulders where a little soil material must occur. The type profile is located on Grassy Point on the south coast of Timbun Mata island. It is on a 25° slope, under a secondary growth of grass and was formerly cleared for dry padi.

1793	9 - 4"	Very dark greyish brown, 10 YR 3/2; loam; poor (massive large, sub-angular blocky; hard, non-sticky; many grass roots; merging to
1794	4 - 12"	Dark greyish brown, 10 YR 4/2; clay loam; poor (massive), large sub-angular blocky; hard (big cracks between peds); many felspars and hornblendes embedded in the peds; grass roots, many fungal mycelia, much humus staining on peds; merging to
1795	12 - 24"	Deeply weathered hornblende diorite, with humus staining extending along the common cracks.

(For analyses see VIII).

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(d) *Late Pliocene Parent Materials*, - the TAJONG family, including the TAJONG, WULLERSDORG and MARIA sub-families.

All the soils in this division are developed on steep slopes mostly of about 30°. There is a wide variety of soil depending on the type of parent material.

(i) **TAJONG SUB-FAMILY**, derived from late Pliocene andesitic ashes. A typical profile comes from south-western flanks of Mt. Pock on a 25°-30° slope under high primary jungle.

1968	0 - 6"	Dark greyish brown 10 YR 4/2; sandy loam; moderate, medium sub-angular blocky; friable, slightly sticky; weathering rocks; roots; merging to
1969	6 - 12"	Weathering andesitic ash dominant in light yellowish brown, (10 YR 6/4)
1970-1972	12 - 72"	Same as above.

(For analyses see IX).

(ii) **WULLERSDORF SUB-FAMILY**, derived from rhyolitic lavas. A typical profile is found on the extremely localised flat summit of Mt. Wullersdorg surrounded by precipitous slopes at least 500 feet high. The elevation is just over 2,400 feet and the vegetation is "mossy" forest.

1739	9 - 0"	Dark reddish brown, 2.5 YR 3/4; organis matter, with abundant roots and fungal mycelia abruptly to
1740	0 - 9"	Pale brown, 10 YR 6/3; silt loam; poor (massive) structure; sticky; no roots; merging to
1741	9 - 15"	Weathered rhyolite, mainly in brownish yellow (10 YR 6/6) but also mottled (red) and gleyed (grey).

(For analyses see X).

(iii) **THE MARIA SUB-FAMILY** derived from dacitic lavas and ashes which contain numerous porphyritic crystals of biotite and quartz. The upper slopes of Mt. Maria are being so actively eroded that there is virtually no soil development. A typical profile has been selected from the south western flanks where the slope is 20-25° under high primary jungle

1614	0 - 6"	Mixture of dark brown (7.5 YR 3/2) and brown (7.5 YR 5/4); clay loam; moderate, medium to large sub-angular blocky; sticky; abundant quartz crystals and some weathering porphyry; many roots; merging to
1615	6 - 18"	Brown 7.5 YR 5/4; clay loam; moderate, medium to large sub-angular blocky; sticky; slightly mottled and gleyed; quartz and biotite crystals as well as weathering porphyry occur; some roots; merging to
1616	18 - 36"	Same as above but weathering porphyry increasing
1617	36 - 72"	Same as above

(For analyses see XI).

(e) *Quaternary Parent Materials* - the BOMBALAI family including the BOMBALAI and TIGER sub-families.

These soils are developed on slopes in the region of 30°, derived from Quaternary basaltic lavas.

(i) **THE BOMBALAI SUB-FAMILY**, consists of skeletal brown soils derived from a dark grey vesicular basalt. The type profile has been located on the crater lip of the Bombalai cone at a height of 1,700 feet, with a 30° slope to the south, under primary forest with a good leaf litter.

944	0 - 4"	Dark brown, 7.5 YR 3/2; sandy loam; moderate, medium sub-angular to angular blocky and crumb; friable, non-sticky; many quartz fragments and pebbles of vesicular basalt; roots common; worms occur; merging to

945	4 - 9"	Dark brown to brown, 7.5 YR 4/4; clay loam; moderate, medium sub-angular to angular blocky and crumb; friable, slightly sticky; many quartz fragments and pebbles; roots less common, ants occur; merging to
946	9 - 15"	Dark brown to brown, 7.5 YR 4/4; sandy clay loam; moderate, medium sub-angular to angular blocky; friable, slightly sticky; weathering basalt dominant; roots die out; merging to

Weathering parent material.

(For analyses see XII).

(ii) THE TIGER SUB-FAMILY, consists of skeletal red soils, developed from a purple vesicular basalt. The type profile is taken from the northern lip of the Quoin hill crater, it occurs on a 35° slope to the north under good primary forest.

1086	0 - 6"	Dusky red, 10 R 3/4; sandy loam; strong, medium angular blocky; friable, non-sticky; many quartz fragments, some pebbles; merging to
1087	6 - 18"	Weak red, 10 R 4/4; clay loam; moderate to strong, medium angular blocky; friable to firm, slightly sticky; many quartz fragments, more pebbles; roots common; merging to
1088	18"+	Red, 10 R 4/6; sandy loam; interstitial to weathering basalt.

(For analyses see XIII).

Soils Developed on High Level Plateaux

There is only one suite of parent materials, Quaternary basalts, which give rise to the TABLE family of soils; this includes the JARANGAN, TABLE, QUOIN and MOSTYN sub-families. The soils throughout are developed on flat to gently undulating topography and are distinguished from the other soils in the Semporna peninsula by having an extremely strong structure. The soil mass is extremely porous and almost "fluffy", on gently breaking a mass of soil it breaks, first of all, into sub-angular or angular blocky peds (all of which are extremely porous); when the pressure on the peds is increased slightly the whole mass falls into fine strongly developed crumbs.

(i) THE JARANGAN SUB-FAMILY consists of deep, uniform yellow brown soils developed from the oldest of the Quaternary basalts erupted from the Table-Tiger and Quoin centres. The type profile is taken from the area between Kawa and Quoin hill in the present day headwaters of the Jarangan river on a slope of 10° under high primary jungle.

1037	0 - 6"	Yellowish brown, 10 YR 5/4; clay; moderate, medium to large sub-angular blocky and strong; fine crumbs; friable, non-sticky; many quartz fragments; many roots; merging to
1038	6 - 21"	Yellowish brown, 10 YR 5/6; clay; moderate to strong, medium sub-angular to angular blocky and strong, fine crumb; friable, non-sticky; many quartz fragments; roots common; merging to
1039	21 - 36"	Transitional horizon
1040	36 - 72"	Strong brown, 7.5 YR 5/6; clay; moderate to strong, medium, angular blocky and strong, fine crumb; friable, non-sticky; many quartz fragments; fine roots.

(For analyses see XIV).

(ii) THE TABLE SUB-FAMILY, consists of deep (17 feet +), uniform, dark brown soils developed on the main Quaternary lava flows erupted from the Table-Tiger and Quoin centres. The type profile is located in the northern forested area of Table estate near the ridge which connects Table and Bombalai hills, there is a slope of 5° at the site and it is under high primary forest.

959 0 - 4" Dark brown 7.5 YR 3/2; clay loam, moderate, medium subangular blocky and strong, fine crumb; very friable non-sticky; quartz fragments; roots common; merging to

960 4 - 15" Dark brown to brown, 7.5 YR 4/3; clay; moderate to strong, medium angular blocky and strong, fine crumb; friable (brittle), slightly sticky; quartz fragments; few roots; merging to

961 15 - 33" Dark brown to brown, 7.5 YR 4/3; clay; weak to moderate, medium angular blocky and strong, fine crumb; very friable (brittle), slightly sticky; quartz fragments; few roots; merging to

962 33 - 72" Dark brown to brown, 7.5 YR 4/4; clay; weak to moderate, medium angular blocky and strong, fine crumbs; friable, slightly sticky; quartz fragments; few roots.

(For analyses see XV).

(iii) THE QUOIN SUB-FAMILY, consists of deep, uniform reddish soils developed on the most recent of the Quaternary basalts erupted from the Table-Tiger and Quoin hill centres. A type profile has been taken from about a mile south of Quoin hill on a slope of 2° under an exceptionally good growth of primary forest. It was impossible to differentiate horizons below a thin surface soil.

1073 0 - 2" Dark brown to brown, 7.5 YR 4/3; clay; moderate to strong, fine to medium angular blocky and strong, fine crumb; friable, slightly sticky; quartz fragments; roots common; merging to

1074 2 - 72" Reddish brown, 5 YR 4/3; clay; moderate, medium subangular to angular blocky and strong, fine crumb; friable to firm, slightly sticky, quartz fragments; fine roots.

(For analyses see XVI).

(iv) THE MOSTYN SUB-FAMILY, differs from the rest of the Table family due to the fact that these soils are derived from a basalt which has been erupted from a fissure onto a very dissected landscape. This has restricted the depth of weathering and a bouldery dark brown soil has resulted. The type profile has been taken on a level site 3 miles inland from Kunak wharf at Mostyn, near to the Kalumpang-Mostyn road junction under thinned primary jungle.

1666 0 - 3" Dark brown, 7.5 YR 3/2; clay; strong, medium, granular; friable, slightly sticky; numerous roots; merging to

1667 3 - 14" Dark reddish brown, 5 YR 3/4; clay; strong, medium subangular to angular blocky and strong, fine crumb; friable, slightly sticky; small manganese nodules common; some roots; merging to

1668 14 - 32" Dark brown to dark reddish brown, 7.5 YR - 5 YR 3/3; clay; strong, medium angular blocky and strong, fine crumbs; friable (brittle), slightly sticky; roots very few; merging to

1669 32 - 60" Same as above but with occasional large boulders of vesicular basalt.

(For analyses see XVII). (see plates 10 and 11).

Soils Developed on Ridge Country

The soils of this division are developed on slopes of up to 30°. The length of these slopes, however, is never so great or continuous as those which make up the mountains.

(a) *Pre-Upper Eocene parent materials* - the TINGKAYU family only one sub-family, of the same name, has been differentiated in this reconnaissance survey.

(i) THE TINGKAYU SUB-FAMILY consists of soils derived from serpentinised ultrabasics (analogous to the Binuang sub-family of mountain soils). The type profile is taken from 2 miles south-east of the Kalumpang-Mostyn road junction.

In this area, between the Sapang river and Kunak road, a very fine-scale stream dissection has affected what was originally a small upraised plateau. Streams are now about a quarter of a mile apart and the valleys are about 200 feet deep. There is very little if any of the original plateau surface left and the whole area is cut up into short and severe slopes. The type profile occurs on a restricted ridge top under primary forest.

1870	0 - 3"	Brown 10 YR 5/3; clay loam; moderate, medium sub-angular blocky; hard, sticky; many fungal mycelia, roots common; merging to
1871	3 - 8"	Yellowish brown, 10 YR 5/4; clay loam; moderate to strong, medium sub-angular blocky; hard (brittle), sticky; weathering rock; roots occur; merging to
1872	8 - 15"	Page brown, 10 YR 6/3; clay; sticky; interstitial to weathering rock.

(For analyses see XVIII).

(b) *Miocene Parent Materials* - consists of the KALUMPANG family which includes the MANTRI and KALUMPANG sub-families.

All these soils are rather shallow and yellowish brown. They are developed on short steep slopes typical of the ridge country.

(i) **THE MANTRI SUB-FAMILY**, is derived from Miocene ashes and agglomerates (analogous to the Hewett sub-family). The type profile is located between Mt. Sangster and the Mantri river, on a 15^{o} slope, under high primary forest.

1276	0 - 1"	Dark brown, 7.5 YR 3/3; clay loam; granular; very friable, non-sticky; many roots; merging to
1277	1 - 4"	Dark yellowish brown, 10 YR 4/4; silty clay loam; moderate, medium sub-angular blocky; firm, slightly sticky; many roots; merging to
1278	4 - 12"	Yellowish brown, 10 YR 5/4; clay loam; strong, medium sub-angular blocky and granular; very friable, slightly sticky; fragments of parent material; many roots; merging to
1279	12 - 36"	Weathering ash.

(For analyses see XIX).

(ii) **THE KALUMPANG SUB-FAMILY** is derived from Miocene sandstones and shales, which may be contaminated with volcanic ashes which are not visible in the parent materials (analogous to the Malatai sub-family). The type profile is taken from the same area and the same general topographic position as the previous profile.

1361	0 - 3"	Dark brown, 7.5 YR 3/4; silt loam; moderate, medium sub-angular blocky; friable, non-sticky; root mat; merging to
1362	3 - 10"	Brown to dark brown, 10 YR 4/3; silty clay loam; moderate, medium, sub-angular blocky; friable, slightly sticky; roots common; merging to
1363	10 - 20"	Dark yellowish brown, 10 YR 4/4; silty clay loam; moderate, medium sub-angular blocky and strong, fine crumbs, friable, non-sticky; some fragments of weathering parent material; roots occur; merging to
1364	20 - 30"	Yellowish brown, 10 YR 5/4; silty loam; moderate, medium sub-angular to angular blocky; friable, non-sticky; many fragments of parent material; roots few; merging to
1365	30 - 72"	Weathering parent material.

(For analyses see XX). (see plate 9).

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(c) *Early Pliocene Parent Marerials* consists of the CONNER family, which includes the CONNER and SANGSTER sub-families.

These soils are rather shallow brown or reddish brown soils developed on the 10-20° slopes.

(i) **THE CONNER SUB-FAMILY**, consists of shallow brownish soils derived from early Pliocene agglomerates (analogous to the Tinagat sub-family). A typical profile is that on the eastern face of Bakong hill south of Semporna, on a slope of 15° under a dense cover of *Eupatorium*, on what was formerly dry padi land.

1694	0 - 4"	Dark brown, 7.5 YR 3/2; loam; moderate to strong, medium sub-angular blocky; friable, slightly sticky; some weathering rocks; roots common; merging to
1695	4 - 12"	Dark brown to brown, 7.5 YR 4/2; clay loam; moderate, medium sub-angular blocky; slightly sticky; much weathering agglomerate, merging to
1696	12 - 24"	Dark greyish brown, 10 YR 4/2; otherwise it is the same as above.

There are no analyses available. (see plates 12 and 13).

(ii) **THE SANGSTER SUB-FAMILY**, consists of shallow reddish soils derived from early Pliocene intermediate intrusives. The type profile is taken from the lower southern slopes of Mt. Sangster, on a 15° slope under high primary jungle.

1426	0 - 6"	Reddish yellow 7.5 YR 6/6; silty clay loam; moderate, medium sub-angular blocky; friable, slightly sticky; roots common; merging to
1427	6 - 15"	Yellowish red, 5 YR 5/8; clay; strong, medium sub-angular to angular blocky; hard, sticky; root occur; merging to
1428	15 - 30"	Red, 2.5 YR 5/6; clay; strong, medium sub-angular to angular blocky; sticky; few roots
		Abruptly onto boulders of diorite.

There are no analyses available.

(d) *Late Pliocene Parent Materials* - the KINABUTAN family which includes the KINABUTAN and APAS sub-families.

All the soils within this family are developed on 15-25° slopes and the weathered profiles are much deeper than the previously described soils with the exception of the Table family of soils. They do not however have quite such a good structure as the Table soils.

(i) **THE KINABUTAN SUB-FAMILY**, consist of a deep, uniform, yellowish red soil derived from andesitic ashes. The type profile is located about 2 miles north-east of White Bridge on the Tawau river, on a 20° slope, under primary jungle

1626	0 - 6"	Reddish yellow, 7.5 YR 6/6; silty clay loam; moderate, fine to medium sub-angular blocky; friable, sticky; no quartz; many roots; merging to
1627	6 - 18"	Reddish yellow, 7.5 YR 6/8; clay; moderate, medium sub-angular to angular blocky; firm, sticky; no quartz; some roots; merging to
1628	18 - 36"	Reddish yellow, 5 YR 6/8; clay; strong; fine to medium sub-angular to angular blocky; firm, sticky; no quartz; some roots; merging to
1629	36 - 72"	Same as above but andesitic ash increasing

(For analyses see XXI).

(ii) **THE APAS SUB-FAMILY** consist of deep, yellowish red soils derived from dacite ash. The type profile is located on a gently rolling ridge top at mile 19 on the Tawau-Quoin hill road under high primary forest.

1447	0 - 5"	Yellowish red 5 YR 4/6; clay; moderate, medium, sub-angular blocky; friable; slightly sticky; some quartz fragments and small ironstone concretions; many roots; merging to
1448	5 - 18"	Red 2.5 YR 4/6; clay; moderate to strong, medium sub-angular to angular blocky; friable, sticky; some ironstone concretions; roots common; merging to
1449	18 - 32"	Red, 2.5 YR 4/6; clay; interstical to ironstone nodules; too wet for structure; sticky; many quartz fragments; few roots, merging to
1450	32 - 46"	Same as above but with gleying around the ironstone nodules.
1451	46 - 72"	Red, 10 R 4/6 with occasional prominent medium gleys of light yellowish brown 2.5 Y 6/4; clay; too wet for structure; sticky; many small ironstone concretions, many quartz fragments; few roots.

(For analyses see XXII).

(e) *Pliocene-Quaternary Parent Materials* - the QUARRY family of which there is only one sub-family of the same name.

The parent material is ill-graded mud-flow deposits derived from the late Pliocene andesitic and dacitic lavas and ashes. It gives rise to a shallow brownish soil. The type profile is taken from Imam estate of Borneo Abaca Limited, a level site on a ridge top under young rubber.

1458	0 - 4"	Dark grey brown 10 YR 4/2; clay loam; moderate to strong, medium sub-angular to angular blocky; friable, slightly sticky; some quartz fragments; roots common; merging to
1459	4 - 12"	Brown, 10 YR 5/3; clay loam; moderate medium sub-angular to angular blocky; friable, slightly sticky; weathering parent material; many worm channels; some roots; abrupt and undulating to
1460	12 - 60"	Level bedded, light yellowish brown ash.

(For analyses see XXIII). (see plate 14).

Soils Developed on the Erosional Coastal Platform

(a) *Miocene Parent Materials*, the SIPIT family which consists of the BURONG, GARAM and SIPIT sub-families. They consist of shallow to moderately deep soils of a yellowish brown colour

(i) **THE BURONG SUB-FAMILY** is derived from bedded andesitic ashes. The type profile is located two miles south of the Sipit river, on the gently undulating coastal platform under good primary forest.

1817	0 - 3"	Brown, 10 YR 5/3; loam; moderate to strong, medium sub-angular blocky; friable, non-sticky; many roots; merging to
1818	3 - 7"	Light yellowish brown; clay loam; moderate, medium sub-angular blocky; hard, sticky; some mottling and gleying; manganese nodules; some roots; merging to
1819	7 - 18"	Yellow, 10 YR 7/6; clay loam; moderate, medium, sub-angular to angular blocky; firm, sticky; numerous manganese nodules and weathering ash; few roots; merging to
1820	18 - 39"	Weathering ash with much manganese staining; abruptly onto
1821	30 - 54"	Deeply weathered mudstone underlying the andesite

(For analyses see XXIV).

(065087)

(ii) THE GARAM SUB-FAMILY, is derived from rhyolitic tuffs. The type profile is situated 1 mile to the south west of Mostyn estate to the south of the dam. On a level site which projects slightly above the basalt flows, under thinned primary forest.

1770	0 - 4"	Light yellowish brown, 10 YR 6/4; clay; moderate to poor, medium sub-angular blocky; hard, sticky; roots occur; merging to
1771	4 - 12"	Reddish yellow, 7.5 YR 6/6; clay; moderate, medium sub-angular blocky; hard, sticky; roots occur; merging to
1772	12 - 24"	Reddish yellow, 5 YR 6/8; clay; moderate, medium sub-angular to angular blocky; firm, sticky; merging to
1773	24 - 48"	Light red, 2.5 YR 6/8; clay; moderate to strong, medium sub-angular to angular blocky; friable, sticky; weathering rhyolite; merging to
1774	48 - 72"	Weathering rhyolitic tuff.

(For analyses see XXV).

(iii) THE SIPIT SUB-FAMILY, is derived from interbedded sandstones and shales. The soils are generally deeper than the other members of this family. The type profile is located on the coastal platform on the south side of the Sipit river towards Mt. Siagil, under high primary forest.

1803	0 - 14"	Reddish yellow, 7.5 YR 6/6; silty clay loam; moderate, medium sub-angular blocky; friable, sticky; roots common; merging to
1804	14 - 25"	Reddish yellow, 5 YR 6/8; clay; moderate, medium sub-angular to angular blocky; firm, sticky; abundant ironstone nodules; faintly varicoloured; some roots; merging to
1805	25 - 43"	Same as above but varicoloured in yellow (10 YR 7/6) with no nodules; merging to
1806	43 - 61"	Varicoloured in red, 10 R 4/6 and yellow, 10 YR 7/6; clay; moderate, medium sub-angular to angular blocky; firm, sticky; no roots; merging to
1807	61 - 72"	Strongly varicoloured in red, 10 R 4/6 and pale yellow, 5 Y 7/3; clay; moderate, medium angular blocky; hard, sticky; no roots.

(For analyses see XXVI). (see plate 8).

(b) *Early Pliocene Parent Materials* - the KAWA family which includes the MEMBALUA, KAWA and KUKUSAN sub-families.

All the soils of this family are shallow and form a very restricted margin to some of the hills which carry soils of the Besar family.

(i) THE MEMBALUA SUB-FAMILY consists of shallow reddish soils derived from intermediate and basic ashes, lavas and agglomerates. The type profile is taken from near the coast road on the east side of Tinagat head. There is a general slope of 3°. At the time of sampling the area had been cleared prior to planting maize.

1439	0 - 4"	Dark brown, 7.5 YR 3/2; clay loam; moderate, medium sub-angular blocky; hard, slightly sticky; quartz fragments; many roots; merging to
1440	4 - 8"	Brown to dark brown, 7.5 YR 4/4; sandy clay loam; weak to moderate, fine to medium subangular blocky; hard, sticky; abundant, small iron and manganese concretions; quartz fragments common; roots rommon; abrupt and undulating to

1441	8 - 16"	Varicoloured in red, 2.5 YR 4/6, and greyish brown 10 YR 5/2; clay; moderate, medium sub-angular blocky; hard, sticky; concretions of iron larger and more common; quartz less common; roots few; merging to
1442	16 - 32"	Varicoloured in strong brown, 7.5 YR 5/6 and yellowish brown, 10 YR 5/4; clay; strong, large angular blocky; hard, sticky; abundant large iron nodules; ped surfaces are glazed; few roots; merging to
1443	32"+	Pale brown, 10 YR 6/3; clay; moderate, medium sub-angular blocky; firm, slightly sticky; much weathering andesitic ash.

(For analyses see XXVII).

(ii) <u>THE KAWA SUB-FAMILY,</u> is derived from doleritic intrusive rocks. The type profile is located on the small platform on the south side of Kawa hill which is being actively eroded into by streams. It is under high primary jungle.

1061	0 - 6"	Reddish brown, 5 YR 4/4; clay loam; moderate to strong, medium to large sub-angular blocky and strong, fine crumb; friable, slightly sticky; quartz fragments, many boulders; many roots; merging to
1062	6 - 12"	Reddish brown, 5 YR 4/4; clay; moderate, medium sub-angular blocky and strong, fine crumb; too wet for consistence; slightly sticky; quartz fragments and numerous dolerite boulders; some roots.

Digging stopped at 12" due to rocks.

(For analyses see XXVIII).

(iii) *The Kukusan sub-family* is derived from intermediate intrusive rocks. It has been observed on Tawau aerodrome but not described.

<u>Soils Developed on the Depositional Coastal Platform</u>

(a) *Late Pliocene Parent Material*, the GADING family which includes the IMAM and GADING sub-families. Three elements can be recognised in these profiles, a rather sandy, poorly structured, sometimes massive, topsoil; a stone line and/or a zone of concretions; a sub-soil which is very much heavier and strongly varicoloured.

(i) <u>THE IMAM SUB-FAMILY</u> is developed from late Pliocene ashes laid down at or near sea level and subsequently upraised about 100 feet. The colours in this sub-family are rather pale. The type profile is taken from Merutai Kechil estate near the junction with the road to Tiger estate. It is a level site under mature rubber.

1512	0 - 3"	Yellowish brown 10 YR 5/4; clay loam; moderate, medium sub-angular blocky; friable, slightly sticky; slight surface mottling and gleying; root mat; merging to
1513	3 - 15"	Light yellowish brown, 10 YR 6/4; clay loam; moderate, medium sub-angular blocky; firm, sticky; faintly varicoloured; roots occur; merging to
1514	15 - 42"	Light yellowish brown, 2.5 Y 6/4 and reddish yellow 5YR 6/8; clay; moderate to strong, medium sub-angular to angular blocky; firm, sticky; gravel and quartz pebbles; very few roots; merging to
1515	42 - 60"	Red, 2.5 YR 4/6 and light grey, 7/0; clay; moderate, medium to large sub-angular to angular blocky; very firm, sticky; iron concretions and gravel common, no roots.

(For analyses see XXIX).

(ii) <u>THE GADING SUB-FAMILY,</u> is developed in the same type of materials as the Imam family but is rather stronger coloured. The type profile is taken from 1½ miles west of Balung estate on a slope of 2-3° under primary forest.

(065087)

1022	0 - 4"	Dark yellowish brown, 10 YR 5/4; loam; weak, medium sub-angular blocky; friable to firm, non-sticky; roots common; merging to
1023	4 - 25"	Yellowish brown, 10 YR 5/4; loam; weak, medium sub-angular to angular blocky; very friable, slightly sticky; some iron concretions; some roots; merging to
1024	25 - 37"	Brown 7.5 YR 5/4; sandy clay loam; weak to moderate, medium sub-angular blocky; very friable, slightly sticky; many stones and iron concretions; merging to
1025	37 - 48"	Red, 10 R 5/8 forming a network in a body colour of yellowish brown, 10 YR 5/4; clay; moderate, medium angular blocky; friable, slightly sticky; some iron concretions; some roots; merging to
1026	48 - 72"	Very strongly varicoloured in dark red through yellowish brown to grey; clay; strong, medium angular blocky; sticky; no roots.

(For analyses see XXX)

(b) *Late Pliocene-Quaternary Parent Materials* ? - the KUBOTA family is found sporadically throughout the areas of Gading soils and in one case with Sipit soils. The soil consists of coarse angular quartz sand throughout and is probably a beach deposit. It has probably been much altered by the "kerangas" vegetation, which is peculiar to it. The type profile is taken from mile 16 on the Apas road, near the Apas river, on a level but elevated site under "kerangas" vegetation. (Coastal Padang Forest).

1452	0 - 5"	Humus stained quartz sand; interstitial to the root mat; merging to
1453	5 - 22"	White quartz sand, no structure; no roots; abrupt and undulating boundary to
1454	22 - 31"	Cemented white quartz sand; massive and structureless; merging to
1455	31 - 41"	Very dark brown, 10 YR 2/2; quartz sand; cemented, massive and structureless; merging to
1456	41 - 54"	Brown, 10 YR 5/3; sandy clay; structureless, sticky; much angular quartz; merging to
1457	54 - 72"	Grey brown, 2.5 Y 5/2; sandy clay; structureless, sticky; much angular quartz.

(There are no analyses available).

Soils Developed on the Coral Platform

(a) *Late-Pliocene Quaternary Materials*, the SEMPORNA family, which consists of the SEMPORNA and BUM-BUM sub-families. They are both developed on coral limestone and are differentiated only on the depth to solid parent material.

(i) THE SEMPORNA SUB-FAMILY, is the deeper type of soil. The type profile is located half a mile west of Semporna on a flat site under mature coconuts and bananas.

1713	0 - 3"	Very dark greyish brown 10 YR 3/2; clay; strong, medium to large sub-angular blocky; hard, sticky; abundant roots; merging to
1714	3 - 12"	Brown to light olive brown, 10 YR - 2.5 Y 5/3; clay; strong, large sub-angular to angular blocky; hard, sticky; fewer roots; merging to
1715	12 - 18"	Light yellowish brown, 10 YR - 2.5 Y 6/4; clay; moderate, medium sub-angular blocky; sticky; much coral limestone; few roots; merging to
1716	18 - 54"	Light yellowish brown, 2.5 Y 6/4; clay; interstitial to coral limestone.

(For analyses see XXXI). (see plate 15).

(ii) **THE BUM-BUM SUB-FAMILY** consists of shallow soils on coral limestone. The type profile is located ¼ of a mile inland from Tando Bulan on Bum-Bum island. It is a flat site under poor primary forest.

1711	0 - 3"	Brown to dark brown, 10 YR 4/3; clay; strong, fine to medium sub-angular blocky; friable, non-sticky; interstitial to root mat and coral limestone boulders; merging to
1712	3 - 6"	Brown 10 YR 5/3; same as above but fewer roots and more limestone

On solid coral limestone.

(There are no analyses available).

Soils Developed on "Lake Bed" Sediments

(a) *Derived from Quaternary Parent Materials* - the LIMAU and LUCIA families. They are differentiated on a basis of the source of their parent materials. The first being older than Miocene and the second Pliocene and Quaternary.

THE LIMAU FAMILY - with further work this family could be split into badly and well drained soils. Due to weather conditions it was only possible to sample the well drained soils. The type profile is located about 2 miles south east of Baturong hills, on gently rolling topography with streams incised below the general level, under primary jungle.

1784	0 - 3"	Yellowish brown, 10 YR 5/6; loam; moderate, medium sub-angular blocky; friable to firm, non-sticky; many roots; merging to
1785	3 - 12"	Reddish yellow, 7.5 YR 6/6; silty clay; moderate, medium sub-angular to angular blocky; firm, sticky; roots common; merging to
1786	12 - 24"	Reddish yellow, 7.5 YR 6/8; silty clay; moderate to strong, medium to large sub-angular to angular blocky; firm, sticky; roots few, merging to
1787	24 - 48"	Reddish yellow, 5 YR 6/8; clay; moderate to strong, medium sub-angular to angular blocky; firm, sticky; varicoloured in pale yellow 2.5 Y 7/4; few roots; merging to
1788	48 - 66"	Varicoloured in white, 2.5 Y 8/2 (dominant) and reddish yellow, 7.5 YR 6/8; clay; strong, large angular blocky; firm, sticky; no roots.

(For analyses see XXXII).

THE LUCIA FAMILY. As with the Limau family no representatives of the ill drained soils of this family could be described. The type profile is located near the southern end of the Mantri valley, on a flat area of high level alluvium which is undergoing dissextion, under primary jungle.

1745	0 - 9"	Yellow 10 YR 7/6; silt loam, strong, medium sub-angular blocky; friable, non-sticky; very slightly mottled and gleyed; some roots; merging to
1746	0 - 24"	Yellow, 10 YR 7/6; silt loam; moderate, medium sub-angular blocky; friable, non-sticky; very slightly mottled and gleyed; some roots; merging to
1747	24 - 48"	Reddish yellow, 5 YR, 7/6; loam to silt loam; moderate to strong, medium sub-angular to angular blocky; friable, sticky; varicoloured in yellow, 10 YR 7/6; many ironstone concretions; few roots; merging to

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1748	48 - 72"	Varicoloured in red, 2.5 YR 5/8, reddish yellow, 7.5 YR 7/6 and light grey, 7/0; silty clay loam; strong, fine sub-angular to angular blocky; friable, sticky; few roots.

(For analyses see XXXIII).

Soils Developed on Riverine Plains

Two families of riverine alluvium have been differentiated on the same basis as the soils derived from "Lake Bed" Sediments. The SAPANG, derived from materials which are Miocene and older and the BALUNG, derived from materials which are Pliocene and Quaternary in age.

THE SAPANG FAMILY, no well drained examples of this type of soil were found. The type profile was taken from a quarter of a mile south of the Sapang river 4 miles from its mouth. The site was level under thinned primary forest.

1859	0 - 3"	Very dark greyish brown, 10 YR 3/2; silt loam; moderate, medium sub-angular blocky; friable, non-sticky; roots common; merging to
1860	3 - 12"	Brown, 7.5 YR 5/4; silty clay loam; moderate, medium to large sub-angular blocky; firm, sticky, roots occur; merging to
1861	12 - 42"	Yellowish brown, 10 YR 5/4; otherwise the same as above

Digging stopped due to lateral inflow of water.

(For analyses see XXXIV).

THE BALUNG FAMILY - due to the greater amount of clearing carried out on this alluvium it was possible to define two sub-families on a basis of drainage. The BALUNG, well drained and the TAWAU, poorly drained.

(i) BALUNG SUB-FAMILY. The type profile is located on Balung estate within 10 yards of the river, which is incised 20 feet below the level of the soil. It is a flat site under mature hemp.

1110	0 - 6"	Brown to dark brown, 10 YR 4/3; silt loam; moderate, medium sub-angular to angular blocky and crumb; friable to firm, slightly sticky; slightly mottled and gleyed; many roots; merging to
1111	6 - 20"	Yellowish brown, 10 YR 5/4; silty clay loam; moderate, medium angular blocky; friable to firm, slightly sticky; some roots; merging to
1112	20 - 32"	Same as above; merging to
1113	32 - 48"	Extensively mottled and gleyed; clay loam; too wet for structure or consistence, slightly sticky; merging to
1114	48 - 72"	Strongly gleyed; loam.

(For analyses see XXXV).

(ii) TAWAU SUB-FAMILY. The type profile is taken from the Agricultural Station at Tawau. It is within 100 yards of the river bank, a flat site, under old coconuts with ballang.

1007	0 - 4"	Brown to dark brown, 10 YR 4/3; silty clay loam; moderate, medium to large, sub-angular blocky; very firm, slightly sticky; many roots; merging to
1008	4 - 15"	Brown, 7.5 YR 5/4; silty clay; moderate, medium angular blocky; very firm, slightly sticky; many roots; merging to
1009	15 - 22"	Mottled and gleyed clay interstticial to ironstone nodules; merging to

1010 22 - 40" Gleyed clay.

(For analyses see XXXVI).

Soil Developed on the Coastal Plain

The parent material of these soils has been deposited by the sea in the form of sand dunes separated by shallow lagoons. In time the lagoons are infilled. The TAJONG family covers all the soils found on this coastal plain and two sub-families are recognised the TANJONG, the well drained soils of the old dunes and HITAM for the badly drained soils of the old lagoons.

(i) **THE TANJONG SUB-FAMILY** - The type profile is taken from the seaward side of the Apas road at mile 3 on an old dune site under mature coconuts

1648	0 - 6"	Dark brown, 10 YR 3/3; sand; single grain; abundant roots; merging to
1649	6 - 18"	Yellowish brown 10 YR 6/6; sand; single grain; roots common;
1650	18 - 36"	Same as above;
1651	36 - 72"	Same as above.

(For analyses see XXXVII).

(ii) **THE HITAM SUB-FAMILY,** includes all the heavier textured ill-drained soils. The type profile is near to the above profile but on the north side of the road. The site is flat and under mature coconuts.

1656	0 - 12"	Very dark greyish brown 10 YR 3/2; clay loam; moderate to strong; medium sub-angular blocky and crumb; friable, sticky; quartz fragments; many roots; abrupt and even to
1657	12 - 38"	Brown, 10 YR 5/3; clay; too wet for structure, sticky; abundant large, strong mottles along old root channels; few roots; abrupt and even to
1658	38 - 60"	Olive grey, 5 Y 4/2; when dry surface colour much nearer green; sandy clay loam; too wet for structure, sticky; abundant quartz fragments; smells strongly of hydrogen sulphide.

(For analyses see XXXVIII).

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METHODS OF SOIL ANALYSIS

All analyses were carried out by Mr. C. L. Bascomb of the Soil Survey of England and Wales at Rothamsted Experimental Station using the following methods.

Preparation of Samples. The soil taken from the field is air dried and crushed to pass a 2 mm. screen, using a Rukuhia Soil Grinder. (1) A sub-sample is taken and ground using a Morrice mechanical pestle and mortar (agate) to pass a 0.2 mm. sieve.

The < 0.2 mm. sample is used for the determination of carbon, nitrogen and calcium carbonate. All other determinations are done on the < 2 mm. material.

Moisture and Loss on Ignition. These values are determined using an oven over-night at 105°C and a muffle furnace maintained at 850°C. Loss on ignition values are corrected for decomposition of calcium carbonate, if present.

Moisture is calculated as a percentage of the air dry soil and loss on ignition as a percentage of the oven dry material.

Mechanical Analysis. (2) A 50g. sample is dispersed overnight on an end-over-end shaker using 25 ml. of a 5 per cent alkaline solution of calgon (sodium hexameta-phosphate) in 500 ml. of de-ionised water. The suspension is transferred to a 1 litre measuring cylinder and made up to volume. Hydrometer readings are taken at suitable intervals to determine fractions < 50µ. Appropriate sieves are used for coarser fractions.

Calcium carbonate. A calcimeter is used for this determination.

Nitrogen. A Kjeldahl digestion is followed by steam distillation using a Hoskins apparatus. (3) The distillate is absorbed in boric acid and titrated with 0.01N HCl.

Carbon. A wet digestion procedure is used in accordance with the recommendations of Tinsley. (4) The oxidising agent is a mixture consisting of sodium dichromate (0.4N) and sulphuric acid (15N) and phosphoric acid (3N). The excess of dichromate is titrated against ferrous ammonium sulphate using barium diphenyl-amine sulphonate as indicator.

pH Measurements. A glass electrode is used for the determination of pH on a 1:2.5 suspension of soil in water or M/100 $CaCl_2$.

Exchangeable Bases. 15g. of soil is leached with 250 ml. of neutral, normal ammonium acetate. The leachate is evaporated to dryness and organic matter is destroyed with nitric acid and hydrogen peroxide. The residue is taken up in N/5 nitric acid. Magnesium is determined spectrographically using a porous cup technique. Calcium is determined by a versenate back-titration procedure. Sodium and potassium are determined using an Eel flame photometer.

Exchangeable Hydrogen. A modification of the method of Mados (5) is used. 10g. of <2. mm. soil are shaken with 100 ml. of 0.2N NH_4OH for 2 hours. Formalde-hyde is added followed by barium chloride solution. The supernatent liquid is titrated with N/10 Na9H with 2 ml. excess and then back titrated with N/10 HCl. (This was used in most analyses).

Base Exchange Capacity. After leaching with ammonium acetate, the soil is washed with 95% ethyl alcohol to remove the excess ammonium acetate solution and is then leached with 250 ml. of 10 per cent sodium chloride solution to displace the ammonium ions absorbed on the soil. The ammonium content in the leachate is determined using the Hoskins apparatus. (Some analyses were carried out by this method).

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DISCUSSION OF ANALYSES

The continuous high rainfall and high temperature of the Semporna peninsula acting on parent rocks, which are rich in volcanic ash, have given rise to soils which in general have a high percentage of clay and low pH values.

If pH is plotted against percentage base saturation (Peech 1939) it is found that one group of soils arrange themselves in a linear fashion between pH 5 and 6, parallel with Peech's hypothetical line, while another group of soils occur above this theoretical line at very low base saturation (fig.6(a)). Mehlich (1941 and 42) was dealing with soils which, in their natural state, were rather similar in chemical properties to the first group, except that they were mature, but not to the last and hence his results are not applicable to this case.

The first group of soils may be referred to as group A. They include: all those soils developed on mountainous topography from parent rocks rich in primary minerals; those ridge soils which are developed from relatively resistent parent rock, Tingkahu (Eocene ultrabasics) Kalumpang (Miocene volcanics and sediments) and possibly Conner (Early Pliocene volcanic); the platform soils, Sipit (Miocene volcanics and sediments) and Kawa (Early Pliocene volcanics) and also the Balung and Sapang families forming on river valley aluviums. The characteristic common to all these soils is that they have weathering parent rock rich in nutrient elements within a short distance of the surface.

The soils of low base saturation (see figure 6(a)) are divisible into two groups. First lowland soils developed from base rich parent rocks which have been so deeply weathered that no unweathered parent rock is found within 6 feet of the surface. This includes the Table family (Quaternary basalts on high level plateaux), the Kinabutan (late Pliocene volcanics on ridge topography), the Gading (late Pliocene volcanics on coastal platform) and the Limau and Lucia families (Quaternary lake bed deposits). They may be referred to as group B. Secondly soils developed on mountainous topography from parent materials initially low in nutrients, this includes the Cook sub-family (Eocene sandstones and shales) and the Wullersdorf sub-family (Late Pliocene rhyolites). They may be referred to as group C.

A soil group D may be defined as including those soils which have a pH above 7 and a base saturation of above 100 per cent. This includes the soils of the Semporna (Coral limestone) and Tanjong (coastal dunes and marine sediments) families.

It is of interest to compare these Borneo soils with those of W. Africa. Charter (1955) in discussing the forest soils of Ghana said that they belong

"in the main, to two great soil groups: the ochrosols and the oxysols.

The ochrosols consist of red to yellowish-brown kaolinitic earths with characteristic reaction profiles: the surface horizons vary from moderately acid to mildly alkaline and the lower horizons become increasingly acid. ----------------------. It is on soils of this great soil group that the vast majority of cocoa is produced.

The oxysols typically consist of pale orange-coloured kaolinitic earths, though red examples also occur. This great soil group also displays a characteristic reaction profile: the surface horizon is highly to very highly acid and the horizons below only slightly less acid. Oxysols are developed in similar parent materials to the ochrosols but typically under rainfalls exceeding 70-80 inches, ----------------------. The soils of this great soil group produces very little cocoa.

It is considered that modal oxysols have surface reactions of pH 4-5 and modal ochrosols surface reaction of pH 6-7. Intergrades between these great soil groups occur with surface reactions between pH 5 and 6. Such intergrades are abundant amongst the soils of the Gold Coast forest zone and observation suggests that they are far less productive for cocoa than are the ochrosols proper".

Considering the analyses of the soils of the Semporna peninsula, if the pH of the surface horizon and that of the subsoil is plotted against base saturation

(065087)

Table 6

SOIL FAMILIES SEMPORNA PENINSULA IN RELATION TO CHEMICAL ANALYSES

GEO-MORPHIC UNIT / AGE OF PARENT ROCK	EOCENE	MIOCENE	EARLY PLIOCENE	LATE PLIOCENE	PLIOCENE QUATERNARY	QUATERNARY	RECENT
COASTAL PLAIN							TANJONG
RIVERINE PLAIN							SAPANG BALUNG
RELIC LAKE BEDS						LIMAU LUCIA	
DEPOSITIONAL COASTAL PLATFORM				GADING	SEMPORNA		
EROSIONAL COASTAL PLATFORM		SIPIT	KAWA				
RIDGE COUNTRY	TINGKAYU	KALUMPANG	CONNER	KINABUTAN			
HIGH LEVEL PLATEAUX						TABLE	
MOUNTAINS AND HILLS	COOK	MALATAI	BESAR	TAJONG		BOMBALAI	

Group A - "Ochrosolic" soil types Group B - "Oxysolic" soil type (apparently rich) Group C - "Oxysolic" soil type (apparently poor) Group D - Soils of high base saturation (fig. 6(b)), it can be seen that the soils of group A have "ochrosolic tendencies" whole the soils of groups B and C have "oxysolic tendencies". However there are some important features which differentiate these soils from those of Ghana. According to Charter the factor which determines whether an ochrosol or an oxysol develops is rainfall, the former being characteristic of lower and the latter of higher rainfall. In the soils of the Semporna peninsula the factor controlling whether soils of group A (ochrosolic tendencies) or groups B and C (oxysolic tendencies) develop is dependent on age and composition of parent materials and topographic position. Due to these factors the soils belonging to group A are immature shallow soils while the Ghana ochrosols are more deeply weathered. The modal pH of the soils of group A (5-6) approximate to those of the intergrade rather than to the type ochrosol. In colour the soils of group B approach nearer to the red and yellowish brown of the ochrosols rather than the pale orange of the oxysols despite showing chemically "oxysolic tendencies". In addition these soils are much more strongly leached than the typical oxysol quoted by Charter. They agree with the Ghana oxysols in their modal pH and their depth of weathering.

There is in addition a practical aspect which differentiates the Ghana and North Borneo soils. In Ghana the oxysols are not suitable for the growth of cocoa while in Borneo among the soils of group B (oxysolic tendencies) it has been found that the Table family of soils are suited to the growth of cocoa and probably the Kinabutan soils will be very nearly as good, despite the apparent lowness of the fertility as revealed by chemical analyses. It may be that this apparent suitability to cocoa may not last beyond the first few years of cultivation.

In the same paper Charter goes on to discuss the base status of the forest soils of Ghana. It will be instructive to continue the comparison with the soils of the Semporna peninsula. Charter states that investigation of the individual bases shows that:

> "as one passes from the slightly calcareous ochrosols, through the non-calcareous ochrosols and intergrade soils to the oxysols, the divalent bases, calcium and magnesium diminish in amount and there is a tendency for magnesium to be lost to a greater extent than calcium. On the other hand the proportions of potassium diminish far less or hardly at all".

However in a subsequent paper by de Endredy and Montgomery (1956) they stated:

> "With advancing leaching, first $CaCO_3$ is removed, followed by the removal of exchangeable Ca and the Ca/Mg ratio narrows. It must be borne in mind that with advancing leaching the relative abundance of Mg increases ---------------------. When the final stage of leaching is reached the soil has the second type of reaction profile (oxysol) and the Ca/Mg ratio drops to 2-3:1 in the surface horizon and 1:1 or less in the subsoil. In the course of the leaching, however, the absolute amounts of Ca and Mg decrease also very steeply and the really acid soils have only a few tenths of m.e. of Ca and Mg left--. The leaching of potassium usually lags behind the loss of divalent cations, and the ratio CA+Mg/K decreases with increasing acidity".

Turning to the analyses of the soils of the Semporna peninsula, if the Ca/Mg ratio is plotted against the percentage base saturation (fig.6(c)) it can be seen that the ratio decreases from an average of 4 at 90 per cent saturation to 1 at 30 per cent, for the soils of group A. The soils of group B are all less than 15 per cent base saturated, with extremely low absolute amounts of exchangeable cations and with magnesium frequently occurring in greater quantities than calcium.

In so far as the comparison is valid, this would seem to confirm the conclusions of de Endredy and Montgomery rather than those of Charter.

In the soils of group A the amount of exchangeable magnesium is high, averaging 7 m.e. per 100 grms. (2.7 to 19.6) and 22 per cent of the total exchange capacity (7-40 per cent). This is probably related to the primary volcanic products which form a considerable proportion of the parent rocks. It is also noticeable that the percentage of magnesium found in the exchange complexes of the upland soils and in the alluvial soils which are forming from their erosion products remains constant, Tingkayu 40 per cent and the alluvial soil derived from it, Sapang 40 per cent; Tajong 17 per cent and its related alluvium, Balung 17 per cent.

This relatively and absolutely high content of exchangeable magnesium may be of considerable importance in the growth of cocoa for Charter (1955) states:

(065087)

"The evidence to hand suggests that the divalent bases calcium and magnesium, and particularly the latter, play a highly significant role in the nutrition of cocoa, and for soils to produce cocoa satisfactorily these bases must be present in adequate amounts".

Potassium, though present in small amounts when compared with the divalent cations, is relatively concentrated in the more leached soils. The ratio of CA+Mg/K in the soils of group A averages 185 while in group B it is 7. It would seem that most of the potassium is removed in the very early stage of weathering while a small amount is very much more resistant to removal than the divalent cations.

Darby and Orchard (1956) describe the occurrence of yellow earths in the Natal mist-belt found on a variety of geological formations ranging from sandstone to dolerite. A typical residual or colluvial/residual profile on dolerite is as follows:

" 0 - 12" - Dark brown loam, nutty structure with fairly hard aggregates; stoneless, porous, loose, abundant roots; merging into

12 - 50" - red ferruginous friable clay (but of loamy appearance and feel). Column-like structure, stoneless, mellow, porous, many roots. A few scattered purplish-black hard concretionary nodules, 2-4m.m. diameter; merging into

50 - 144" - yellowish red clay. The yellow colour becomes increasingly dominant with depth; column-like structure, stoneless, mellow, porous, a few tree roots penetrate to 12 feet".

This profile resembles to a considerable extent some of the profiles examined which belong to the Kinabutan sub-family of soils. The analytical details of this profile have been added to the Kinabutan analyses (sheet XXI) for comparison. The soils show oxysol properties in that the pH rises with depth, as well as being very acid; the absolute amount of cations is small and the Ca/Mg ratio is low, much smaller and lower than in the case of the type oxysol quoted by Charter.

Returning to the analyses of the Semporna peninsula soils it can be seen that the percentage of organic carbon in the surface horizon varies from 1.2 to 7.8 but this quickly falls within 3 or 4 inches of the surface to generally much below 1 per cent. The C/N ratio of the top-soil varies from 9.5 to 17.5 (excluding the Sinon profile, VIII, which has a peculiar grass vegetation). This ratio generally falls with depth except in the case of the Table, Kinabutan and Gading families of soils belonging to group B, which maintains a ratio of between 11 and 13 to a depth of 6 feet.

General conclusions

If the analytical figures alone were available the conclusion would be reached that in the soils of group A there are a number of families of considerable agricultural potential while the soils of group B would be considered to be of very little value.

The situation, however, is profoundly altered by the fact that the Table family of soils, in group B, is actually extremely productive and when last seen in 1959 was growing very good crops of Manila hemp, cocoa and oil palm. On Table estate itself Manila hemp has been grown more or less continuously without fertilizer for over 30 years, without any apparent decline in yield. During the last 6 years replicated experiments have been carried out and none of the usual fertilizer applications led to any economic increase in yield. On the Kinabutan soils rubber trees are growing at an exceptional rate and the soil would probably be almost as suitable for cocoa and oil palms as the Table soils. Gading soils, in spite of the apparent almost complete lack of nutrient elements, have rubber trees growing on them of a quite remarkable quality.

The Limau and Lucia families of soil, derived from high-level ancient alluvium, present greater difficulties than the other members of group B, to anyone trying to assess their potential agricultural value, because they are under primary forest and no agricultural crop has yet been grown upon them. It would present an unbalanced picture to compare the nutrient status of these soils with any of the soils of group A; comparison must be kept to the soils of group B. On this basis they are better supplied with nutrients and, with the exception of the swampy areas. have a better structure and internal drainage than the soils of the Gading family and hence can be considered to have an agricultural potential superior to them.

The chemical characteristics of the soils developed on mountainous topography puts them into either group A or C. However the factor controlling their potential use is their instability due to great slope, which means that they must be kept under protective forest. This point will be discussed at greater length in the next section on soil evolution.

Apart from the soils developed on mountains, group A consists of 7 families whose agricultural potential will now be discussed. The Tingkayu family of ridge soils despite a high chemical fertility is subject to a fine scale intense dissection and because of this should be kept under protective forest. The riverine alluviums (Balung and Sapang families) in conformity with their favourable analytical data, are suitable for a wide range of crops. This has been proved in the Tawau river valley.

The remaining 4 soil families (Kalumpang, Sipit, Conner and Kawa) have not carried any agricultural crops, apart from a rather poor example on the Kawa soils of Tinagat head. Their analyses and the type of soil evolution (see next section) would seem to indicate that the Kalumpang and Conner soils have a good agricultural potential, possibly cocoa. The rather poor internal drainage of the Sipit family detracts from its potential value but rubber, at least, should grow reasonably well, even on the less well-drained parts. The Kawa soils are very limited in extent, but where they do occur they should be reasonably fertile.

The Semporna family of soils, which belong to group D are calcimorphic and as such according to Charter should be:

"excellent producers of cocoa"

The other family within group D, Tanjong, derived from coastal dunes and marine alluvium is suitable for coconuts.

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The mountain soils, typically developed on slopes of about 30° or more, are thin and weathering cannot proceed far before the material is removed by erosion. In these soils montmorillonite-vermiculite is dominant. The only exceptions are in the case of the Besar soil (1750 & 1752), but in this case the profile is rather atypical in that it occurs in a rather more gently sloping area, within the mountainous zone, where weathering products can accumulate. This can be compared to the other Besar soil (1796), which occurs on a 30° slope. The Bombalai soil (1087) may be dominantly kaolinitic due to hydrothermal alteration. The dominance of vermiculite in the Cook soil derived from sandstone (3603 & 3605) is rather unexpected in view of the extremely low saturation figure revealed in the chemical analyses.

Soils of the Table family are derived from Quaternary basalts. The ease of weathering of this parent material combined with the gentle topography of occurrence cause weathering products to accumulate and throughout this family kaolin is dominant.

The deeply weathered soils of the Kinabutan family (1448 & 1451) are also kaolin dominant. The Quarry soils (1459 & 1460), which have not weathered much in their present position but are derived from a mixture of previously weathered and unweathered material, are still dominantly kaolin but with moderate amounts of montmorillonite-vermiculite.

The Platform soils can be split into two groups:

(i) the Gading soils (1023 & 1026) in which virtually all that is present is kaolinite. This is due to its derivation in large part by the erosion of previously weathered material.

(ii) the other soils, in which parent material is generally found within 3 feet of the surface, where there is always a considerable amount of montmorillonite-vermiculite. The Kawa soil (1440 & 1443) is rather atypical in this respect but even so there is some montmorillonite-vermiculite present. The Semporna (1714 & 1716) and the Sipit soils (1818) show a change from kaolin dominance at the surface to montmorillonite-vermiculite dominance in the sub-soil.

The alluvial soils show the dominance of kaolin for those derived from strongly weathered materials, Balung (1008-1010); the dominance of vermiculite in those derived from little weathered materials, Lucia (1746-1748) (This is probably confined to the Lucia soils of the upper Mantri valley, which are in a special situation surrounded by unstable hillsides composed of andesitic ash. The Lucia soils of the Baturong "lake-beds" will probably be dominantly kaolinitic); and the dominance of mica in those derived from marine clays, Tanjong (1657 & 1658).

The virtual absence of gibbsite is to be noted, but it does occur as a trace in those soils which may be considered to have been subject to the greatest amount of weathering within the Table (962, 1038, 1040, 1087) and Kinabutan (1448) soil families.

SEMPORNA PENINSULA SURVEY: X-RAY ANALYSIS OF CLAY FRACTIONS

		Kaolin	Mica	Montmorillonite	Vermiculite	Goethite	Haematite	Gibbsite	Quartz	α-Cristobalite	Felspar	Other minerals present
MOUNTAIN SOILS												
COOK	1185	little	-	dom	-	v. little	-	-	pres	-	-	
COOK	3603	"	little	-	dom	trace	-	-	pres	-	-	lepidocrocite
	3605	"	"	-	dom	"	-	-	"	-	-	lepidocrocite
BESAR	1796	little	-	d o m i n a n t		trace	trace	-	pres	-	pres	amphibole
BESAR	1750	dom	-	trace	-	v. little	-	-	pres	-	pres	
	1752	"	-	"	-	"	-	-	"	-	pres	
TAJONG	1969	little	little	m o d e r a t e		trace	-	-	pres	-	pres	
	1972	"	v. little	"		"	-	-	"	-	"	
TAJONG	1740	mod	-	-	-	-	-	-	pres	-	pres	*? crandallite, dickite
	1741	"	-	-	-	mod	-	-	"	-	"	*? crandallite
BOMBALAI	1087	dom	-	-	-	-	little	trace	-	pres	pres	
HIGH LEVEL PLATEAU (deep basaltic soils)												
TABLE	957	dom	-	-	-	v. little	-	-	pres	-	-	
	958	"	-	-	-	"	-	-	"	-	-	
TABLE	960	dom	-	-	-	v. little	-	-	pres	-	-	
	962	"	-	-	-	"	-	trace	"	-	-	
TABLE	1038	dom	-	v e r y l i t t l e		v. little	trace	trace	pres	pres	-	
	1040	"	-	"		v. little	"	"	pres	"	-	
TABLE	1667	dom	-	-	-	little	-	-	pres	-	-	
	1668	"	-	-	-	"	-	-	"	-	-	

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RIDGE SOILS												
TINGKAYU	1871	mod	-	dom	-	-	-	-	pres	pres	pres	
KALUMPANG	1277	dom	-	-	mod	-	-	-	pres	-	pres	halloysite
	1279	"	-	-	"	-	-	-	"	-	"	
KINABUTAN	1448	dom	-	very little		trace	-	trace	pres	pres	pres	
	1451	"	-	"		"	trace	-	"	"	-	
QUARRY	1459	dom	-	moderate		-	-	-	pres	pres	pres	
	1460	"	-	"		-	-	-	"	"	"	
PLATFORM SOILS												
SIPIT	1818	dom	-	v. little	-	trace	-	-	pres	-	pres	
	1821	mod	-	dom	-	"	-	-	"	-	"	
SIPIT	1804	little	little	-	dom	trace	trace	-	pres	-	pres	
	1807	"	"	-	"	"	"	-	"	-	"	
KAWA	1440	dom	-	little		trace	-	-	pres	pres	-	
	1443	"	-	"		-	-	-	"	"	-	
GADING	1023	dom	-	-	-	-	trace	-	pres	pres	-	
	1026	"	-	-	-	-	"	-	"	"	-	
SEMPORNA	1714	little	trace	moderate		trace	-	-	pres	-	-	calcite
	1716	mod	"	dominant		"	-	-	"	-	-	
ALLUVIUM												
LUCIA	1746	mod	-	-	dom	-	-	-	pres	pres	pres	lepidocrocite
	1748	mod	trace	- "	"	little	-	-	"	"	"	*? crandallite
BALUNG	1008	dom	v. little	little	-	trace	-	-	pres	pres	pres	
	1010	"	"	"	-	"	-	-	"	"	"	
TANJONG	1657	little	dom	very little		trace	-	-	pres	pres	-	calcite, crandallite
	1658	"	"	little		"	-	-	"	"	-	

*$Ca\ Al_3\ (PO_4)_2\ (OH)_6$

(065087)

SOIL EVOLUTION

The different characters of the four groups of soils as revealed by chemical analyses are probably related to the manner in which the particular landscape units on which they occur have developed as a result of the interaction between the composition and type of parent rock on the one hand and the degree of weathering and leaching on the other.

In the mountainous areas where soils have developed on slopes generally in excess of 30°removal of weathered material constantly rejuvenates the soils. As most parent rocks are rich in bases, due to their igneous origin, there is not enough time in view of the instability of the land surface for a leached soil to develop. Therefore most soils developed on mountainous topography fall into group A. The Cook sub-family provides an instance where the parent rock mostly consists of residual materials from a previous cycle, sandstones and some shales. With the removal of the slight amount of cementing material the sandstone is very easily weathered to a considerable depth even on exceptionally steep slopes. Similar soils occur on the massive sandstones within the Malatai family of soils but so far none has been described.

The Wullersdorf sub-family, derived from late-Pliocene silicified rhyolite, is different from the other two cases in that the silica is primary and not residual and is colloidal and not in the form of quartz.

These soils have been placed in group C. They have similar chemical characteristics to the soils of group B, but they lack their good structure and strong colouration. The very low nutrient status of this group as shown by chemical analyses probably coincides with the potential fertility of the soil. This makes it all the more essential that the forest canopy on these soils must not be broken in any way as there is virtually no inherent fertility present which can be utilised to combat mismanagement.

The evolution of three analogous soil groups developed on ridge country and coastal platform must now be considered. An abstract from table 6 may help to clarify the matter.

	Miocene	*Early Pliocene*	*Late Pliocene*
Coastal Platform	SIPIT	KAWA	GADING
Ridge Country	KALUMPANG	CONNER	KINABUTAN

No such analogous group was recognised for the pre-Upper Eocene rocks, only the Tingkayu ridge soils being differentiated. The Quaternary basalts were erupted after the landscape consisting of the ridge country and the coastal platform had been developed and therefore do not coincide with either of these landforms.

The three analogous groups of soils provide contrasting reasons why in certain cases ridge country is developed while in others the coastal platform occurs. The evolution of soils on the Miocene parent rocks will be considered first. As outlined earlier the Miocene deposits consist of several facies. From the relative resistance of these materials to a weathering and erosion four groups may be distinguished,

(i) Massive sandstone.

(ii) Massive lavas and agglomerates.

(iii) Less massive volcanic materials.

(iv) Thinly bedded sediments.

Their resistance to weathering and erosion decreases from (i) to (iv) (i) and (ii) give rise to mountainous areas, for example south of the Kalumpang between the Malatai and the Mantri and in the Mt. Hewett area. Up to the end of the Tertiary there was probably little difference between (iii) and (iv), though the latter was probably of gentler topography than the former. However, between the late Tertiary and the eruption of the Quaternary basaltic lavas, a period of marine erosion occurred. To this the thinly bedded sediments of group (iv) offered little resistance and the erosional coastal platform was formed across them (see plate 8). The more massive volcanic materials of group (iii) resisted

(065087)

this marine erosion to a much greater extent. With the uplift of this area which preceded the basaltic eruptions there were created the conditions under which Kalumpang soils developed on the materials of group (iii) while the Sipit soils developed on the materials of group (iv). Subsequent weathering has not penetrated very deeply probably due to the induration resulting from the post-Miocene orogenic movements, so that the weathering mantle is never very thick, even in the areas of Kalumpang soil where a great depth of aerobic weathering is theoretically possible. The typical form of the ridge topography with Kalumpang soils is due to the sharp incision of streams subsequent to the latest uplift. The streams crossing the platform have also incised their valleys but due to the shorter time during which streams have been active on this surface large inter-stream areas have not yet been affected. The line of junction between the ridge and platform area is generally sharp and is best seen in the mid-Kalumpang valley slightly to the east of Sangster and Forbes hills.

To sum up, the soils of the Kalumpang and Sipit families (group A) have parent rock in the profile, which is due to orogenic induration causing resistance to weathering. Whether or not one or other soil family develops is dependent on the type of parent rock and its resistance to marine erosion.

The development of soils on early Pliocene materials (the second analogous group) is intimately connected with their outcrop as steep sided isolated hills. Whether Conner or Kawa soils develop on the lower slopes of these hills depends on their geomorphological setting. Where these hills are surrounded by the coastal platform a pediplain tends to form on the lower hill slopes by extension from the coastal platform and retreat of the hillslopes. This is well seen on the northern face of the Tinagat hill mass to the east of Tawau. While this process is continuing very little colluvium from the mountain slopes can accumulate at the upper margin of the pediplain. Thus in this situation there develops an abrupt junction between the mountain slopes with Tinagat soils and the pediplain with Kawa soils (plate 6). The shallowness of the weathering is due to the orogenic induration of the parent rock. In such a topographic situation the Kawa soils, Membalua sub-family, show a clear differentiation into surface creep horizons and a sedentary sub-soil. There is also clear evidence of lateral translocation of material in solution in the abundant occurrence of nodules of iron and manganese. The chemical analysis shows the two layered character of the profile very well.

In contrast Sangster hill in the Kalumpang valley occurs within a region of Kalumpang ridge soils. Here no pediplain has developed so that little of the waste material accumulating by colluvial slip on the lower slopes of Sangster hill has been removed. Thus a soil of the Conner family has been allowed to develop in this situation.

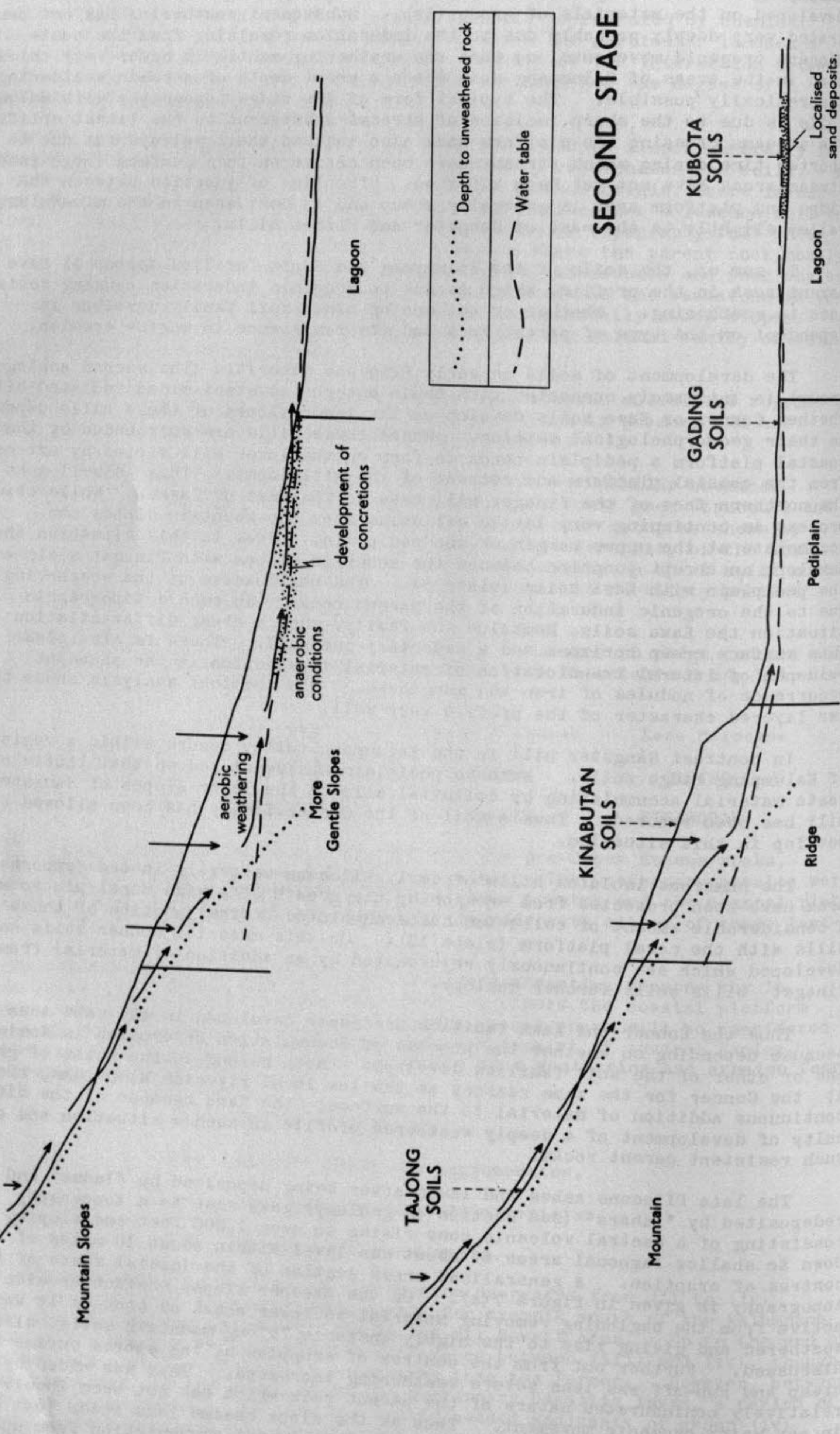
The numerous isolated hills of early Pliocene materials in the Semporna area have been protected from erosion by the growth of a wide coral platform. A considerable amount of colluvium has accumulated at the junction of these hills with the coral platform (plate 12). On this material Conner soils have developed which are continuously rejuvenated by an addition of material from the Tinagat hills soils further upslope.

Thus the Conner and Kawa families are never developed in the same area because depending on whether the process of accumulation or erosion is dominant, one or other of the soil families develops. Both belong to the soils of group A; the Conner for the same reasons as the low level riverine alluviums, the continuous addition of material to the surface; the Kawa because of the difficulty of development of a deeply weathered profile in such a situation and on such resistent parent rocks.

The late Pliocene ashes and lavas after being deposited by "ladus" and redeposited by "lahars" (see section on geology) gave rise to a topography consisting of a central volcanic cone rising to over 4,000 feet and sloping down to shallow lagoonal areas at about sea level within about 10 miles of the centres of eruption. A generalised cross section of the initial state of this topography is given in figure 7(a). On the steeper slopes surface erosion was active from the beginning removing material to lower areas as soon as it was weathered and giving rise to the highly unstable Tajong mountain soils, already discussed. Further out from the centres of eruption as the slopes became less steep and run-off was less severe weathering increased. This was aided by the relatively nonindurated nature of the parent rock which has not been involved in any major orogenic movement. Thus as the slope became less steep just above the lagoonal area, this would be the site of colluvial accumulation from upslope

Fig 7

INITIAL DEVELOPMENT ON LATE-PLIOCENE MATERIALS



(065087)

and deep weathering. This area is now marked by the occurrence of soils of the Kinabutan family.

The lagoon surface was the boundary between aerobic and anaerobic weathering, the water table rising inland from this surface sub-parallel to the land surface. It was in that segment of the landscape lying above the water table and which did not have weathering rock within 6 feet of the surface that soils of the Kinabutan family developed. Within this segment of land soils would have varied from the upper limit where a completely aerobically weathered soil overlay weathering rock at just below 6 feet, to the lower limit where an aerobically weathered layer overlay an anaerobically weathered layer at just below 6 feet from the surface. At the junction of the two layers particularly towards the lagoon margin there would have been a concentration of iron and manganese nodules due to the lateral translocation from anaerobically altered material higher upslope.

From the time that these late-Pliocene ashes were laid down above sea level they were subject to erosion. This was effected by pedi-planation into the lower areas of aerobically weathered materials adjacent to the lagoon. This process was more extensive than was the case in the other two analogous series for there was much less resistance from the late-Pliocene materials. Figure 7(b) gives a cross section to show these developments. These pediplain areas can be recognised in the Tawau area rising gently from the flat areas of the coastal platform, which were then lagoons, backed abruptly by the ridge areas into which they are eroding. They are characterised by the more abrupt division between creep and sedentary horizons separated by a more strongly developed stone and gravel horizon as compared to the true old lagoonal material where creep has not been active. These soils were not differentiated during this survey. In the lagoonal areas various local concentrations of beach sand were deposited, which consisted of angular quartz fragments derived from the dacitic ashes, later to develop into Kubota soils.

Sometime prior to the eruption of the Quaternary basalt the whole area was relatively uplifted by a hundred feet or more. The changes in soil evolution this has brought about may be discussed under three headings (i) the anaerobic lagoonal area (ii) the area of aerobic weathering (iii) the area at the junction of (i) and (ii).

(i) The materials laid down in the lagoon had accumulated under anaerobic conditions. The uplift caused the condition to become potentially aerobic. However, apart from the surface quartz sand deposits, the mass of the material was a fine clay, which reduced the penetration of oxidative conditions to structure planes and root channels penetraing from the surface. The present state of the Gading soils, which have developed on this material, reflects the gradual penetration of weathering from the surface. At a depth of about 40 feet, in the upper valley of the Apas, a pallid clay is seen, which is a relic of how all the material was when first uplifted. This gradually passes upwards into a strongly mottled zone of red and light grey, in which the red forms a network on the grey body colour. This represents the initial penetration of oxidative conditions along selective routes into the anaerobically deposited clay. The nearer the surface is approached the more the oxidative conditions have penetrated until a more uniform reddish colour occurs. In the surface two or three feet other pedological processes have come into operation. Clay has been differentially removed, or destroyed, leaving a lighter textured and paler coloured top-soil. The action of termites has increased this tendency and has led to the formation of a stone-line at its base, though more diffuse than in the soils developed on the pediplains.

(ii) In the area of deeply weathered aerobic soils no change of conditions occurred as a result of uplift but there was an intensification of the processes which were previously active. In particular it caused the streams flowing through the area to incise their valleys very rapidly leading to the formation of deep narrow valleys with local base levels, broken by many small waterfalls where one base level is replaced by another. This has given rise to the typical ridge topography on which the soils of the Kinabutan family have developed.

(iii) The area of junction between (i) and (ii) is occupied by the pediplain soils which at the time of the uplift consisted of an aerobic creep horizon and an anaerobic sedentary soil separated by a stone line. The aerobic horizon increased towards the ridge country the anaerobic towards the lagoon. This was an area in which a delicate balance had been attained between anaerobic and aerobic conditions and between creep and sedentary soil horizons, uplift caused the balance to be disturbed towards the aerobic side. At the same time however the pediplain has continued to be formed at the expense of the ridge country and a perched water table exists at the former junction between the aerobic and anaerobic layers due to the persistence of the textural break at this point. This has led to a most complicated association of contemporary and fossil pedological features which will require extremely detailed mapping of the kind being pioneered in Australia by Butler to work out the complexities of such an area.

The kinabutan and Gading soils belong to group B, and the above discussion shows them to have been subject to different enviromental factors during their evolution to the other two groups previously discussed, which belong to the soils of group A.

This discussion on the complexities of the soil relationships within these groups may serve to emphasise how much this has been a reconnaissance survey and how much remains to be done before a full picture of pedological development can be made.

It was onto this landscape of strongly developed ridge topography and uplifted coastal platform that the Quaternary basaltic lavas of the Table-Tiger and Quoin hill centres was erupted. Since that time they have been weathered in strongly aerobic conditions under a continuously hot and humid climate and have given rise to the deep, strongly structured soils of the Table family. This again is a case of strong deep weathering of a parent material rich in bases giving rise to a soil belonging to group B. However, even in the case of the Mostyn subfamily derived from shallowly weathered Quaternary basalt, the percentage base saturation is low considering its actual agricultural production and despite the occurrence of weathering basalt within two feet of the surface it is already trending towards the soils of group B rather than those of group A.

The formation of the high level alluvium, which is the parent material of the Limau and Lucia families, behind the dams caused by the Quaternary basaltic lava flows is described in the geological section. These soils have developed in a lowland area on deep unindurated parent material which must have originally been as rich in bases as the present day riverine alluviums. The laying down of this material under anaerobic conditions and, subsequent to the removal of the basalt dams, its development under aerobic conditions, gives it a general similarity to the evolution of the Gading soils. The only difference being that the parent materials of the Limau and Lucia families were laid down under fresh water conditions while that of the Gading was under brackish water or marine conditions. These considerations would lead one to consider these soils to be much more closely associated with the soils of group B than those of group C (Cook subfamily). This is of importance for it can be concluded from this that it is probable that the nutrient status of these soils as shown by chemical analysis is not an accurate reflection of their agricultural potential.

The Quarry family of soils presents a great difficulty. The parent material is the same as that of the Kinabutan and Gading families and it has been deposited in a strongly aerobic position, that is one in which quick weathering is to be expected. Yet the shallow soil developed on this material makes it very much a soil of group A and there is no sign of deep weathering throughout its occurrence. There are three possible explanations

(i) The deposition of this ash is even more recent than is supposed.

(ii) The parent material differs considerably from the late Pliocene materials.

(iii) Weathering processes prior to the basaltic eruptions were of a different intensity to what they are now.

At the moment the first possibility would appear to be the more feasible.

(065087)

CORRELATION WITH OTHER AREAS

The soils of the Semporna peninsula are for the most part derived from late-Tertiary and Quaternary ashes and lavas under a continuously humid climate. An area where similar materials have been acted upon by a similar climate under similar vegetation is the Cameroon Mountains of West Africa. Laplante and Bachelier (1954) have described soils developed on recent basalts and the Table family of soils would seem to resemble "Les sols brun foncé" or 'Les sols "chocolat"'. However, the Borneo soils appear to have a much higher clay content and much lower available nutrients. In the Cameroons they have worked out an evolutionary tendency which shows a change in soil colour from black --> dark brown --> chocolate --> red, as age increases, this is connected with a decline in nutrient status and weatherable minerals in the same direction. In the Table family an evolution of colour with age has been worked out as being red (Quoin) --> brown (Table) --> yellowish brown (Jarangan). In the extremely shallow soild of the Bombalai family very dark coloured soils occur but as they are skeletal soils developed on steep slopes they cannot be included in the evolutionary sequence of soils developed on a more gentle topography. The Cameroon soils do not appear to have such a good structure or be as capable of retaining water as the Table soils for Laplante and Bachelier remark "Mais ce sont des sols très permeables et retenant mal l'eau" while the Table soils despite being extremely permeable always retain enough water for plant growth.

The soils of Mauritius are derived from basalts but they have evolved under great variations in rainfall. N. Craig and P. Halais (1934) only investigated the surface soil but they suggested a colour change with increased rainfall from red or red with a purplish tinge to brownish red to yellowish brown. They suggested this was due to increasing water of hydration associated with iron oxide. Substituting rainfall, as the dominant factor in soil formation, for time there would appear to be similarities to the North Borneo soils. The depth and profile characteristics would also appear to be similar for describing a mature soil Craig and Halais state "In certain of these pits more than 30 feet deep have been dug without reaching the parent-rock materials, and except at a depth of about 9 in., when the surface soil stops, there has been no sign of sudden alteration.

Darby and Orchard (1954) also regard a yellowish colour as being found in the more moist areas "the higher the moisture status of the soil, the more marked becomes the yellowish shade and the nearer to the surface it advances".

The soils of Hawaii are also derived mainly from basic volcanic products under widely varying rainfall. None of the soils described (Cline 1955) from Hawaii is anything like the Table or Kinabutan soils of the Semporna peninsula. There are no descriptions which indicate a very deep, strongly structured, uniform soil. If the bed rock is deeply weathered core relics are usually found within three or four feet of the surface. In addition organic matter would seem to accumulate to a much greater extent in the Hawaiian soils than those of Borneo but this may be due in part to the effect of altitude which does not intrude to any extent in Borneo. The soils of Hawaii would appear to have followed a different evolutionary course from those of Borneo for with increase in rainfall there ia a continuous increase in gibbsite and iron and titanium oxides while in Borneo under conditions of extreme leaching the process appears to have halted at the stage of halloysite formation. The different evolutionary tendencies may be connected with different type of basalt in the two areas. That this may be an important factor is indicated to some extent by Cline (1955), for on pp.78 when discussing the formation of the soil showing the most advanced stage of weathering, the "Humic Ferruginous Latosols", he says "This suggests that development of this kind of profile is more rapid on rocks dominated by feldspathoids than those dominated by feldspars".

There would appear to be a few points of similarity between soils in Java (Dames 1955) and those in Borneo. The soils are either too young to have developed a deep profile or if somewhat older to have suffered from a great deal of erosion. The humic soils of Dames in their physical structure would seem to approach the Table soils and they are developed on lower lying areas from recent basaltic ashes.

The more recent work of van Schuylenborgh (1955, 57, 58 and 59) does not offer many possibilities of comparison with the Semporna peninsula for most of the soils dealt with occur on relatively flat sites above 1,000 metres in altitude. Above about 400 metres in the Semporna peninsula slopes are generally extremely steep and skeletal soils are produced which are of no value as far as such comparisons go. The few soils profiles that are taken below the 1000 metre level do not seem to be very similar to the Borneo soils on similar parent materials, but this is only making use of inadequate profile descriptions.

The soils of the Kinabutan and Apas families appear to have a lot in common with the Australian "krasnozems" (Stephens 1953) for they are described by him as "red to brown, deep friable, clay soils showing very little horizon development beyond the accumulation of organic matter in the A-horizon. Although generally a clay in texture throughout the profile, the surface soil, because of its organic matter content, and the flocculated nature of the clay, has the tilth usually associated with a loam, and the B and C horizons of granular and nutty structure also have a very porous and friable character". These soils which in Queensland are thought of as fossil soils (Bryan 1939 and Whitehouse 1940) are associated with soils which would appear to be very similar to the soils of the Gading family. Stephens names these soils "Lateritic red earths" and describes them as "red to light red soils with a deep profile containing a horizon of laterite with mottled and pallid kaloinitic horizons beneath. The A horizon is commonly sandy to loamy in texture and darkened with a little organic matter. It passes gradually into a slightly finer textured B-horizon, which is usually a bright red in colour, and of compact but somewhat vesicular structure. The horizon of laterite is found at various depths and it is of a variable character, nodular, pisolitic, vermicular or massive. The mottled and pallid horizons beneath the laterite are variable in depth and may occasionally be missing". They are considered as relics of a Pliocene age of soil formation. Considering the much greater age of the Australian soils as compared to those of Borneo the resemblances between the two soils are very marked. The geomorphological similarities are further brought out by G. A. Stewart (1956) in his "Soils of the Katherine-Darwin region of the Northern Territory", for here the lateritic red earths occupy an uplifted coastal peneplain in many ways analogous to that of the Semporna peninsula but probably of a greater age.

If this question of geomorphological evolution of the soils of the Gading family be compared with soil evolution in other areas it will be seen that the general course, as outlined in a previous section could be applied to the west coast of India, the laterite type area. For if Buchanan's original description of the area is read in full there can be no doubt that what he was describing was a coastal peneplain which had been uplifted and subsequently maturely dissected. It differs in age and degree of dissection from the Semporna peninsula of Borneo. W. H. Bryan (1939) in his paper on the Red Earth Residuals and their significance in South-Eastern Queensland makes a remark on the same subject.

"Associated with the more normal development of the Red Earths in these coastal regions, and quite patently variants of them, are laterites (lateritic red earths of Stephens) very similar to those originally described by Buchanan from the Malabar Coast of India".

Nye (1955) from the fact that quarry sites in the type area at Ibadan, southwest Nigeria are located in mid-slope concludes that the laterite occurs there due to catenary formation as described in his papers. However if the geomorphic development as suggested here has taken place, then if a peneplain was dissected the mottled zone, or Buchanan's laterite, would approach nearest to the surface in mid-slope. It is not to be denied that the material developed in the mid-slope of catenas as described by Nye and also Milne (1936) should be called laterite but it is postulated that its mode of formation is different from that in the type area.

The soils derived from limestone fall into two main groups. The Madai sub-family of soils, derived from hard, crystalline, deeply weathered pre-upper Eocene limestones. These are shallow red earths developing as pockets in karst like topography and are obvious members of Kubiena's "terra rossa" group. The Semporna family of soils which are derived from Quaternary to Recent coral limestone would appear to be more like a rendzina, the soil having an A/C profile, but the colour is almost an olive brown and the percentage of clay is extremely high. The shallow soils have a typical crumb structure, but the deeper soils tend to have a much coarser structure, which could be considered as being transitional to the much larger structural elements of the tropical black earths. Thus in this area of continuously high rainfall two distinct types of soil are derived from different types of limestone. This is in agreement with Australian experience.

Most of the developed soils in the Semporna peninsula i.e. soils which would formerly be known as zonal soils, would belong to the order of Oxisols according to the United States Soil Survey's 7th Approximation. The Gading soils would probably fit into Aquox sub-order and the Kinabutan, Apas and Table into the Acrox. The Semporna soils would belong to the Rendolls in the order of Mollisols and the other soils into various sub-orders of the Entisols.

(065087)

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(065067)

SOIL EROSION

Soil erosion of an accelerated type is common within the area. This is due to the young rocks which make up the region and the recent earth movements which have caused it to be totally out of adjustment with its base level of erosion. This is aggravated by the concentrated rainfall which is so typical of the region. The major factor causing the erosion to be kept down to the limits at which it is now is the cover of primary forest. If this cover is disturbed at all more erosion will occur until a new cover is established. However, if any development is to occur at all a certain amount of additional erosion is, in most cases, inevitable especially in the initial phases of clearing and establishing a crop.

Factors leading to soil erosion may be classified under three heads:

1. Factors inherent in the composition of the soil
2. External factors such as rainfall, topographic position and animals
3. The effect of man which can be treated separately as a special external factor.

This division is merely to facilitate the description of the various phenomena as they all interact.

I. Inherent factors

(a) The most important factor in a soil determining its susceptibility to erosion is the degree of heterogeneity either within a particular horizon or throughout the profile. Uniform soils are much less prone to erosion than heterogenous ones. Stony soils are an example of profile heterogeneity. The stones will be more resistant to erosion and after a little while will stand out as minor elevations and the erosive power of the rain will be concentrated on the interstitial soil material. This would tend to initiate gullying. In a uniform soil there is no selective concentration of rainfall and so no gullying can be initiated from this cause.

Where a poorly structured horizon (massive), overlies a much better structured and distinct horizon there is a case of horizon heterogeneity. If due to external factors this top horizon is penetrated the second horizon will be preferentially removed leaving the top horizon as an overhanging mass, which will eventually become detached in large pieces. This causes an accelerated type of erosion which could not possibly occur if the soil were uniform. Another type of heterogeneity is common in the area. It occurs where a slightly indurated ash overlies a resistant doleritic intrusive rock. A position which commonly occurs round the central hill masses, this is naturally an unstable relationship and when the interface between the two deposits is lubricated landslides on a large scale occur.

(b) Soil structure is also important in assessing susceptibility to erosion. It can be poor if it belongs to either of two extremes, single grained or massive. Soils which have either of these structures are prone to erosion. Single grain structure allows rain to dislodge particles and, if the soil is shallow, gullying is initiated as excess water flows downhill. A massive horizon will not allow rainwater to percolate in a uniform manner and this will give rise to a surface flow and an occasional concentrated downward movement where there is a major crack in the soil surface. This will aid erosion particularly if it is associated with horizon heterogeneity.

A well structured soil, however, behaves in a totally different manner. When the rainfall reaches its surface most of the water is absorbed into the soil mass. The flow of surface water is negligible, except after heavy rainfall, percolation through the soil mass is slow and soil erosion is on a very small scale.

II. External factors

(a) The most important external factor contributing to erosion is rainfall. From the sparse figures that are available, and from personal experience, it is evident that rain is mostly in the form of very heavy showers of short duration. Nothing could be more suited than this to cause soil erosion, for these heavy downpours tax the absorptive capacity of even the best

(065087)

structured and most friable of soils so that there is a certain amount of surface run-off and erosion in even the best of them.

(b) Topography is particularly important as a factor leading to erosion in this area as it is totally out of balance with the present base level. When an unstable topographic position is combined with any other factor leading to soil erosion the result is apt to be catastrophic, even under primary jungle. This out-of-balance topography causes even the most stable of soils, such as those of the Table family, to be prone to erosion at the margins.

(c) Erosion by animals is of some importance. The most serious is that due to wild pig. During the fruiting season they cause considerable damage to the surface horizon of the soil by rooting for fallen fruits and this could initiate erosion if the soil was in any way heterogenous. A second and more important way in which pigs cause soil erosion is due to their need for wallows.

III. The effect of man

If man is to exploit and develop this area at all the canopy of high primary forest must be broken to a greater or lesser extent. This will cause an intensification of all the factors memtioned above with the exception of that due to animals. Certain practices will lead to less intensification than others and these are to be preferred.

The various types of human activity leading to development and exploitation will be examined and various means suggested that should be employed to limit the deleterious effect on the soil.

(a) To achieve any development roads are essential. The breaking of the canopy and the formation of a long and impermeable strip of country is bound to intensify erosion. This can be brought within reasonable limits by protecting the roadside with covers. This is essential and must be done within a short time of constructing the road for otherwise soil deterioration may occur which is irreversible, for instance the surface horizon of soils of the Gading family lose the weak structure they have naturally and become massive and indurated or in other cases, such as in the soils of the Kinabutan and Kalumpang families gullying is initiated which is difficult to stop.

(b) Extraction of timber on a large scale by mechanical methods is a big factor in aiding subsequent agricultural development, for by this means a good road system is developed. In the course of logging operations a certain amount of soil deterioration is inevitable but as long as this does not become disastrous it can be considered as **worthwhile if a reasonable road system results.**

The area of land affected to a greater or lesser extent by logging operations (apart from road construction) is estimated at 6 per cent, this includes both skid tracks formed by tractors dragging logs from the stump to the landing areas and the landing areas themselves. No work has been done to ascertain how permanent this damage is to the soil. This work should be initiated without delay for most observations by the author were made on the effect on soils of the Mostyn sub-family, which are very well structured and developed on level topography. Work within these soils in block II is now completed and the poorly structured Limau soils have to be crossed to log areas on the much more erosive soils of the Kalumpang family. In addition the employment of machines such as the track loader and of bigger trucks to haul the loads greater distances may combine to **trigger off a disastrous increase in soil deterioration and erosion which may adversely** affect the whole of the soils of the middle Kalumpang valley. If the big developments envisaged by Mostyn Estates Limited and Darvel Tobacco Plantations are not to be put in jeopardy there must be a much tighter control of logging operations and road construction in the area.

(c) Agricultural development can be considered under three heads:

(i) Type of Crop

No further commercial plantings of annual crops should be allowed within the area. Annual food crops for natives should be confined to the **riverine** alluvium and the deeper soils of the Semporna family, and even then must be strictly watched to prevent abuse. There are areas of Gading soil round Tawau where attempts are being made to grow annual crops but the soil is deteriorating rapidly with the formation of a massive surface horizon which is subject to accelerated erosion. In such situations tree crops are to be encouraged but agronomic experiments must decide which ones.

(ii) Preference for tree crops

The less clearing that has to be carried out to establish an agricultural crop the better from the point of view of the soil. If complete clearing with burning is essential the quicker this can be done the better. Therefore cocoa planted under thinned primary forest is to be preferred to any other crop. Clearing of the second type is best carried out by a large concern which can clear, terrace and plant an area in the shortest possible time. The practice of slow clearing and a burn over a small area followed by a considerable interval before a crop is planted is to be discouraged.

(iii) Subsequent husbandry

To control soil erosion and deterioration the policy should be to form a cover as quickly as possible and keep it there. Anything which militates against this is to be critically examined. For instance in the case of coconuts which form a discontinuous canopy there should be a continuous grass cover. Thus the combination of coconuts and cattle is ideal from the point of view of both economics and protecting the soil. Even where annual crops are allowed care should be taken not to exhaust the soil by continuous cropping. This has occurred in certain areas of Bum Bum island where maize was grown continuously for a number of years.

Table 7 gives the susceptibility to erosion and potential land use of the soil families of the Semporna peninsula. The indications as to possible land use are extremely tentative and must be checked by agronomic experiments.

Table 7

SUSCEPTIBILITY TO EROSION AND POTENTIAL LAND USE OF THE SOIL FAMILIES OF THE SEMPORNA PENINSULA

Families	*Heterogeneity*	*Structure*	*Topography*	*Possible effects if cleared with care*	*Potential land use*
COOK	Shallow, stony profile	Moderate	Mountainous	Large scale erosion	Protective Forest
MALATAI	Shallow, stony profile	Moderate to good	Mountainous	Large scale erosion	Protective Forest
BESAR	Shallow, stony profile	Moderate to good	Mountainous	Large scale erosion	Protective Forest
TAJONG	Shallow ash soils over Dolerite in places	Poor to moderate	Mountainous	Large scale erosion and landslides	Protective Forest
BOMBALAI	Shallow, stony profile	Good	Mountainous	Erosion	Protective Forest
TABLE	Nil	Very good	Dissected Plateau	None	High quality tree crops
TABLE (MOSTYN)	Shallow, bouldery profile		Hummocky	None	Much more essentially a tree crop soil than the table soil
TINGKAYU	Shallow, stony profile	Moderate	Ridge but very fine state of dissection	Considerable increase in erosion	Protective Forest

Families	Heterogeneity	Structure	Topography	Possible effects if cleared with care	Potential land use
KALUMPANG	Nil	Moderate to good	Ridge	No increase in erosion	Tree crops possibly cocoa
CONNER	Generally stony	Moderate to good	Ridge	No increase in erosion	Tree crops possibly cocoa
KINABUTAN	Nil	Good	Ridge	No increase in erosion	Tree crops probably cocoa
SIPIT	Shallow to moderate profiles	Moderate to good	Erosional Platform	No increase in erosion	Tree crops possibly oil palm
KAWA	Shallow and stony profiles	Good	Erosional Platform	No increase in erosion	Tree crops possibly cocoa
GADING	Degraded topsoil often nodular	Poor to moderate	Depositional Platform	No increase in erosion	Tree crops such as rubber possibly oil palm
KUBOTA	A B C Profile	Poor	Depositional Coastal Platform	No increase in erosion	Forest reserve due to low natural fertility
SEMPORNA	Shallow to moderately deep	Good	Coral Platform	No increase in erosion	Range of crops with possibly annuals on the deeper soils
LIMAU-LUCIA	Nil	Moderate to good	Slightly Dissected Lake Beds	No increase in erosion	Tree crops but little idea of potential

(065087)

(065087)

Families	*Heterogeneity*	*Structure*	*Topography*	*Possible effects if cleared with care*	*Potential land use*
SAPANG-BALUNG	Deep	Good	Level Riverine Flats	No increase in erosion	Range of crops including annuals
TAJONG	Moderate to deep	Poor	Level Coastal Plain	No increase in erosion	Coconuts

PLANNING AND POTENTIAL

In discussing this topic there are three points to be kept in mind:

1. There is a great natural wealth of timber.

2. There is little likelihood of any mineral deposits being found.

3. There is a considerable agricultural potential.

Therefore planning and development must be thought of as a means of obtaining the greatest return from the timber without spoiling the land for subsequent agricultural development and the agriculture must be of such a kind as to preserve the soil. To achieve these ends certain conditions must be fulfilled and fundamental facts faced.

1. Development leading to the production of agricultural crops is going to yield much more to the colony than timber extraction on a rotational basis. Therefore to allow any area of the Semporna peninsula to be permanently reserved as a timber concession is unwise from the point of view of the future economy of North Borneo. That is not to say however that the land should not be logged under a series of short term leases.

2. Certain areas, if they are logged, contain land which is so steep and soils that are so unstable, that catastrophic erosion would occur which would affect the water regime of the whole region and would adversely affect the lower lying, more valuable areas capable of agricultural development. Such areas of steep forest should be designated as natural resources reserves and rigorously protected from both logging and agricultural development.

3. The natural vegetation of the area is high tropical forest. This is protecting the land to a great extent from excessive soil erosion. Therefore, if the area is to be developed to agricultural crops, which are to maintain the fertility of the area and to prevent erosion, this rain forest must be replaced by crops with a permanent canopy, which protects the soil from degradation and erosion. Therefore tree crops are to be preferred to annual crops.

Possible future land use

Caution must be used in suggesting that any particular crop may be grown on any particular soil, for soil analyses afford insufficient guidance and agronomic experiments on these soils are lacking. The only major clearing planted to agricultural crops occur in the Tawau, Mostyn and Semporna areas. From observations of crop growth in these areas and by taking into account pedogenetic factors observable in the field such as, degree of development of profile, type and age of parent materials, drainage conditions, structure and root distribution, it is possible to arrive at some tentative conclusions as to the value and potential of most of the areas in the peninsula. It must be stressed that these conclusions are tentative and they must be backed up with more analyses and agronomic experiments.

Due to steepness of slopes causing soil instability the following areas must be kept under permanent forest as natural resources reserves. They are:

1. The area north-west of the Merutai-Besar, Binuang watershed.

2. The Magdalena-Lucia-Maria-Andrassy mountain area.

3. The Wullersdorf area.

4. The Sigalong-Pock-Siagal area.

5. Timbun-Mata island.

The area between the upper Kalumpang and Binuang should be forbidden to agriculture but could possibly be logged with special precautions. The same is true of the Hewett area.

This accounts for some 375,000 acres of the 1,000,000 within the peninsula. The high level plateaux are of proved exceptional quality. They cover some 48,000 acres and are capable of growing a range of tropical crops.

The rest of the land in the peninsula may be divided into four classes of declining value.

1. The Apas, Conner and Kalumpang ridge soils, the Balung and Sapang riverine alluviums and the deeper soils of the Semporna family. The area of the these soils approximates to some 240,000 acres. This area could possible grow oil palms or cocoa.

2. The Limau and Lucia "lake bed" alluviums and the Sipit soils of the erosional coastal platform. Field criteria suggest that these soils should have a moderate agricultural potential but no crops have ever been grown on these soils so that it is essential at the earliest possible moment for agronomic experiments to be started. They cover some 140,000 acres.

3. The Gading soils of the depositional coastal platform if carefully cleared and a tree crop established are of moderate potential. It is possible that other crops apart from rubber may thrive, yet again agronomic experiments are required. Soils of the Tanjong family which are suited to the growth of coconuts can be included here. This gives a total of 73,000 acres in this group.

4. Soils of low agricultural potential are the Kubota family (40,000 acres) and the swamps (76,000 acres). Though the fresh or brackish water swamps could be reclaimed to grow coconuts as they have been in the Tawau area.

Thus in the Semporna peninsula there is a total of 513,000 acres of land of agricultural value of which not more than 15-20 per cent has been cleared in any way. If this area can be developed in a rational manner it could contribute a great deal to the future economy of North Borneo.

(065087)

Profile No: Merutai-Binuang I

Sub-family - Binuang

Laboratory No: 3549-50

	Horizon	1	2	3	4	5
	Moisture 100–105°C.	17.32	7.29			
Texture	50μ – 2 m.m.	50	67			
	2μ – 50μ	17	8			
	< 2μ	18	15			
	% $CaCO_3$		Tr.			
	Loss on Ignition	17.3	11.8			
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.8	7.5			
	pH in M/100 $CaCl_2$	6.5	7.0			
Exchangeable cations m.e./100 grms.	Ca					
	Mg					
	K					
	Na					
	Total					
	Exchangeable H+ m.e/100 grms.					
	Base Exchange Capacity by addition					
	% Base Saturation					

(065087)

II

Profile No: Mostyn 32

Sub-family - Madai

Laboratory No: 1183-85

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	9.89	9.05	9.58		
Texture	50μ - 2 m.m.	17	7	10		
	2μ - 50μ	28	22	25		
	< 2μ	37	67	61		
	% $CaCO_3$			Tr.		
	Loss on Ignition	22.1	10.7	9.6		
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.7	6.6	7.8		
	pH in M/100 $CaCl_2$	6.4	6.0	7.1		
Exchangeable cations m.e./100 grms.	Ca		52.35			
	Mg		1.27			
	K		0.26			
	Na		0.13			
	Total		54.00			
	Exchangeable H+ m.e/100 grms.		7.40			
	Base Exchange Capacity by addition		61.40			
	% Base Saturation		88			

(065087

Profile No: Merutai-Binuang 14

Laboratory No: 3602-06

Sub-family - Cook

	Horizon	1	2	3	4	5
Moisture 100-105°C.		2.11	1.55	2.06	1.80	1.98
Texture	50μ - 2 m.m.	44	48	41	48	45
	2μ - 50μ	29	28	25	19	20
	< 2μ	18	22	29	28	30
% $CaCO_3$						
Loss on Ignition		8.4	3.6	4.0	3.6	4.0
Organic carbon, % C.		2.9	0.65	0.40	0.20	0.18
Nitrogen, % N.		0.16	0.07	0.05	0.04	0.04
C/N ratio.		17.5	9.3	8.5	4.7	4.7
pH in water (1:2.5)		4.3	4.8	5.1	5.2	5.1
pH in M/100 $CaCl_2$		3.8	4.0	4.1	4.2	4.1
Exchangeable cations m.e./100 grms.	Ca	0.21	0.16	0.17	0.11	0.09
	Mg	0.11	0.09	0.18	0.12	0.04
	K	0.08	0.05	0.06	0.06	0.09
	Na	0.05	0.06	0.06	0.02	0.02
	Total	0.5	0.4	0.5	0.3	0.2
Exchangeable H+ m.e/100 grms.		9.8	8.8	10.6	9.8	7.7
Base Exchange Capacity by addition		10.3	9.2	11.1	10.1	7.9
% Base Saturation		4	4	4	3	3

(085087)

Profile No: Mostyn 43

Sub-family - Hewett

Laboratory No: 1789-92

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	5.29	5.18	5.92	5.56	
Texture	50μ - 2 m.m.	31	33	25	51	
	2μ - 50μ	33	29	28	13	
	< 2μ	23	34	41	32	
	% $CaCO_3$					
	Loss on Ignition	12.0	7.3	7.6	6.6	
	Organic carbon, % C.	4.1	0.7	0.6	0.4	
	Nitrogen, % N.	0.27	0.09	0.08	0.06	
	C/N ratio.	14.6	7.8	7.5	7.0	
	pH in water (1:2.5)	6.9	5.7	6.0	6.4	
	pH in M/100 $CaCl_2$	6.5	5.3	5.6	6.1	
Exchangeable cations m.e./100 grms.	Ca	32.19	26.30	26.90	30.08	
	Mg	1.71	2.70	3.18	3.20	
	K	0.72	0.17	0.13	0.11	
	Na	1.07	4.03	2.02	4.24	
	Total	35.5	33.2	32.2	37.6	
	Exchangeable H^+ m.e/100 grms.	2.6	3.1	4.2	1.0	
	Base Exchange Capacity by addition	38.1	36.3	36.4	38.6	
	% Base Saturation	94	91	89	97	

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Profile No: Kuala Kalumpang 1

Sub-family - Tinagat

Laboratory No: 1796

	Horizon	1	2	3	4	5
Moisture 100-105°C.		8.72				
Texture	50μ - 2 m.m.	31				
	2μ - 50μ	37				
	< 2μ	25				
% $CaCO_3$						
Loss on Ignition		9.5				
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)		6.1				
pH in M/100 $CaCl_2$		5.5				
Exchangeable cations m.e./100 grms.	Ca	23.58				
	Mg	19.61				
	K	0.10				
	Na	0.41				
Total		43.70				
Exchangeable H^+ m.e/100 grms.		5.4				
Base Exchange Capacity by addition		49.1				
% Base Saturation		89				

(065087)

VI

Profile No: Semporna 1

Laboratory No: 1677-78

Sub-family - Tinagat

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	10.43	9.51			
Texture	50μ - 2 m.m.	20	39			
	2μ - 50μ	28	21			
	< 2μ	38	32			
	% $CaCO_3$					
	Loss on Ignition	17.7	11.4			
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.8	6.4			
	pH in M/100 $CaCl_2$	6.5	5.9			
Exchangeable cations m.e./100 grms.	Ca	42.02	33.31			
	Mg	18.95	13.81			
	K	0.07	0.05			
	Na	0.08	0.13			
	Total	61.1	47.3			
	Exchangeable H+ m.e/100 grms.	7.5	6.4			
	Base Exchange Capacity by addition	68.6	53.7			
	% Base Saturation	89	88			

(065087)

Profile No: Balung 34

Sub-family - Besar

Laboratory No: 1749-52

	Horizon	1	2	3	4	5
Moisture 100-105°C.		3.23	3.55	6.90	5.64	
Texture	50μ - 2 m.m.	5	3	3	19	
	2μ - 50μ	65	59	37	52	
	< 2μ	24	33	56	19	
% $CaCO_3$						
Loss on Ignition		7.3	6.7	10.1	8.0	
Organic carbon, % C.		1.2	0.53	0.48	0.20	
Nitrogen, % N.		0.15	0.06	0.05	0.02	
C/N ratio.		8.6	8.5	9.0	10.0	
pH in water (1:2.5)		5.8	5.3	5.2	5.0	
pH in M/100 $CaCl_2$		5.2	4.5	4.6	4.2	
Exchangeable cations m.e./100 grms.	Ca	9.41	8.97	10.80	4.08	
	Mg	0.76	0.50	3.16	7.84	
	K	0.10	0.06	0.23	0.51	
	Na	0.09	0.09	0.11	0.27	
	Total	10.40	9.7	14.3	12.0	
Exchangeable H+ m.e/100 grms.		4.7	5.2	9.5	12.7	
Base Exchange Capacity by addition		15.1	14.9	23.8	24.7	
% Base Saturation		69	65	60	40	

(085087)

VIII

Profile No: Semporna 12

Laboratory No: 1793-95

Sub-family - Sinon

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	3.08	3.98	4.33		
Texture	50µ - 2 m.m.	34	37	53		
	2µ - 50µ	35	30	17		
	< 2µ	22	28	26		
	% $CaCO_3$					
	Loss on Ignition	7.8	5.8	4.9		
	Organic carbon, % C.	2.4	0.8	0.4		
	Nitrogen, % N.	0.09	0.08	0.05		
	C/N ratio.	25.6	10.0	8.0		
	pH in water (1:2.5)	6.1	6.2	6.2		
	pH in M/100 $CaCl_2$	5.7	5.8	6.0		
Exchangeable cations m.e./100 grms.	Ca	11.20	14.42	14.88		
	Mg	3.53	2.30	3.52		
	K	0.30	0.05	0.05		
	Na	0.48	0.55	0.50		
	Total	15.5	18.1	19.0		
	Exchangeable H^+ m.e/100 grms.	5.2	3.1	2.5		
	Base Exchange Capacity by addition	20.7	21.0	21.5		
	% Base Saturation	75	86	88		

(065087)

Profile No: Kuala Kalumpang 15

Laboratory No: 1968-72

Sub-family - Tajong

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	4.07	3.68	6.17	6.02	5.18
Texture	50µ - 2 m.m.	51	47	47	59	70
	2µ - 50µ	29	29	29	19	14
	< 2µ	18	21	22	20	13
	% $CaCO_3$					
	Loss on Ignition	8.6	5.8	6.9	6.5	5.3
	Organic carbon, % C.	2.1	0.3	0.16	0.09	0.06
	Nitrogen, % N.	0.22	0.05	0.03	0.02	0.01
	C/N ratio.	9.5	7.5	5.3	4.5	6.0
	pH in water (1:2.5)	6.8	5.2	5.0	5.4	6.0
	pH in M/100 $CaCl_2$	6.5	4.2	4.5	4.8	5.7
Exchangeable cations m.e./100 grms.	Ca	23.6	3.04	22.4	30.5	32.8
	Mg	5.45	5.27	6.40	4.28	2.93
	K	1.05	0.57	0.32	0.22	0.13
	Na	0.31	0.28	0.60	1.15	1.15
	Total	30.6	8.1	29.8	36.2	37.1
	Exchangeable H+ m.e/100 grms.	-	14.7	3.6	-	-
	Base Exchange Capacity by addition	28.2	22.8	33.4	31.0	30.2
	% Base Saturation	Sat.	35	89	Sat.	Sat.

X

Profile No: Balung 32

Sub-family - Wullersdorf

Laboratory No: 1739-41

	Horizon	1	2	3	4	5
Moisture 100-105°C.		12.42	0.28	0.32		
Texture	50μ - 2 m.m.	ORGANIC HORIZON	31	32		
	2μ - 50μ		53	54		
	< 2μ		12	9		
% $CaCO_3$						
Loss on Ignition		95.5	5.4	5.4		
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)		3.3	4.3	4.9		
pH in M/100 $CaCl_2$		2.5	3.7	4.2		
Exchangeable cations m.e./100 grms.	Ca		0.10	0.26		
	Mg		0.01	<0.01		
	K		0.02	0.02		
	Na		0.04	0.04		
Total			0.2	0.3		
Exchangeable H+ m.e/100 grms.			5.4	4.5		
Base Exchange Capacity by addition			5.6	4.8		
% Base Saturation			4	6		

(065087)

Profile No: Tawau 71

Sub-family - Maria

Laboratory No: 1614-17

Horizon	1	2	3	4	5
Moisture 100-105°C.	14.04	7.14	7.01	5.46	
Texture 50μ - 2 m.m.	20	28	46	46	
Texture 2μ - 50μ	33	30	21	20	
Texture < 2μ	38	37	27	30	
% $CaCO_3$					
Loss on Ignition	13.0	8.9	8.4	7.1	
Organic carbon, % C.					
Nitrogen, % N.					
C/N ratio.					
pH in water (1:2.5)	6.2	5.3	5.0	5.8	
pH in M/100 $CaCl_2$	5.9	4.6	4.5	4.7	
Exchangeable cations m.e./100 grms. Ca	20.18	7.09	2.64	6.37	
Exchangeable cations m.e./100 grms. Mg	3.93	3.45	4.06	4.05	
Exchangeable cations m.e./100 grms. K	0.90	0.86	0.65	0.23	
Exchangeable cations m.e./100 grms. Na	0.02	0.04	0.10	0.16	
Total	25.0	11.4	7.5	10.8	
Exchangeable H^+ m.e/100 grms.	5.9	7.1	8.8	5.8	
Base Exchange Capacity by addition	30.9	18.5	16.3	16.6	
% Base Saturation	81	62	46	65	

(065087)

XII

Profile No: Tawau 12

Sub-family - Bombalai

Laboratory No: 944-46

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	9.58	9.08	9.40		
Texture	50µ – 2 m.m.	42	30	44		
	2µ – 50µ	22	34	18		
	< 2µ	17	25	28		
	% $CaCO_3$					
	Loss on Ignition	20.5	13.7	12.4		
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	5.3	5.4	5.4		
	pH in M/100 $CaCl_2$	5.1	4.7	4.7		
Exchangeable cations m.e./100 grms.	Ca		6.99	4.30		
	Mg		9.39	7.66		
	K		0.03	0.09		
	Na		0.23	0.60		
	Total		16.6	14.7		
	Exchangeable H+ m.e/100 grms.		11.8	11.6		
	Base Exchange Capacity by addition		28.4	26.3		
	% Base Saturation		58	56		

(065087)

Profile No: Balung 16

Laboratory No: 1086-88

Sub-family - Tiger

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	3.98	2.35	1.28		
Texture	50μ - 2 m.m.	38	25	62		
	2μ - 50μ	23	32	17		
	< 2μ	18	38	19		
	% $CaCO_3$					
	Loss on Ignition	22.4	9.3	4.3		
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.7	6.1	6.1		
	pH in M/100 $CaCl_2$	6.4	5.7	5.7		
Exchangeable cations m.e./100 grms.	Ca		6.81	2.90		
	Mg		4.13	2.47		
	K		0.25	0.12		
	Na		0.64	0.66		
	Total		11.8	6.2		
	Exchangeable H+ m.e/100 grms.		8.5	3.9		
	Base Exchange Capacity by addition		20.3	10.1		
	% Base Saturation		58	61		

(065087)

XIV

Profile No: Balung 5

Sub-family - Jarangan

Laboratory No: 1037-40

Horizon		1	2	3	4	5
Moisture 100-105°C.		2.49	2.47	1.18	1.17	
Texture	50μ - 2 m.m.	6	2	6	3	
	2μ - 50μ	21	12	8	7	
	< 2μ	66	81	82	86	
% $CaCO_3$						
Loss on Ignition		14.1	12.8	12.4	12.7	
Organic carbon, % C.		2.26	0.89	0.44	0.37	
Nitrogen, % N.		0.185	0.081	0.041	0.032	
C/N ratio.		12.2	11.0	10.7	11.5	
pH in water (1:2.5)		4.4	4.6	4.7	4.8	
pH in M/100 $CaCl_2$		3.9	4.1	4.3	4.2	
Exchangeable cations m.e./100 grms.	Ca	0.03	0.16	0.09	0.07	
	Mg	0.15	0.16	0.16	0.10	
	K	0.05	0.03	0.04	0.02	
	Na	0.06	0.10	0.17	0.10	
Total		0.2	0.5	0.5	0.3	
Exchangeable H+ m.e/100 grms.		14.0	8.8	7.8	7.6	
Base Exchange Capacity by addition		14.2	9.3	8.3	7.9	
% Base Saturation		1	5	6	4	

Profile No: Tawau 16

Laboratory No: 959-62

Sub-family - Table

		1	2	3	4	5
	Horizon	1	2	3	4	5
	Moisture 100-105°C.	7.19	5.77	5.97	5.66	
Texture	50μ - 2 m.m.	25	0	0	0	
	2μ - 50μ	22	21	14	20	
	< 2μ	36	76	83	78	
	% $CaCO_3$					
	Loss on Ignition	20.4	14.5	13.1	13.0	
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	5.2	5.0	5.0	5.2	
	pH in M/100 $CaCl_2$	4.9	4.5	4.5	4.7	
Exchangeable cations m.e./100 grms.	Ca		0.57	0.19	0.25	
	Mg		0.51	0.09	0.34	
	K		0.12	0.20	0.46	
	Na		0.09	0.08	0.08	
	Total		1.3	0.6	1.1	
	Exchangeable H^+ m.e/100 grms.		10.4	10.2	9.7	
	Base Exchange Capacity by addition		11.7	10.8	10.8	
	% Base Saturation		11	6	10	

XVI

Profile No: Balung 13

Laboratory No: 1074-77

Sub-family - Quoin

Horizon		1	2	3	4	5
Moisture 100-105°C.		Missing	6.50	6.25	5.99	7.56
Texture	50µ - 2 m.m.		0	0	0	0
	2µ - 50µ		21	11	11	11
	< 2µ		79	89	88	89
% $CaCO_3$						
Loss on Ignition			15.7	14.4	13.8	15.8
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)			5.0	5.3	5.0	4.9
pH in M/100 $CaCl_2$			4.6	4.6	4.4	4.3
Exchangeable cations m.e./100 grms.	Ca		0.25	0.31	0.20	0.49
	Mg		0.75	0.17	0.10	0.12
	K		0.21	0.18	0.30	0.20
	Na		0.20	0.71	0.26	0.26
	Total		1.4	1.4	0.9	1.1
Exchangeable H+ m.e/100 grms.			10.9	9.3	9.2	9.3
Base Exchange Capacity by addition			12.3	10.7	10.1	10.4
% Base Saturation			11	13	9	11

(065087)

Profile No: Mostyn 34

Sub-family - Mostyn

Laboratory No: 1666-69

	Horizon	1	2	3	4	5
Moisture 100-105°C.		7.33	5.95	7.29	7.91	
Texture	50μ - 2 m.m.	7	0	0	20	
	2μ - 50μ	26	21	18	24	
	< 2μ	54	77	82	37	
% $CaCO_3$						
Loss on Ignition		18.7	13.8	13.4	22.5	
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)		6.1	4.8	5.0	6.5	
pH in M/100 $CaCl_2$		5.7	4.5	4.4	6.2	
Exchangeable cations m.e./100 grms.	Ca		0.60	0.12		
	Mg		1.22	0.51		
	K		0.07	0.05		
	Na		0.08	0.13		
Total			2.0	0.8		
Exchangeable H^+ m.e/100 grms.			11.7	11.8		
Base Exchange Capacity by addition			13.7	12.6		
% Base Saturation			15	6		

XVIII

Profile No: Mostyn 45

Sub-family - Tingkayu

Laboratory No: 1870-72

Horizon		1	2	3	4	5
Moisture 100-105°C.		7.20	7.85	9.58		
Texture	50μ - 2 m.m.	19	33	34		
	2μ - 50μ	37	29	16		
	< 2μ	37	35	47		
% $CaCO_3$						
Loss on Ignition		10.8	8.2	9.7		
Organic carbon, % C.		1.9	0.5	0.4		
Nitrogen, % N.		0.2	0.064	0.059		
C/N ratio.		9.5	8.5	5.7		
pH in water (1:2.5)		5.0	5.3	5.2		
pH in M/100 $CaCl_2$		4.5	4.8	4.8		
Exchangeable cations m.e./100 grms.	Ca	18.03	29.18	36.35		
	Mg	9.46	10.22	11.40		
	K	0.06	0.02	0.02		
	Na	0.41	0.42	1.07		
Total		26.0	39.9	48.8		
Exchangeable H+ m.e/100 grms.		13.3	4.0	0.4		
Base Exchange Capacity by addition		39.9	43.9	49.2		
% Base Saturation		70	91	99		
		SO_4				

(065087)

Profile No: Kalumpang 20

Sub-family - Mantri

Laboratory No: 1276-79

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	7.31	5.26	5.40	5.20	
Texture	50μ - 2 m.m.	35	11	19	38	
	2μ - 50μ	33	45	39	30	
	< 2μ	23	35	33	20	
	% $CaCO_3$	0.3				
	Loss on Ignition	20.0	9.1	8.3	6.6	
	Organic carbon, % C.	7.8	1.4	0.6	0.1	
	Nitrogen, % N.	0.63	0.17	0.08	0.02	
	C/N ratio.	12.4	8.8	6.3	5	
	pH in water (1:2.5)	7.1	5.8	5.7	5.9	
	pH in M/100 $CaCl_2$	6.8	5.1	4.8	4.9	
Exchangeable cations m.e./100 grms.	Ca		14.06	12.22	24.15	
	Mg		5.84	2.70	3.14	
	K		0.13	0.05	0.04	
	Na		0.44	1.61	2.12	
	Total		20.4	16.6	29.4	
	Exchangeable H^+ m.e/100 grms.		16.0	6.9	-	
	Base Exchange Capacity by addition		36.4	23.5	29.1	
	% Base Saturation		56	71	SO_4	

(065087)

Profile No: Kalumpang 38

Sub-family - Kalumpang

Laboratory No: 1361-65

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	6.94	5.73	7.28	6.54	4.61
Texture	50μ - 2 m.m.	13	9	8	17	20
	2μ - 50μ	52	51	51	53	62
	< 2μ	26	36	36	25	14
	% $CaCO_3$					
	Loss on Ignition	11.9	8.0	9.3	7.7	5.4
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.1	5.4	5.4	5.5	5.7
	pH in M/100 $CaCl_2$	5.7	4.5	4.3	4.1	4.4
Exchangeable cations m.e./100 grms.	Ca	16.74	4.18	2.12	1.65	12.19
	Mg	7.77	7.97	8.14	8.42	7.42
	K	0.29	0.06	0.06	0.07	0.06
	Na	0.48	0.31	0.46	0.74	0.49
	Total	25.3	12.5	10.8	10.9	20.2
	Exchangeable H+ m.e/100 grms.	8.3	11.2	14.8	18.7	10.6
	Base Exchange Capacity by addition	33.6	23.7	25.6	29.6	30.8
	% Base Saturation	75	53	42	37	66

(065087)

Profile No: Tawau 74 | Sub-family - Kinabutan

Laboratory No: 1626-29

	Horizon	1	2	3	4	5
Moisture 100-105°C.		2.49	3.58	2.60	3.36	
Texture	50μ - 2 m.m.	9	9	14	19	
	2μ - 50μ	56	39	25	19	
	< 2μ	30	49	59	59	
% $CaCO_3$						
Loss on Ignition		7.9	7.5	7.6	9.0	
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)		3.8	4.2	4.5	4.4	
pH in M/100 $CaCl_2$		3.6	3.7	4.0	3.9	
Exchangeable cations m.e./100 grms.	Ca	0.17	0.22	0.10	0.20	
	Mg	0.14	0.10	0.16	0.15	
	K	0.08	0.04	0.03	0.04	
	Na	0.09	0.04	0.03	0.03	
	Total	0.5	0.4	0.3	0.4	
Exchangeable H^+ m.e/100 grms.		13.7	11.9	12.1	11.8	
Base Exchange Capacity by addition		14.2	12.3	12.4	12.2	
% Base Saturation		4	3	2	3	

XXI(a)

Darby and Orchard - yellow earth

derived from dolerite - Natal Mist Belt

	Horizon	1	2	3	4	5
	Moisture 100-105°C.					
Texture	200µ - 2 m.m.	11.6	5.1	14.2		
Texture	50µ - 2 m.m.					
Texture	20µ - 200µ	20.6	17.9	27.8		
Texture	2µ - 50µ					
Texture	2µ - 20µ	10.4	16.1	16.8		
Texture	< 2µ	57.5	60.8	41.2		
	% $CaCO_3$					
	Loss on Ignition					
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	4.4	4.8	5.1		
	pH in M/100 $CaCl_2$					
Exchangeable cations m.e./100 grms.	Ca	.50	-	.20		
Exchangeable cations m.e./100 grms.	Mg	.55	-	.60		
Exchangeable cations m.e./100 grms.	K	.20	-	.05		
Exchangeable cations m.e./100 grms.	Na	.10	-	.20		
	Total	1.35		1.05		
	Exchangeable H+ m.e/100 grms.	9.30		3.20		
	Base Exchange Capacity by addition	10.70		4.28		
	% Base Saturation	12.6		24.5		
	SiO_2/R_2O_3	.66	.76	1.19		

(065087)

Profile No: Balung 28

Laboratory No: 1447-51

Sub-family - Apas

	Horizon	1	2	3	4	5
Moisture 100-105°C.		4.80	5.19	3.81	3.89	3.98
Texture	50μ - 2 m.m.	9	6	24	24	11
	2μ - 50μ	25	18	11	11	12
	< 2μ	60	72	61	61	73
% $CaCO_3$						
Loss on Ignition		12.1	11.5	10.6	10.8	11.0
Organic carbon, % C.		1.67	0.82	0.35	0.27	0.23
Nitrogen, % N.		0.13	0.06	0.03	0.02	0.02
C/N ratio.		12.9	13.0	13.5	13.5	11.0
pH in water (1:2.5)		4.4	4.9	4.8	5.2	4.8
pH in M/100 $CaCl_2$		3.8	4.1	4.2	4.1	4.2
Exchangeable cations m.e./100 grms.	Ca	0.21	0.14	0.15	0.14	0.14
	Mg	0.40	0.10	0.05	0.07	0.07
	K	0.08	0.04	0.02	0.03	0.03
	Na	0.08	0.06	0.04	0.09	0.06
	Total	0.8	0.3	0.3	0.3	0.3
Exchangeable H^+ m.e/100 grms.		10.6	8.6	7.8	8.2	8.1
Base Exchange Capacity by addition		11.4	8.9	8.1	8.5	8.4
% Base Saturation		7	3	4	4	4

(065087)

XXIII

Profile No: Tawau 33

Sub-family - Quarry

Laboratory No: 1458-60

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	4.64	5.05	4.30		
Texture	50µ - 2 m.m.	26	32	46		
	2µ - 50µ	45	36	32		
	< 2µ	25	29	20		
	% $CaCO_3$					
	Loss on Ignition	6.4	5.6	3.6		
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.1	5.7	6.1		
	pH in M/100 $CaCl_2$	5.6	4.8	5.2		
Exchangeable cations m.e./100 grms.	Ca	4.78	3.53	7.61		
	Mg	2.74	2.51	3.19		
	K	0.38	0.09	0.06		
	Na	0.10	0.14	0.47		
	Total	8.0	6.3	11.3		
	Exchangeable H^+ m.e/100 grms.	6.8	5.2	2.5		
	Base Exchange Capacity by addition	14.8	11.5	13.8		
	% Base Saturation	54	55	82		

(065087)

Profile No: Sipit-Samarang 4

Sub-family - Burong

Laboratory No: 1817-21

	Horizon	1	2	3	4	5
Moisture 100-105°C.		3.66	3.97	5.04	5.76	6.36
Texture	50μ - 2 m.m.	32	25	27	31	17
	2μ - 50μ	40	35	31	33	27
	< 2μ	20	35	35	33	41
% $CaCO_3$						
Loss on Ignition		8.9	7.2	8.7	7.4	7.5
Organic carbon, % C.		2.0	0.5	0.3	0.2	0.14
Nitrogen, % N.		0.19	0.09	0.05	0.03	0.03
C/N ratio.		10.6	6.3	6.0	6.7	5.4
pH in water (1:2.5)		5.7	5.2	5.4	5.5	5.4
pH in M/100 $CaCl_2$		5.3	4.4	4.6	4.8	4.9
Exchangeable cations m.e./100 grms.	Ca	9.01	3.66	5.23	9.40	10.90
	Mg	3.98	4.69	7.84	9.31	9.37
	K	0.34	0.17	0.05	0.08	0.31
	Na	0.08	0.17	0.33	0.53	0.45
Total		13.4	8.7	13.4	19.3	21.0
Exchangeable H^+ m.e/100 grms.		3.8	8.6	10.0	10.0	12.3
Base Exchange Capacity by addition		17.2	17.3	23.4	29.3	33.3
% Base Saturation		78	50	57	66	63

(065087)

XXV

Profile No: Mostyn 39

Sub-family - Garam

Laboratory No: 1770-74

	Horizon	1	2	3	4	5
Moisture $100-105^{o}C$.		5.76	5.72	6.46	7.56	5.87
Texture	50µ - 2 m.m.	17	7	5	3	37
	2µ - 50µ	34	34	30	37	34
	< 2µ	44	56	63	57	23
% $CaCO_3$						
Loss on Ignition		10.8	7.2	7.6	7.9	7.1
Organic carbon, % C.		2.9	0.8	0.5	0.4	0.13
Nitrogen, % N.		0.26	0.10	0.07	0.06	0.03
C/N ratio.		11.2	8.0	7.1	6.7	4.3
pH in water (1:2.5)		4.9	4.6	4.6	4.7	5.0
pH in M/100 $CaCl_2$		4.2	3.9	4.0	3.9	4.3
Exchangeable cations m.e./100 grms.	Ca	5.88	0.36	0.13	0.09	46.8
	Mg	2.81	0.40	0.14	0.10	0.24
	K	0.34	0.13	0.10	0.10	0.16
	Na	0.05	0.06	0.06	0.09	32.4
	Total	9.1	1.0	0.4	0.4	79.6
Exchangeable H+ m.e/100 grms.		16.5	23.5	27.5	28.4	3.5
Base Exchange Capacity by addition		25.6	24.5	27.9	28.8	83.1
% Base Saturation		35	4	1	1	96

(065087)

Profile No: Sipit-Semarang 1

Sub-family - Sipit

Laboratory No: 1803-07

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	1.85	2.87	3.14	3.37	3.55
Texture	50µ - 2 m.m.	14	14	10	10	11
	2µ - 50µ	51	37	36	34	31
	< 2µ	33	48	54	56	58
	% $CaCO_3$					
	Loss on Ignition	5.0	5.4	5.1	5.3	5.6
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	4.3	4.7	4.5	4.8	4.6
	pH in M/100 $CaCl_2$	4.0	4.0	3.9	3.9	4.0
Exchangeable cations m.e./100 grms.	Ca	1.28	0.16	0.05	0.09	0.01
	Mg	1.17	0.62	0.53	0.38	0.53
	K	0.29	0.12	0.12	0.18	0.23
	Na	0.06	0.09	0.07	0.09	0.08
	Total	2.8	1.0	0.8	0.7	0.9
	Exchangeable H+ m.e/100 grms.	11.9	13.2	13.2	14.6	15.2
	Base Exchange Capacity by addition	14.7	14.2	14.0	15.3	16.1
	% Base Saturation	19	7	6	5	6

(085087)

XXVII

Profile No: Balung 30

Sub-family - Membalua

Laboratory No: 1439-43

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	7.03	5.65	12.71	12.29	12.69
Texture	50μ - 2 m.m.	37	56	16	17	37
	2μ - 50μ	26	14	3	5	10
	< 2μ	29	25	78	75	48
	% $CaCO_3$					
	Loss on Ignition	10.7	8.0	12.1	11.0	9.7
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.2	5.2	4.8	4.6	4.9
	pH in M/100 $CaCl_2$	6.0	4.4	3.6	3.6	3.9
Exchangeable cations m.e./100 grms.	Ca	11.28	2.95	1.80	3.25	6.15
	Mg	4.37	2.23	5.43	7.11	9.51
	K	0.38	0.19	0.08	0.05	0.07
	Na	0.35	0.15	0.48	1.50	1.46
	Total	16.4	5.5	7.8	11.9	17.2
	Exchangeable H+ m.e/100 grms.	6.6	8.0	18.8	18.9	17.0
	Base Exchange Capacity by addition	23.0	13.5	26.6	30.8	34.2
	% Base Saturation	71	41	29	39	50

Profile No: Balung 10

Sub-family - Kawa

Laboratory No: 1061-62

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	3.36	3.36			
Texture	50μ - 2 m.m.	16	27			
	2μ - 50μ	34	22			
	< 2μ	38	44			
	% $CaCO_3$					
	Loss on Ignition	15.6	11.2			
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	5.9	5.0			
	pH in M/100 $CaCl_2$	5.3	4.3			
Exchangeable cations m.e./100 grms.	Ca	15.39	4.31			
	Mg	4.97	3.60			
	K	0.23	0.08			
	Na	0.16	0.11			
	Total	20.8	8.1			
	Exchangeable H^+ m.e/100 grms.	10.9	16.0			
	Base Exchange Capacity by addition	31.7	24.1			
	% Base Saturation	66	34			

(065087)

XXIX

Profile No: Tawau 45

Sub-family - Imam

Laboratory No: 1512-15

Horizon		1	2	3	4	5
Moisture 100-105^{o}C.		2.17	2.46	3.70	6.55	
Texture	50µ - 2 m.m.	32	32	20	15	
	2µ - 50µ	36	30	22	17	
	< 2µ	29	37	57	66	
% $CaCO_3$						
Loss on Ignition		6.0	4.5	6.7	8.8	
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)		4.9	4.5	4.5	4.6	
pH in M/100 $CaCl_2$		4.0	3.6	3.7	3.8	
Exchangeable cations m.e./100 grms.	Ca	<0.01	<0.01	<0.01	<0.01	
	Mg	0.10	0.04	0.03	0.04	
	K	0.01	0.01	0.01	0.02	
	Na	<0.01	<0.01	<0.01	<0.01	
Total		0.1	0.1	0.1	0.1	
Exchangeable H+ m.e/100 grms.		11.2	8.9	11.3	12.4	
Base Exchange Capacity by addition		11.3	9.0	11.4	12.5	
% Base Saturation		1	1	1	1	

(065087)

Profile No: Balung 2

Sub-family - Gading

Laboratory No: 1022-26

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	0.58	0.55	0.62	1.73	2.22
Texture	50μ - 2 m.m.	55	61	53	31	17
	2μ - 50μ	21	16	13	14	14
	< 2μ	21	21	31	52	65
	% $CaCO_3$					
	Loss on Ignition	4.8	4.4	6.1	8.5	10.9
	Organic carbon, % C.	1.18	0.44	0.27	0.27	0.24
	Nitrogen, % N.	0.085	0.039	0.024	0.022	0.022
	C/N ratio.	13.9	11.3	12.4	12.3	10.9
	pH in water (1:2.5)	4.6	4.8	4.9	5.0	4.8
	pH in M/100 $CaCl_2$	4.0	4.3	4.3	3.9	4.1
Exchangeable cations m.e./100 grms.	Ca	0.06	0.03	0.02	<0.01	0.09
	Mg	0.08	0.04	0.05	0.01	0.08
	K	0.02	0.01	0.02	0.02	0.02
	Na	0.03	0.02	0.07	0.05	0.07
	Total	0.2	0.1	0.2	0.1	0.3
	Exchangeable H+ m.e/100 grms.	11.1	5.9	4.4	6.1	7.1
	Base Exchange Capacity by addition	11.3	6.0	4.6	6.2	7.4
	% Base Saturation	2	2	4	2	4

(065087)

XXXI

Profile No: Semporna 11

Sub-family - Semporna

Laboratory No: 1713-16

	Horizon	1	2	3	4	5
Moisture 100-105°C.		9.61	10.00	10.04	4.73	
Texture	50μ - 2 m.m.	15	1	2	37	
	2μ - 50μ	27	23	21	19	
	< 2μ	50	68	70	42	
% $CaCO_3$		1.8	0.5	1.2	58.3	
Loss on Ignition		19.2	14.4	13.8	5.2	
Organic carbon, % C.		5.7	2.1	1.6	0.4	
Nitrogen, % N.		0.40	0.29	0.22	0.06	
C/N ratio.		13.7	7.3	7.0	6.7	
pH in water (1:2.5)		7.4	7.3	7.4	8.1	
pH in M/100 $CaCl_2$		7.2	6.8	7.2	7.7	
Exchangeable cations m.e./100 grms.	Ca					
	Mg					
	K					
	Na					
Total						
Exchangeable H+ m.e/100 grms.						
Base Exchange Capacity by addition						
% Base Saturation						

(065087

Profile No: Mostyn 42

Laboratory No: 1784-88

Sub-family - Limau family

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	3.51	2.80	2.91	4.31	4.27
Texture	50μ - 2 m.m.	16	13	9	5	11
	2μ - 50μ	48	43	43	32	36
	< 2μ	26	39	44	59	49
	% $CaCO_3$					
	Loss on Ignition	10.1	5.4	5.0	6.1	5.7
	Organic carbon, % C.	3.8	0.7	0.4	0.3	0.2
	Nitrogen, % N.	0.31	0.09	0.08	0.06	0.05
	C/N ratio.	12.3	7.8	5.0	5.0	4.0
	pH in water (1:2.5)	4.2	4.7	4.8	5.0	4.9
	pH in M/100 $CaCl_2$	3.8	4.0	4.0	4.1	4.1
Exchangeable cations m.e./100 grms.	Ca	0.63	0.13	0.08	0.09	0.11
	Mg	0.53	0.14	0.11	0.07	0.08
	K	0.17	0.06	0.07	0.12	0.13
	Na	0.05	0.04	0.03	0.06	0.04
	Total	1.4	0.4	0.3	0.3	0.4
	Exchangeable H+ m.e/100 grms.	16.5	13.4	14.3	19.7	17.7
	Base Exchange Capacity by addition	17.9	13.8	14.6	20.0	18.1
	% Base Saturation	8	3	2	2	2

(066087)

XXXIII

Profile No: Balung 33

Sub-family - Lucia family

Laboratory No: 1745-48

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	0.89	0.49	0.86	1.28	
Texture	50μ - 2 m.m.	29	32	27	27	
	2μ - 50μ	59	51	50	42	
	< 2μ	9	17	23	31	
	% $CaCO_3$					
	Loss on Ignition	3.5	1.7	2.5	3.4	
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	4.4	4.6	4.6	4.7	
	pH in M/100 $CaCl_2$	4.0	4.0	4.0	3.9	
Exchangeable cations m.e./100 grms.	Ca	0.14	0.22	0.39	0.10	
	Mg	0.10	0.03	<0.01	0.04	
	K	0.04	0.02	0.02	0.01	
	Na	0.02	0.03	0.03	0.03	
	Total	0.03	0.03	0.5	0.2	
	Exchangeable H+ m.e/100 grms.	9.6	5.7	6.3	8.1	
	Base Exchange Capacity by addition	9.9	6.0	6.8	8.3	
	% Base Saturation	3	5	7	2	

Profile No: Sipit-Semarang 13

Sub-family - Sapang family

Laboratory No: 1859-61

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	5.41	5.52	4.50		
Texture	50μ - 2 m.m.	18	14	20		
	2μ - 50μ	52	48	43		
	< 2μ	22	35	35		
	% $CaCO_3$					
	Loss on Ignition	10.5	6.3	5.2		
	Organic carbon, % C.					
	Nitrogen, % N.					
	C/N ratio.					
	pH in water (1:2.5)	6.4	5.6	5.6		
	pH in M/100 $CaCl_2$	6.1	4.8	4.8		
Exchangeable cations m.e./100 grms.	Ca	19.44	6.22	3.39		
	Mg	14.43	11.70	10.09		
	K	0.24	0.13	0.10		
	Na	0.12	0.25	0.28		
	Total	34.2	18.3	13.9		
	Exchangeable H^+ m.e/100 grms.	6.5	10.7	8.5		
	Base Exchange Capacity by addition	40.7	29.0	22.4		
	% Base Saturation	84	63	62		

Profile No: Balung 23

Sub-family - Balung

Laboratory No: 1110-14

Horizon		1	2	3	4	5
Moisture 100-105°C.		6.65	6.57	6.61	6.52	6.02
Texture	50µ - 2 m.m.	13	6	11	17	31
	2µ - 50µ	57	59	53	52	43
	< 2µ	20	27	29	25	20
% $CaCO_3$						
Loss on Ignition		11.9	10.3	9.5	8.5	7.7
Organic carbon, % C.		2.57	1.45	0.96	0.71	0.63
Nitrogen, % N.		0.266	0.178	0.127	0.085	0.062
C/N ratio.		9.7	8.2	7.6	8.3	10.2
pH in water (1:2.5)		5.7	6.1	6.0	6.3	6.2
pH in M/100 $CaCl_2$		5.2	5.7	5.7	5.7	5.6
Exchangeable cations m.e./100 grms.	Ca	17.93	17.05	19.21	18.82	19.18
	Mg	5.48	5.84	5.22	4.80	5.63
	K	0.25	0.51	0.40	0.19	0.12
	Na	0.10	0.23	0.26	0.34	0.35
Total		23.8	23.6	25.1	24.2	25.3
Exchangeable H+ m.e/100 grms.		12.0	6.8	8.5	6.1	6.6
Base Exchange Capacity by addition		35.8	30.4	33.6	30.3	31.9
% Base Saturation		66	78	75	80	79

Profile No: Tawau 29

Sub-family - Tawau

Laboratory No: 1007-10

	Horizon	1	2	3	4	5
Moisture 100-105°C.		7.70	8.81	9.63	8.59	
Texture	50μ - 2 m.m.	6	5	14	2	
	2μ - 50μ	47	46	36	38	
	< 2μ	35	43	44	54	
% $CaCO_3$						
Loss on Ignition		13.2	10.2	10.2	9.6	
Organic carbon, % C.		2.6	0.8	0.5	0.4	
Nitrogen, % N.		0.27	0.09	0.07	0.04	
C/N ratio.		9.6	8.8	7.1	10.0	
pH in water (1:2.5)		5.9	5.6	5.9	5.9	
pH in M/100 $CaCl_2$		5.5	5.2	5.5	5.5	
Exchangeable cations m.e./100 grms.	Ca	19.40	15.16	13.21	16.26	
	Mg	3.97	5.29	6.48	5.28	
	K	0.42	0.08	0.06	0.07	
	Na	0.17	0.30	0.34	0.37	
	Total	24.0	20.8	20.1	21.8	
Exchangeable H^+ m.e/100 grms.		30.7	43.3	23.4	26.0	
Base Exchange Capacity by addition		78	48	86	84	
% Base Saturation						

XXXVII

Profile No: Tawau 79

Sub-family - Tanjong

Laboratory No: 1648-51

Horizon		1	2	3	4	5
Moisture 100-105°C.		1.49	1.15	1.56	1.44	
Texture	50μ - 2 m.m.	91	98	98	98	
	2μ - 50μ	4	0	0	0	
	< 2μ	2	0	0	0	
% $CaCO_3$						
Loss on Ignition		3.1	1.8	2.2	1.9	
Organic carbon, % C.						
Nitrogen, % N.						
C/N ratio.						
pH in water (1:2.5)		5.9	6.7	7.2	7.0	
pH in M/100 $CaCl_2$		5.4	6.0	6.4	6.5	
Exchangeable cations m.e./100 grms.	Ca	2.67	1.21			
	Mg	3.54	2.02			
	K	0.36	0.41			
	Na	0.08	0.04			
Total		6.7	3.7			
Exchangeable H+ m.e/100 grms.		4.5	3.6			
Base Exchange Capacity by addition		11.2	7.3			
% Base Saturation		60	51			

(065087)

Profile No: Tawau 81

Sub-family - Hitam

Laboratory No: 1656-58

	Horizon	1	2	3	4	5
	Moisture 100-105°C.	3.53	3.08	3.04		
Texture	50μ - 2 m.m.	31	29	59		
	2μ - 50μ	27	25	14		
	< 2μ	34	42	25		
	% $CaCO_3$					
	Loss on Ignition	11.3	5.8	6.0		
	Organic carbon, % C.	5.6	1.3	1.2*		
	Nitrogen, % N.	0.34	0.15	0.07		
	C/N ratio.	16.4	8.7	17.0		
	pH in water (1:2.5)	4.0	4.3	3.3		
	pH in M/100 $CaCl_2$	3.8	3.8	3.3		
Exchangeable cations m.e./100 grms.	Ca	0.61	1.62	1.79		
	Mg	0.33	4.19	10.5		
	K	0.10	0.26	0.06		
	Na	0.16	2.30	2.18		
	Total	1.2	8.4	14.5		
	Exchangeable H^+ m.e/100 grms.	21.6	9.3	-		
	Base Exchange Capacity by addition	22.8	17.7	12.2		
	% Base Saturation	5	47	SO_4		

* Result probably high owing to the presence of sulphides.

SD 65087/1/Wt. P65409 K.6 8/62 TCL

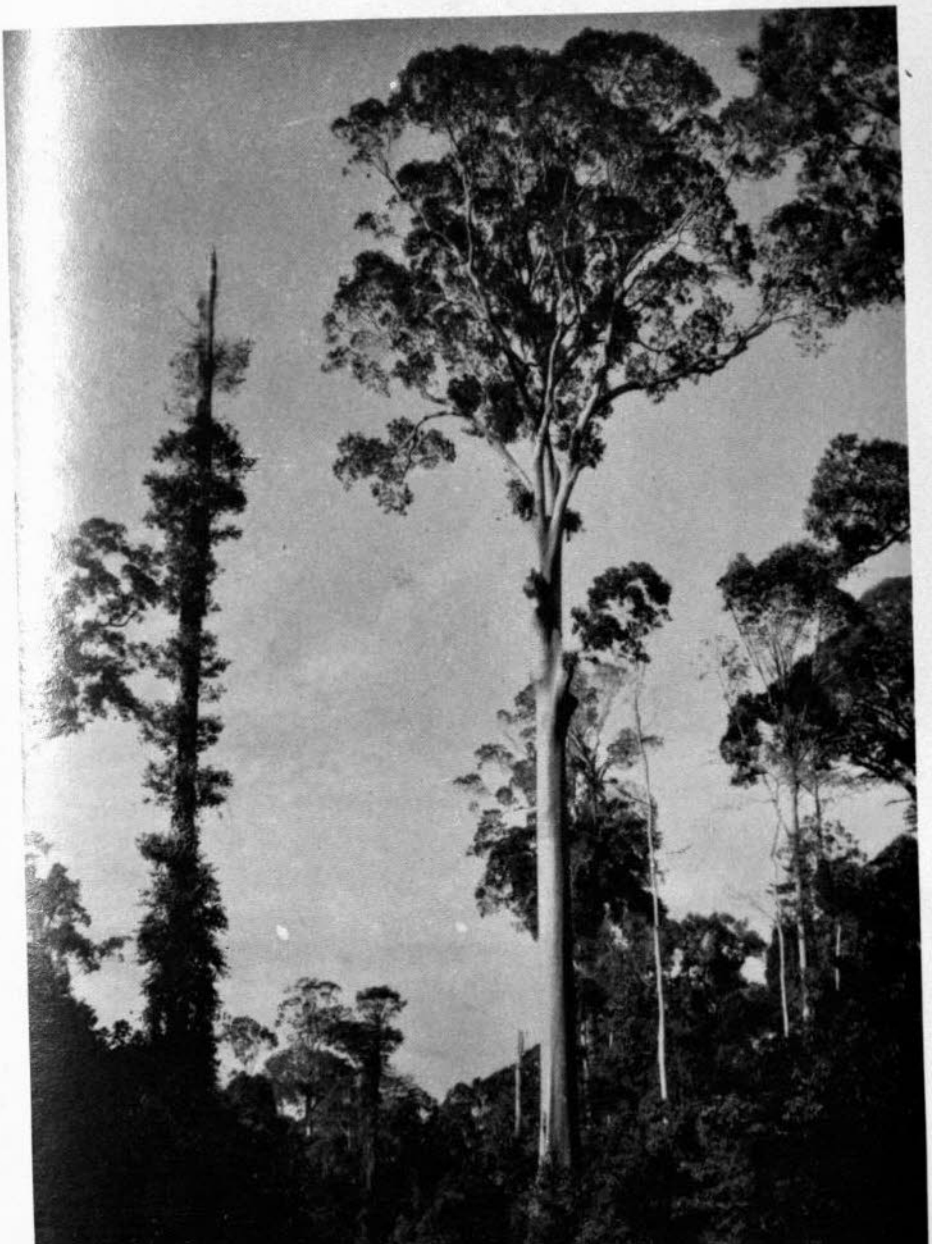


PLATE 1. Secondary forest at Mostyn, showing former height of main canopy.

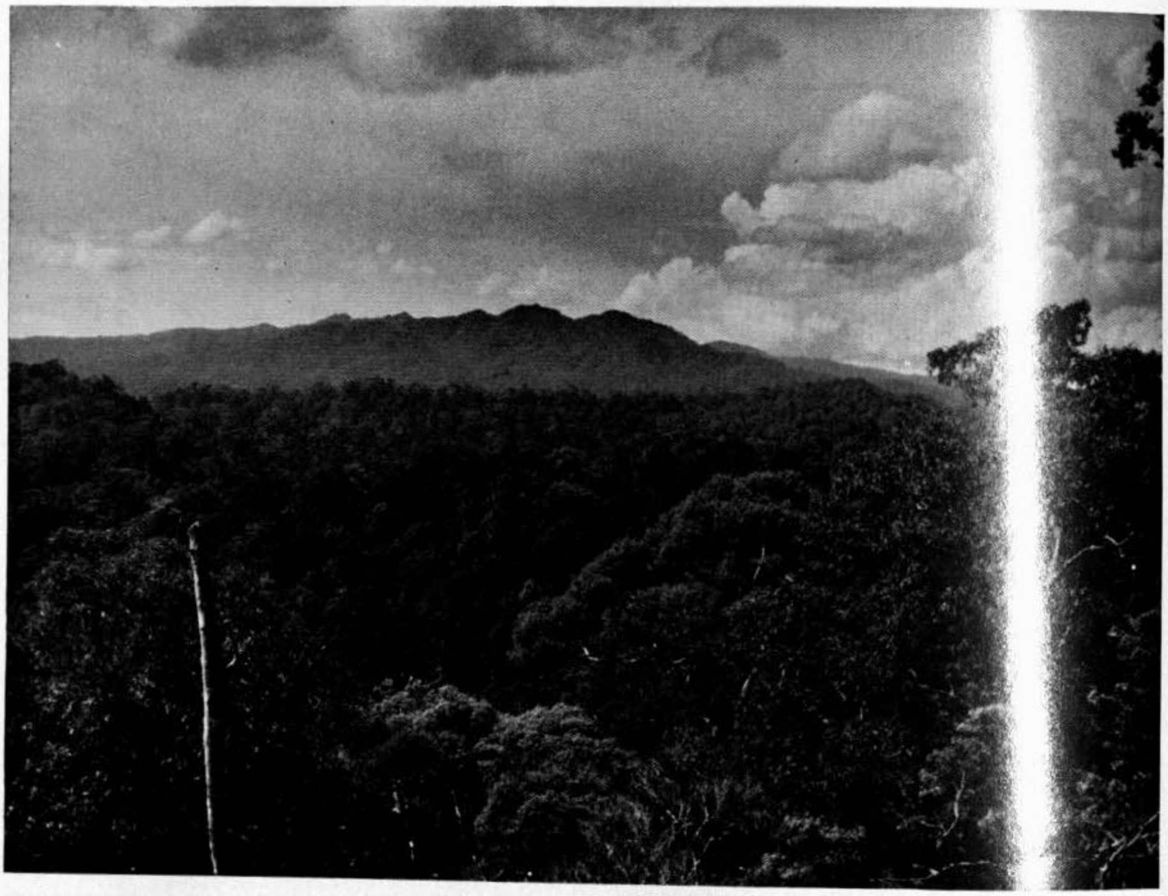


PLATE 2. General view of forest looking north from Mt. Andrassy.

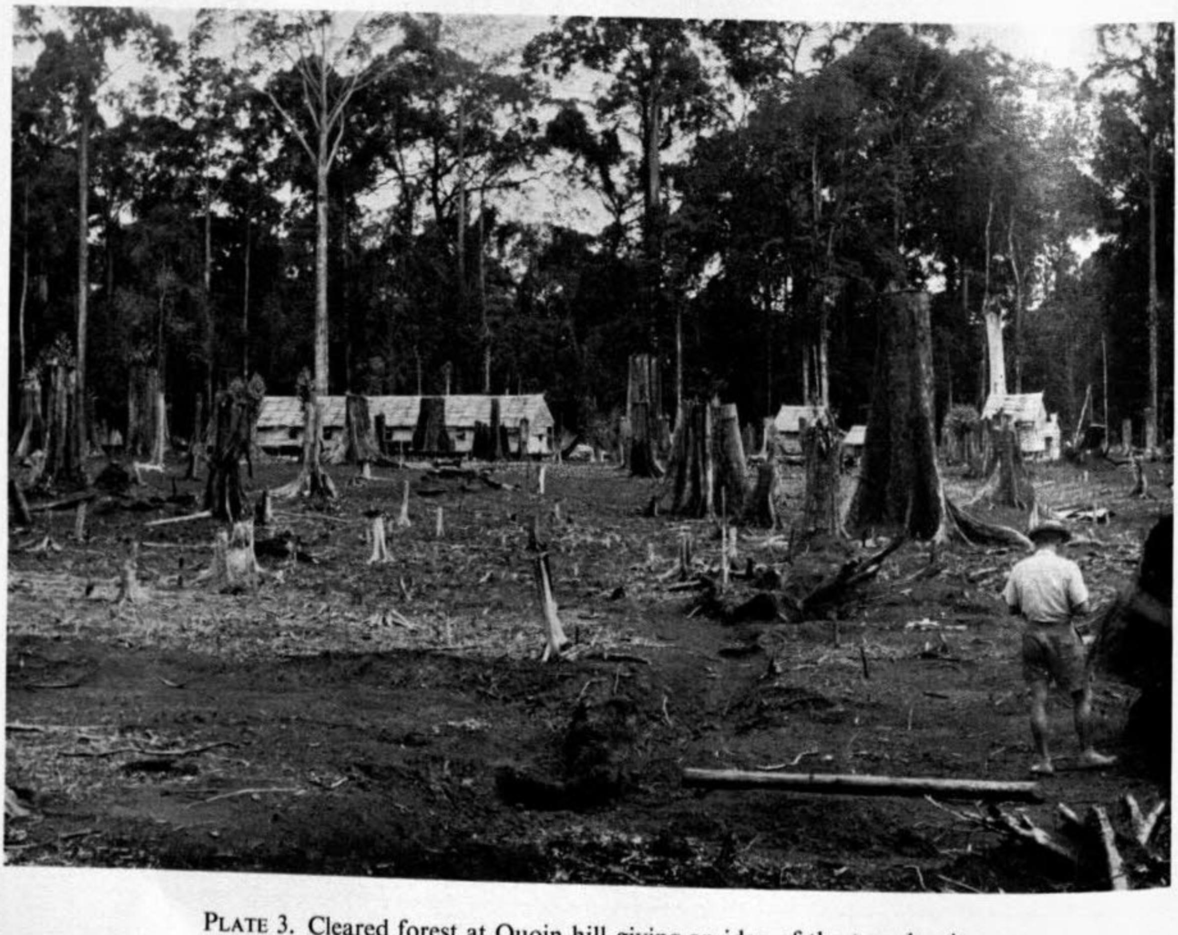


PLATE 3. Cleared forest at Quoin hill giving an idea of the tree density.

PLATE 4. ssive basalt overlying dacite ash at the boundary of Table and Imam estates (note man behind fallen tree in the middle of the photograph).

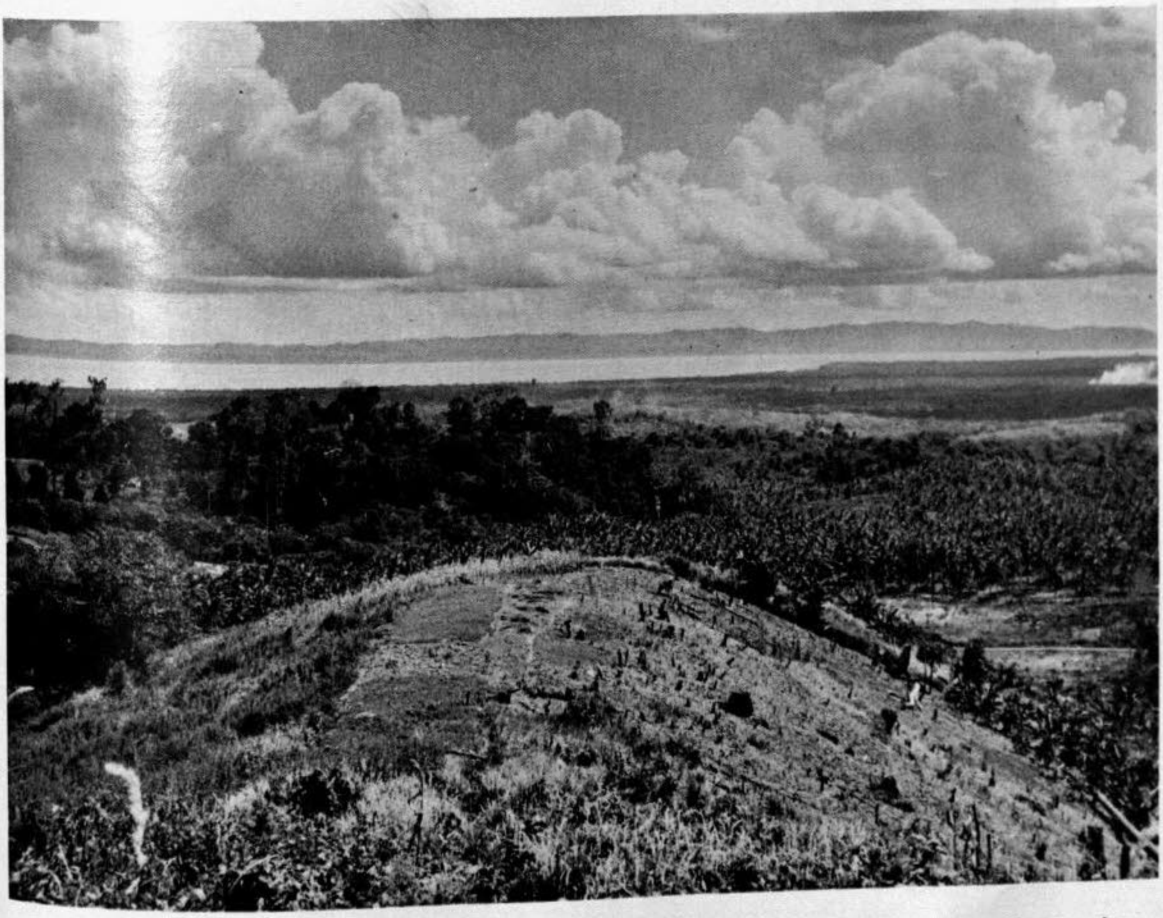


PLATE 5. Looking down on the coastal platform from Tiku hill, note the abrupt junction on the right hand side.

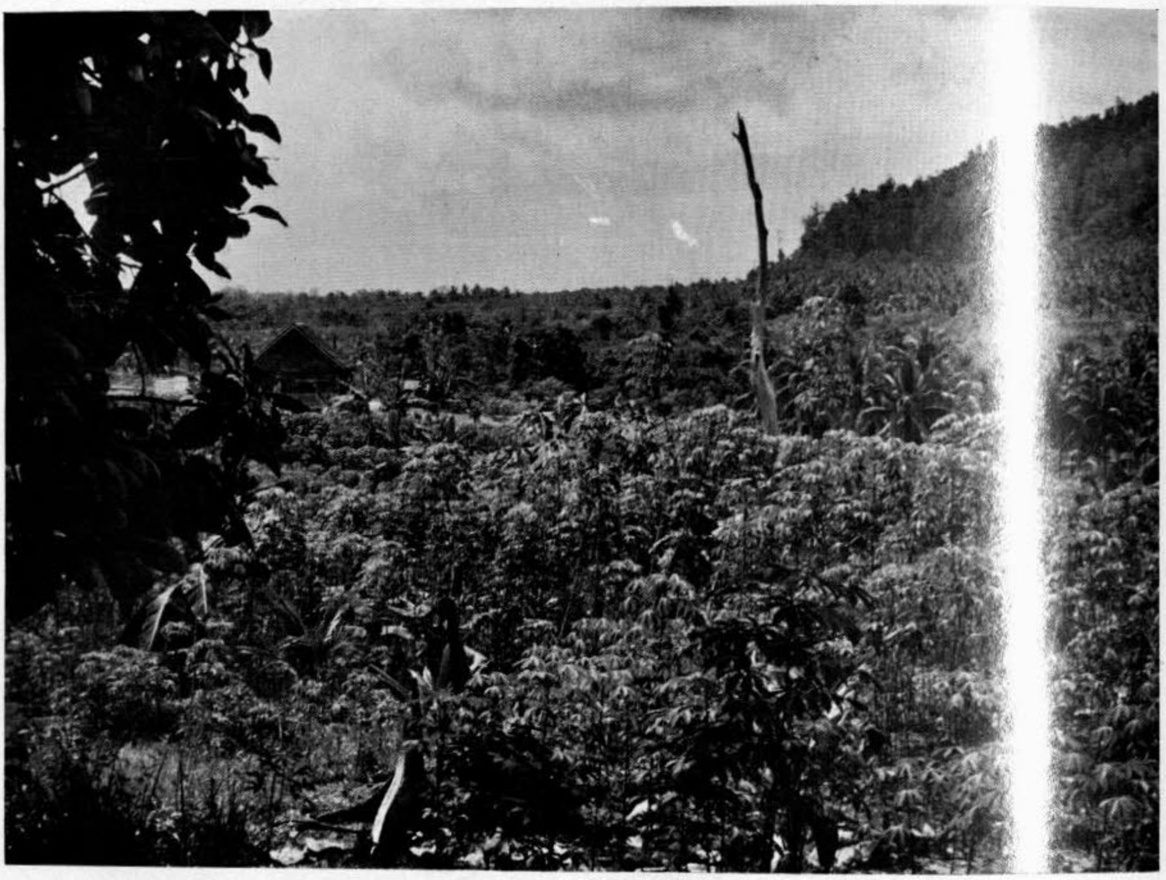


PLATE 6. The abrupt junction between the coastal platform and the Tinagat hills.

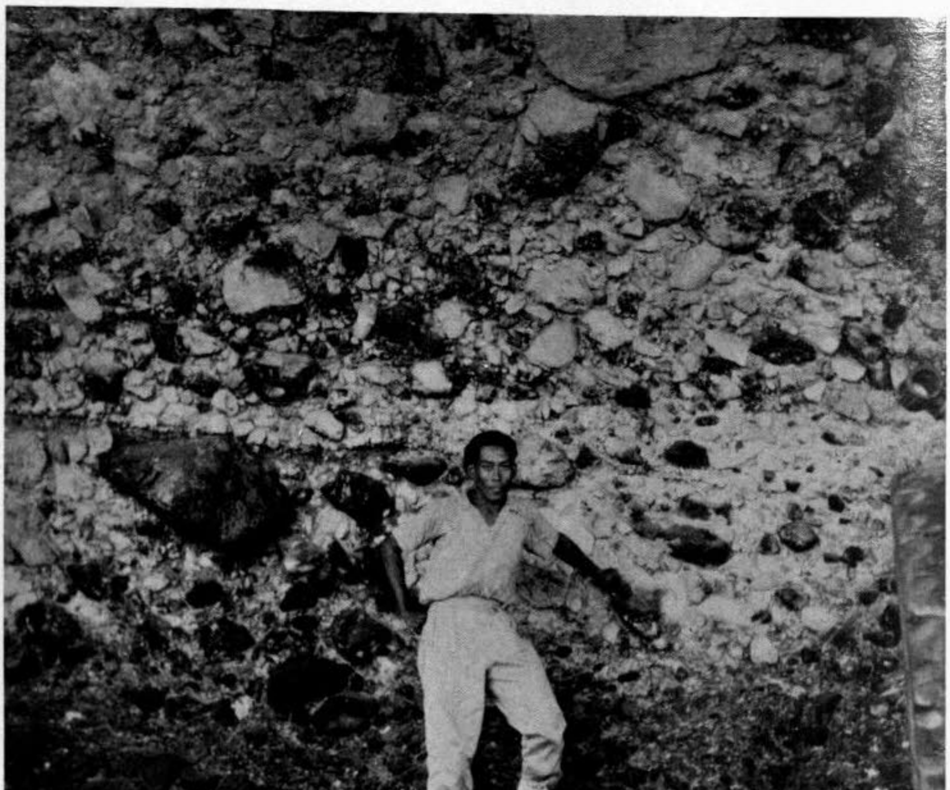


PLATE 7. The volcanic agglomerate which forms the parent material of the Tinagat soils.

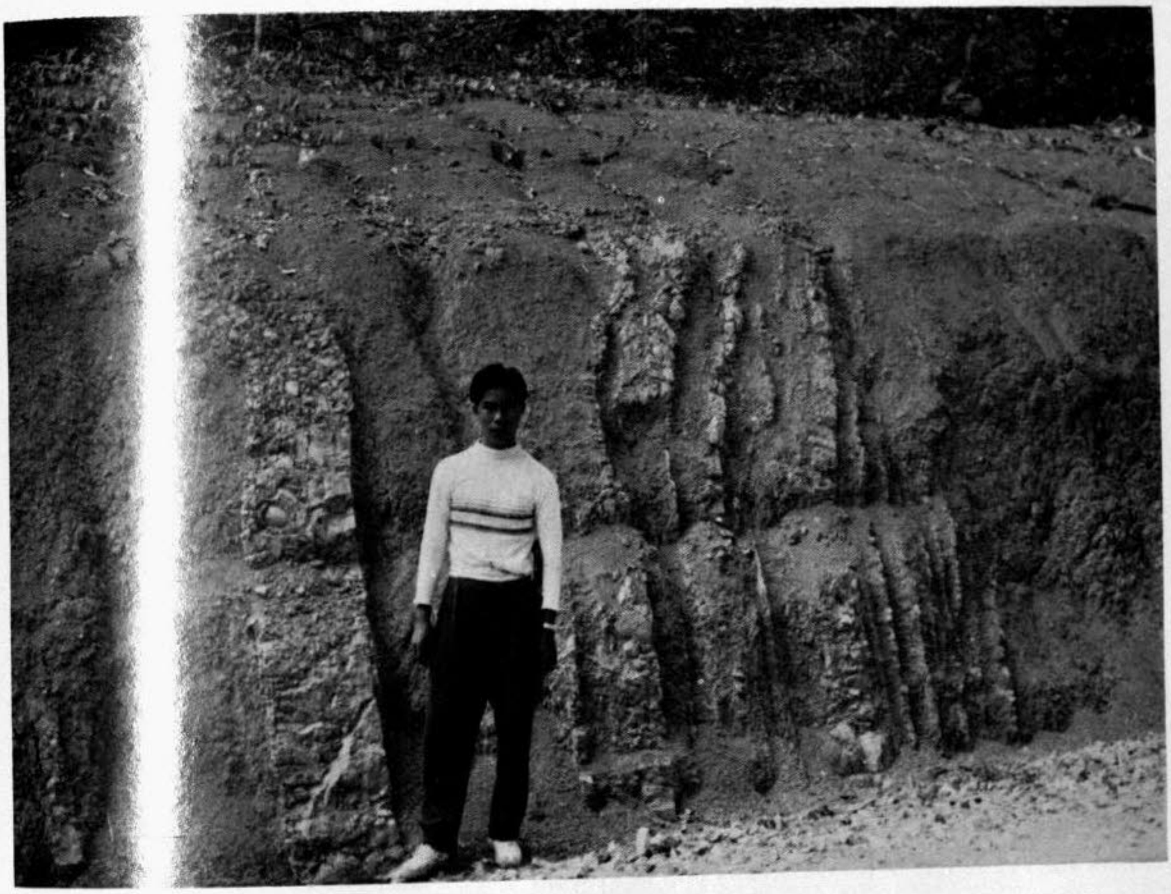


PLATE 8. T.e erosional coastal platform with soils of the Sipit family developed on strongly folded Miocene sediments.

PLATE 9. Kalumpang soils developed on Miocene sediments in ridge topography.

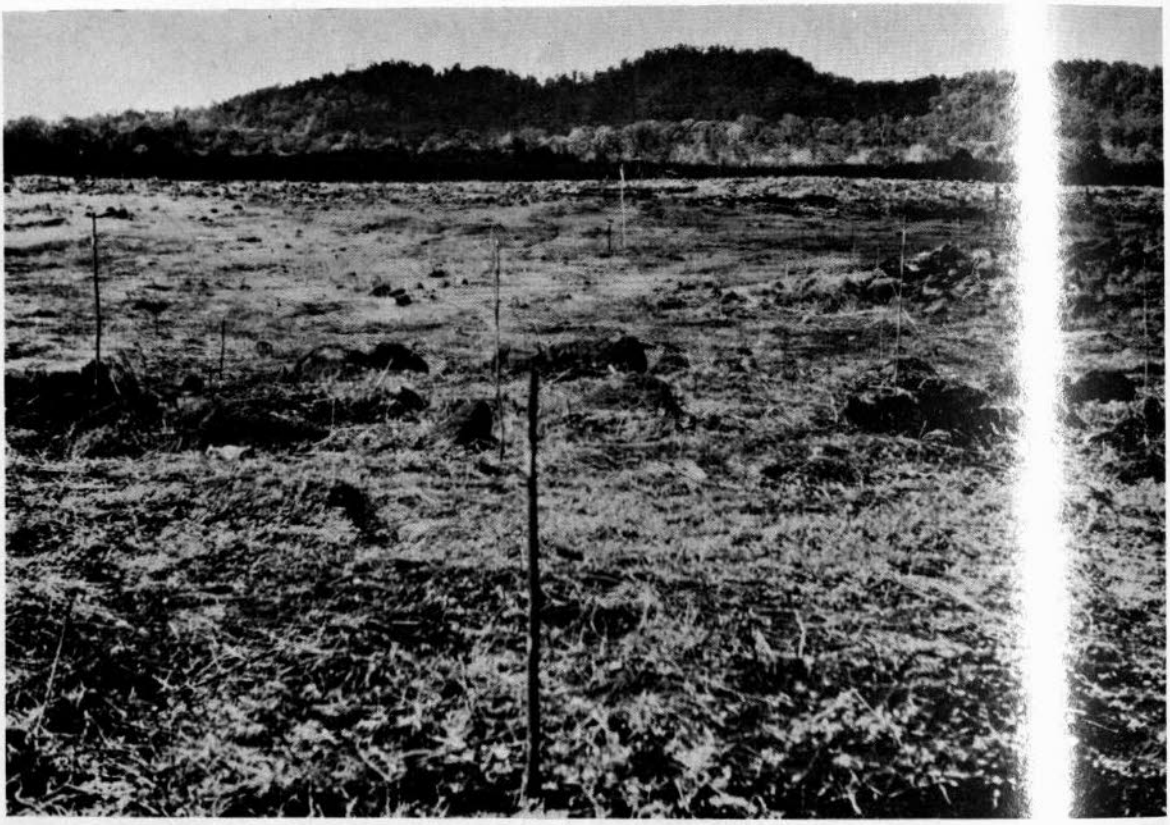


PLATE 10. The surface of the Quaternary lava flows of the Mostyn area. The accumulations of boulders are typical.

PLATE 11. Mankok soils developed from rhyolitic tuff on the left with Mostyn soils from Quaternary basalt on the right.

PLATE 12. The development of Conner soils occurs on the lower more gentle slopes. The parent material is derived as colluvium from the steeper slopes with Tinagat soils.

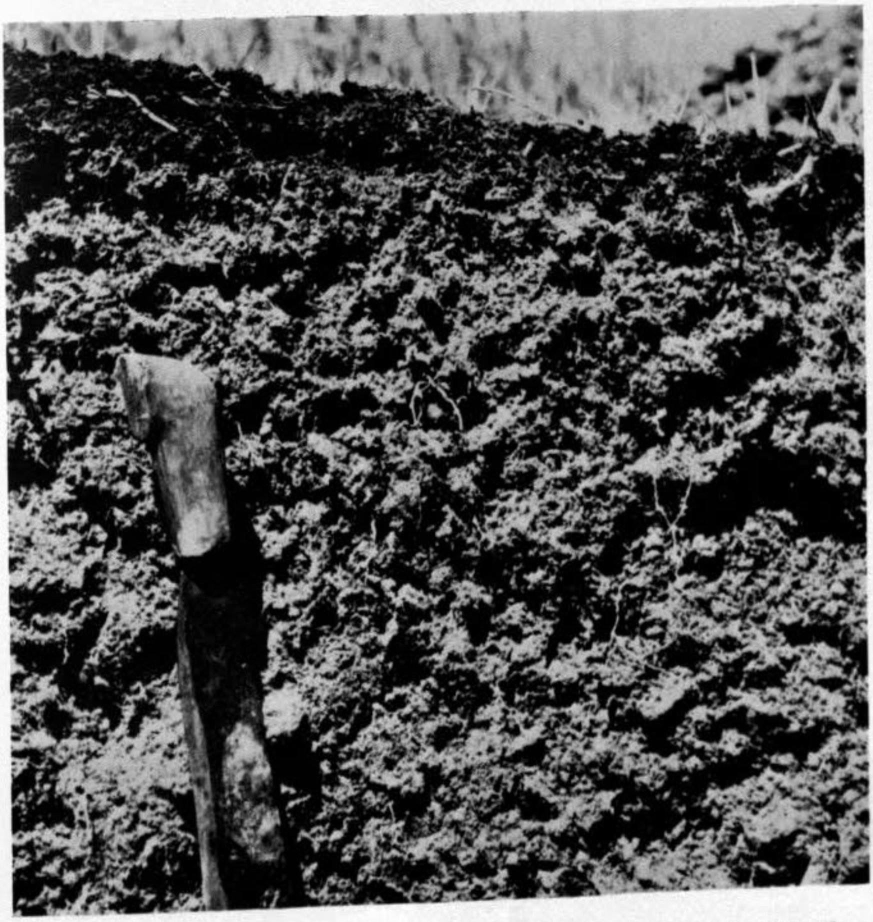


PLATE 13. A Conner soil developed on the lower slopes shown in plate 12.

PLATE 14. The shallow soil of the Quarry family developed on ill-sorted mud flow debris.

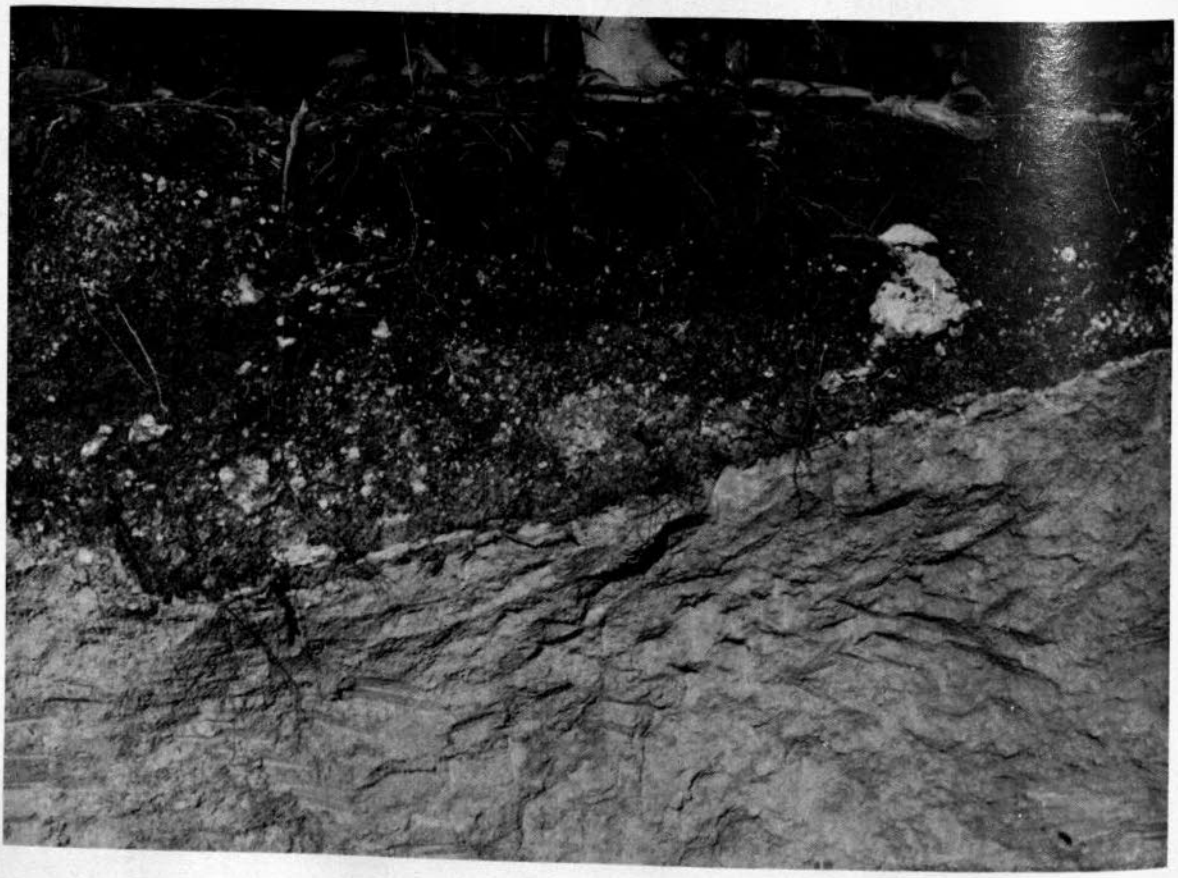
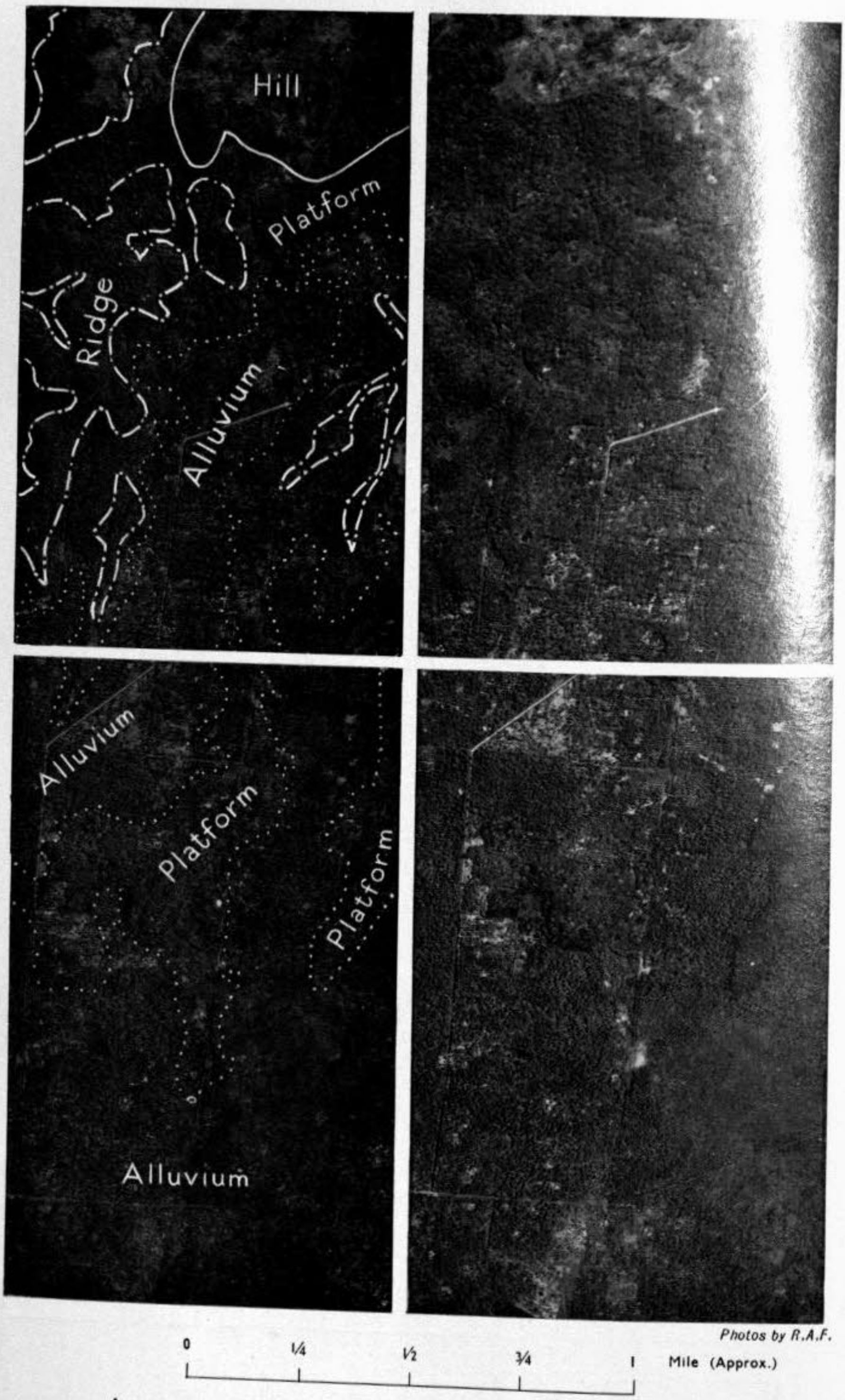


PLATE 15. Semporna family soil developed on coral limestone showing the variation in depth.

PLATE 16. Gully erosion in unstable colluvium under primary jungle.

PLATE 17 TAWAU AREA



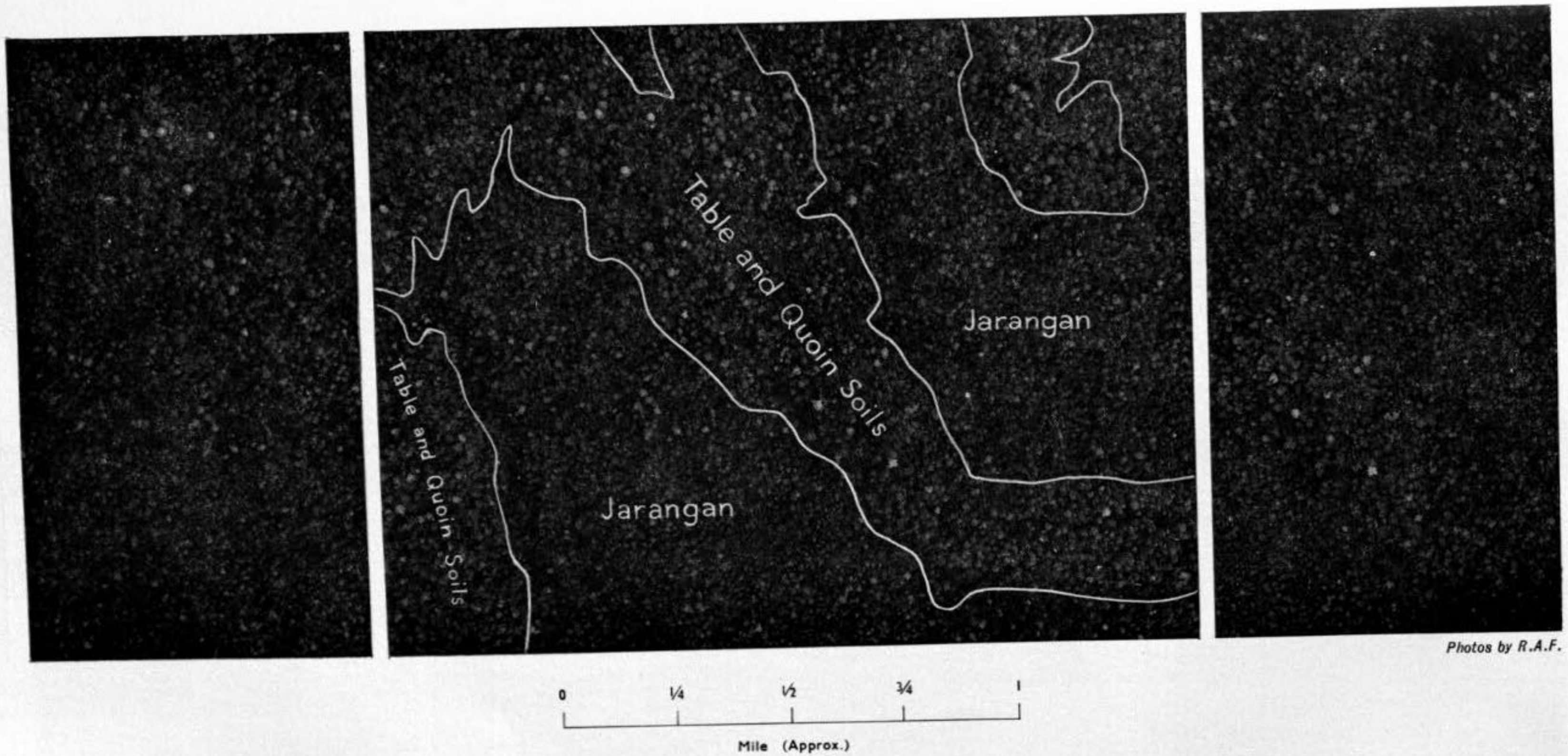
An area near Tawau mainly under rubber showing coastal plain, coastal platform, ridge and hill country.

....	Boundary between alluvium and coastal platform.
—·—·—	Boundary between ridge country and coastal platform.
———	Boundary of hill country.

The stereo-pair should be viewed with a pocket stereoscope with its long axis parallel to the central white lines.

PLATE 17. Aerial photographs of an area near Tawau.

PLATE 18 QUOIN HILL AREA

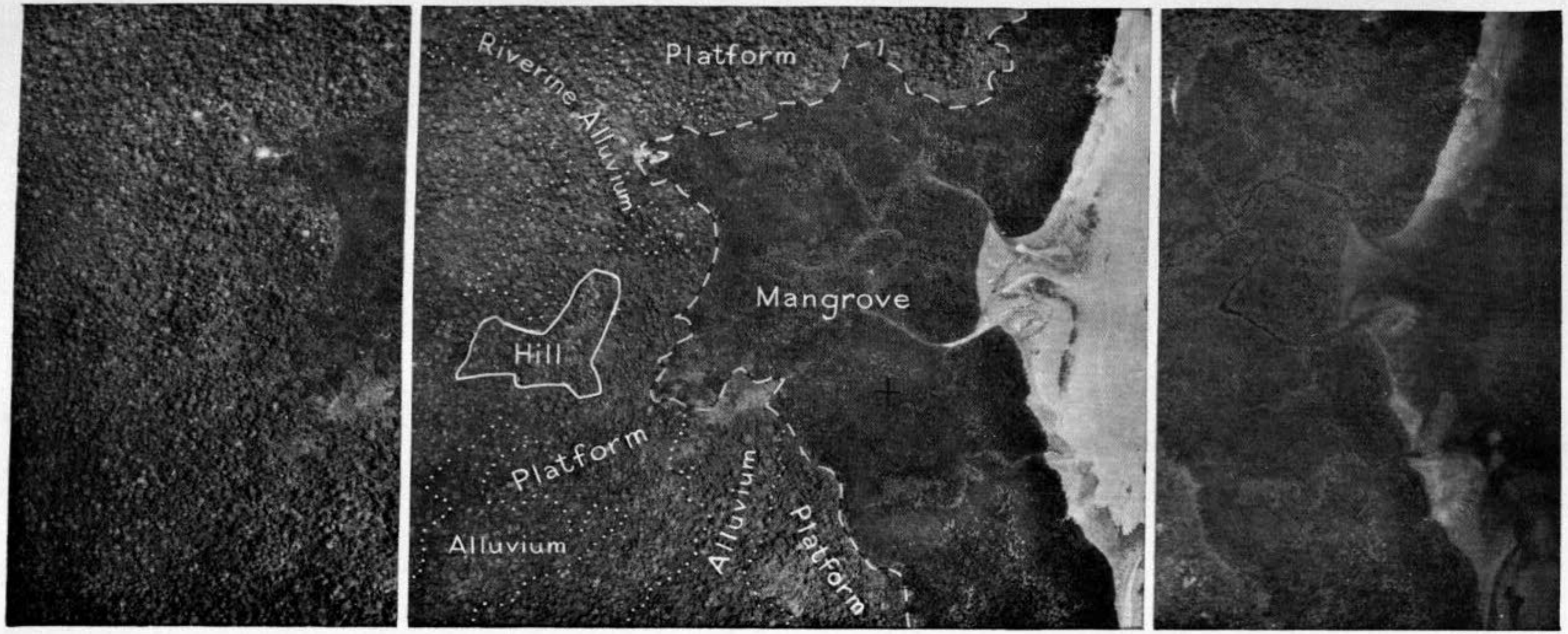


An area under primary jungle showing the differentiation between the Quoin and Table and the Jarangan sub-families of soils, all derived from Quaternary basalts.

The stereo-pairs should be viewed with a pocket stereoscope with its long axis parallel to the base of the photograph.

PLATE 18. Stereo-pairs of the Quoin hill area.

PLATE 19 SIPIT BULU VALLEY



Photos by R.A.F.

0 ¼ ½ ¾ 1 Mile (Approx.)

An area under primary jungle showing mangrove, low level alluvium, coastal platform and hill country.

— — — — — Boundary of mangrove.

. . . . Boundary between coastal platform and riverine alluvium.

———— Boundary of hill country.

The stereo-pairs should be viewed with a pocket stereoscope with its long axis parallel to the base of the photograph.

PLATE 19. Stereo-pairs of Sipit Bulu valley.

NORTH BORNEO 1:50,000 (Approx) — TAWAU SOIL MAP — SHEET 4/117/12 (NORTH B-50 / V-IV-NE)

D.O.S. (Misc) 3007
First Edition - D.O.S.
Published by Directorate of Overseas Surveys

Prepared and photographed by D.O.S.
Base map prepared from D.O.S. 33 with some later corrections.

SCALE 1:50,000

Mile 1 ¾ ½ ¼ 0 1 2 3 4 5 Miles

Printed for D.O.S. by the Ordnance Survey.
2000/10/61/1169/O.S.
Soil survey carried out by T.R. Paton, 1953-1959.
This map is one of eight which accompany the Report on the soils of the Semporna Peninsula, North Borneo, by T.R. Paton, published by Her Majesty's Stationery Office.

- Roads
- Major Tracks
- Minor Tracks
- Watercourses
- Villages
- Hill or Mountain Summit
- Centre of Aerial Photograph — 42
- Major Trigonometrical Station
- Minor Trigonometrical Station

	PRE UPPER EOCENE	MIOCENE	EARLY PLIOCENE	LATE PLIOCENE	LATE PLIOCENE/QUATERNARY	QUATERNARY	RECENT
HILLS and MOUNTAINS	C — Cook	H, Mk, Ma, H-Ma — Malatai	Tt, Br, Sn, Tt-Br — Besar	Tg, W, Mia, Tg-W — Tajong		Tr, Bi — Bombalai	
RIDGE COUNTRY (R) or HIGH PLATEAU (P)	Tu — Tinkayu (R)	Kg, Mi, Mi-Kg — Kalumpang (R)		Kan, A, A-Kan — Kinabutan	Q-A-Kan — Quarry with Apas (R)	Qn, Myn, Te, J — Table (P) and combinations	
COASTAL PLATFORM DEPOSITIONAL (D) EROSIONAL (E)		B-St — Sipit (E)	Kn, K, M — Kawa (E)	G, Kta — Gading (D)	G-Q — Gading with Quarry (D); Sa — Semporna (D)		
LAKE BEDS (LB) RIVERINE PLAINS (RP) and COASTAL PLAINS (CP)						L, La — Limau-Lucia (LB)	S — Sapang (RP); Bg — Balung (RP); T — Tanjong (CP); Fs — Freshwater Swamp (LB RP CP); Ms — Mangrove Swamp (CP)

SHEET INDEX

4/117/8	4/118/5	4/118/6	4/118/7
4/117/12	4/118/9	4/118/10	4/118/11

NORTH BORNEO 1:50,000 (Approx)

SEMPORNA SOIL MAP

SHEET 4/118/11 (NORTH B-50 / W-IV-NW)

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First Edition - D.O.S.
Published by Directorate of Overseas Surveys

Prepared and photographed by D.O.S.
Base map prepared from D.O.S. 33 with some later corrections.

Printed for D.O.S. by the Ordnance Survey.
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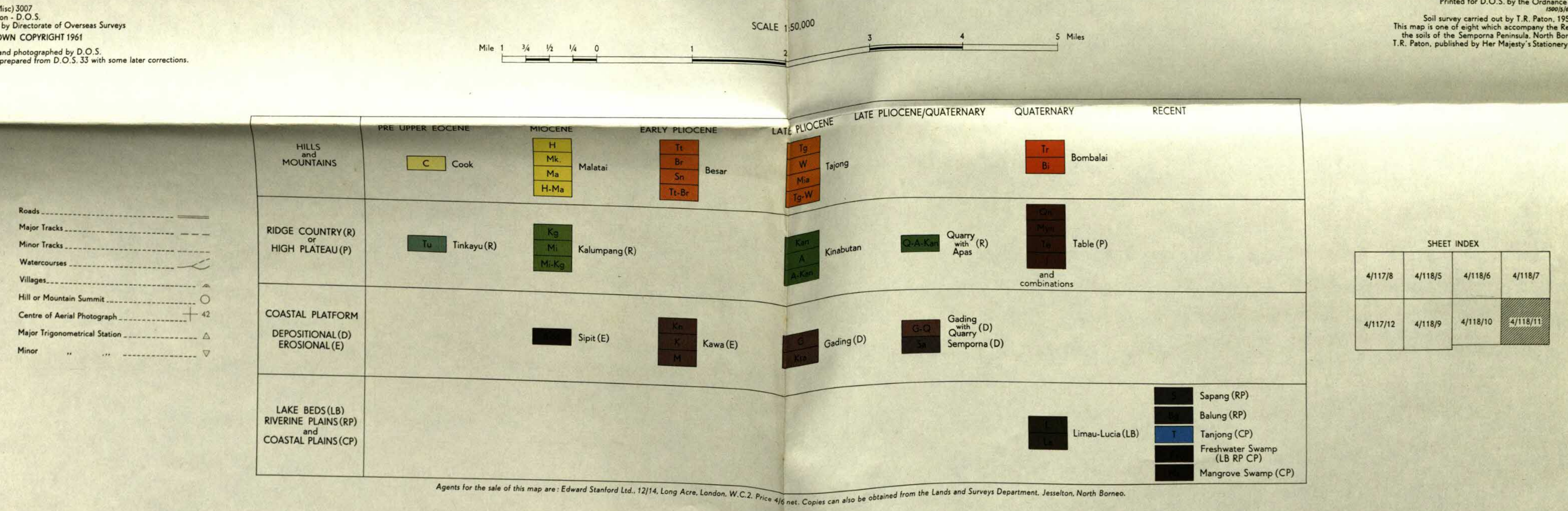
Soil survey carried out by T.R. Paton, 1953-1959.
This map is one of eight which accompany the Report on the soils of the Semporna Peninsula, North Borneo, by T.R. Paton, published by Her Majesty's Stationery Office.



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NORTH BORNEO 1:50,000 (Approx)

KUALA KALUMPANG SOIL MAP

SHEET 4/118/10 (NORTH B-50 / W-III-NE)

D.O.S. (Misc) 3007
First Edition - D.O.S.
Published by Directorate of Overseas Surveys

Prepared and photographed by D.O.S.
Base map prepared from D.O.S. 33 with some later corrections.

SCALE 1:50,000

Mile 1 ¾ ½ ¼ 0 1 2 3 4 5 Miles

Printed for D.O.S. by the Ordnance Survey.
1,500/5/61/1169/OS

Soil survey carried out by T.R. Paton, 1953-1959.
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Roads
Major Tracks
Minor Tracks
Watercourses
Villages
Hill or Mountain Summit
Centre of Aerial Photograph 42
Major Trigonometrical Station
Minor " "

	PRE UPPER EOCENE	MIOCENE	EARLY PLIOCENE	LATE PLIOCENE	LATE PLIOCENE/QUATERNARY	QUATERNARY	RECENT
HILLS and MOUNTAINS	C Cook	H, Mk, Ma, H-Ma Malatai	Tt, Br, Sn, Tt-Br Besar	Tg, W, Mia, Tg-W Tajong		Tr, Bi Bombalai	
RIDGE COUNTRY (R) or HIGH PLATEAU (P)	Tu Tinkayu (R)	Kg, Mi, Mi-Kg Kalumpang (R)		Kan, A, A-Kan Kinabutan	Q-A-Kan Quarry with Apas (R)	Qn, Myn, Te, J Table (P) and combinations	
COASTAL PLATFORM DEPOSITIONAL (D) EROSIONAL (E)		Sipit (E)	Kn, K, M Kawa (E)	G, Ks Gading (D)	G-Q Gading with Quarry (D); Sa Semporna (D)		
LAKE BEDS (LB) RIVERINE PLAINS (RP) and COASTAL PLAINS (CP)						L, La Limau-Lucia (LB)	S Sapang (RP); Bg Balung (RP); T Tanjong (CP); FS Freshwater Swamp (LB RP CP); MS Mangrove Swamp (CP)

SHEET INDEX

4/117/8	4/118/5	4/118/6	4/118/7
4/117/12	4/118/9	4/118/10	4/118/11

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NORTH BORNEO 1:50,000 (Approx) BALUNG SOIL MAP SHEET 4/118/9 (NORTH B-50 W-III-NW)

D.O.S. (Misc) 3007
First Edition - D.O.S.
Published by Directorate of Overseas Surveys

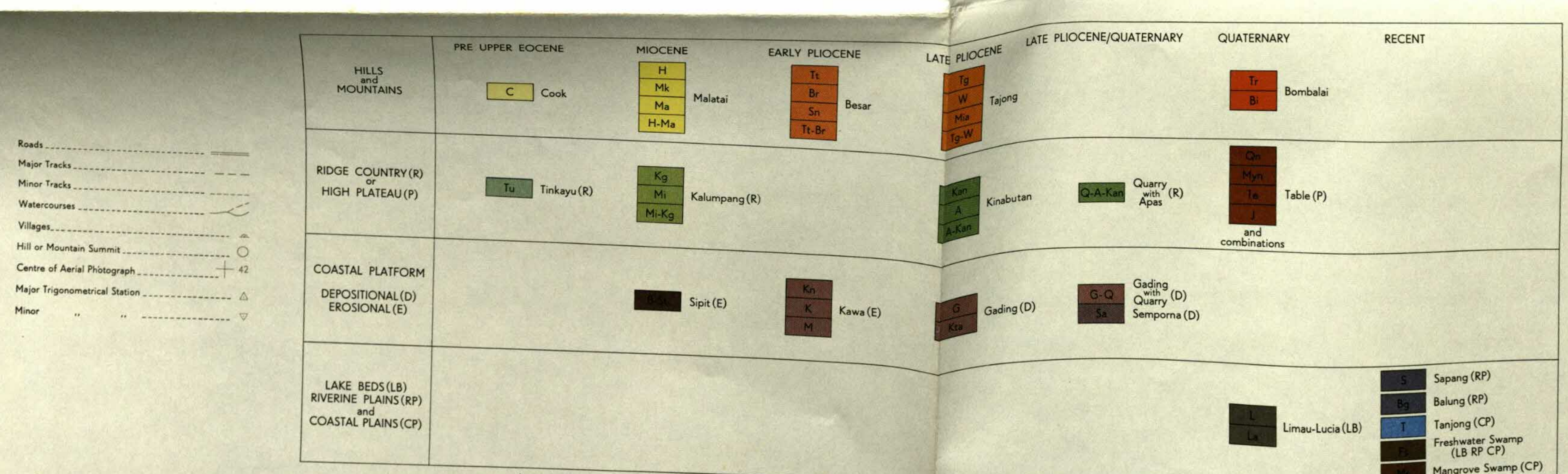
Prepared and photographed by D.O.S.
Base map prepared from D.O.S. 33 with some later corrections.

SCALE 1:50,000

Mile 1 ¾ ½ ¼ 0 1 2 3 4 5 Miles

Printed for D.O.S. by the Ordnance Survey.
1,500/5/61/1169/O.S.

Soil survey carried out by T.R. Paton, 1953-1959.
This map is one of eight which accompany the Report on the soils of the Semporna Peninsula, North Borneo, by T.R. Paton, published by Her Majesty's Stationery Office.



SHEET INDEX

4/117/8	4/118/5	4/118/6	4/118/7
4/117/12	4/118/9	4/118/10	4/118/11

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NORTH BORNEO 1:50,000 (Approx) — MERUTAI BINUANG SOIL MAP — SHEET 4/117/8 (NORTH B-50 / V-II-SE)

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Base map prepared from D.O.S. 33 with some later corrections.

SCALE 1:50,000

Mile 1 ¾ ½ ¼ 0 1 2 3 4 5 Miles

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Soil survey carried out by T.R. Paton, 1953-1959.
This map is one of eight which accompany the Report on the soils of the Semporna Peninsula, North Borneo, by T.R. Paton, published by Her Majesty's Stationery Office.

	PRE UPPER EOCENE	MIOCENE	EARLY PLIOCENE	LATE PLIOCENE	LATE PLIOCENE/QUATERNARY	QUATERNARY	RECENT
HILLS and MOUNTAINS	C Cook	H, Mk, Ma, H-Ma Malatai	Tt, Br, Sn, Tt-Br Besar	Tg, W, Ma, Tg-W Tajong		Tr, Bi Bombalai	
RIDGE COUNTRY (R) or HIGH PLATEAU (P)	Tu Tinkayu (R)	Kg, Mi, Mi-Kg Kalumpang (R)		Kan, A, A-Kan Kinabutan	Q-A-Kan Quarry with Apas (R)	Table (P) and combinations	
COASTAL PLATFORM DEPOSITIONAL (D) EROSIONAL (E)		Sipit (E)	Kn, K, H Kawa (E)	G, Kn Gading (D)	G-Q, Sa Gading with Quarry (D) Semporna (D)		
LAKE BEDS (LB) RIVERINE PLAINS (RP) and COASTAL PLAINS (CP)						L Limau-Lucia (LB)	S Sapang (RP); Bj Balung (RP); T Tanjong (CP); Freshwater Swamp (LB RP CP); Mangrove Swamp (CP)

Roads
Major Tracks
Minor Tracks
Watercourses
Villages
Hill or Mountain Summit
Centre of Aerial Photograph
Major Trigonometrical Station
Minor

SHEET INDEX

4/117/8	4/118/5	4/118/6	4/118/7
4/117/12	4/118/9	4/118/10	4/118/11

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NORTH BORNEO 1:50,000 (Approx)

EASTERN TIMBUN MATA SILAWA SOIL MAP

SHEET 4/118/7 (NORTH B-50 / W-II-SW)

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SCALE 1:50,000
Mile 1 ¾ ½ ¼ 0 1 2 3 4 5 Miles

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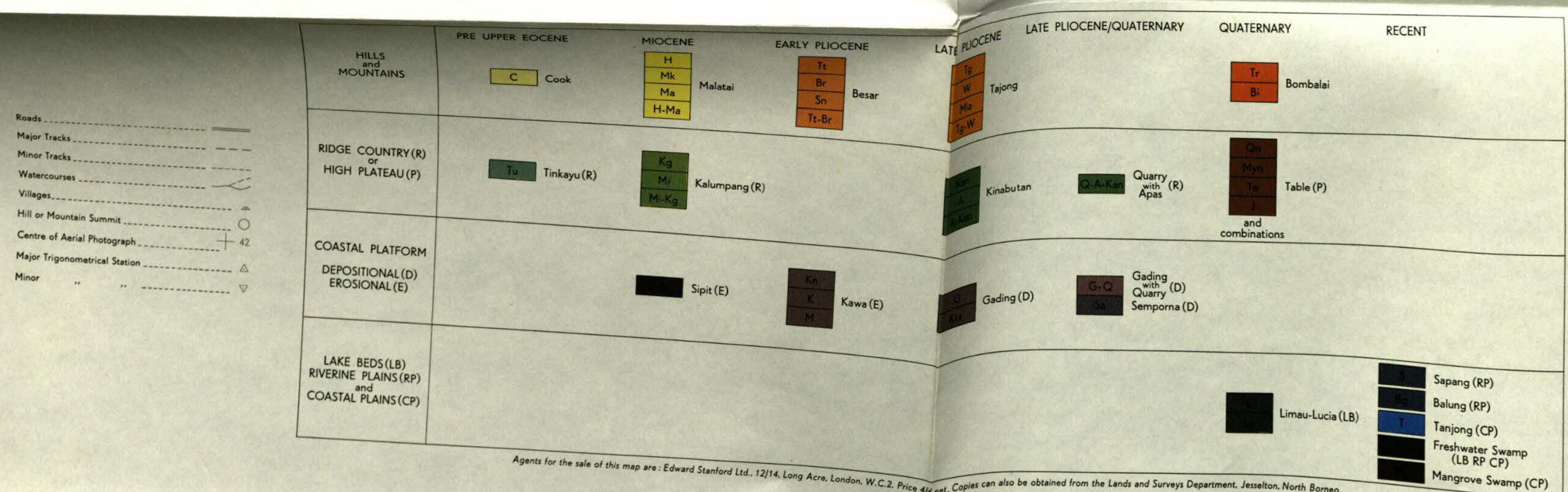
1500/5/6/1169/03
Soil survey carried out by T.R. Paton. 1953-1959.
This map is one of eight which accompany the Report on the soils of the Semporna Peninsula, North Borneo, by T.R. Paton, published by Her Majesty's Stationery Office.



SHEET INDEX

4/117/8	4/118/5	4/118/6	4/118/7
4/117/12	4/118/9	4/118/10	4/118/11

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NORTH BORNEO 1:50,000 (Approx) — SIPIT SEMARANG SOIL MAP — SHEET 4/118/6 (NORTH B-50 / W-I-SE)

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Base map prepared from D.O.S. 33 with some later corrections.

SCALE 1:50,000
Mile 1 ¾ ½ ¼ 0 1 3 4 5 Miles

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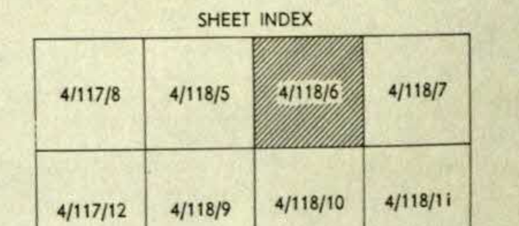
Soil survey carried out by T.R. Paton, 1953-1959.
This map is one of eight which accompany the Report on the soils of the Semporna Peninsula, North Borneo, by T.R. Paton, published by Her Majesty's Stationery Office.

	PRE UPPER EOCENE	MIOCENE	EARLY PLIOCENE	LATE PLIOCENE	LATE PLIOCENE/QUATERNARY	QUATERNARY	RECENT
HILLS and MOUNTAINS	C Cook	H, Mk, Ma, H-Ma Malatai	Tt, Br, Sn, Tt-Br Besar	Tg, W, Mle, Tg-W Tajong		Tr, Bi Bombalai	
RIDGE COUNTRY (R) or HIGH PLATEAU (P)	Tu Tinkayu (R)	Kg, Mi, Mi-Kg Kalumpang (R)		Kinabutan	Q-A-Kn Quarry with Apas (R)	Table (P) and combinations	
COASTAL PLATFORM DEPOSITIONAL (D) EROSIONAL (E)		Sipit (E)	Kn, K, M Kawa (E)	Gading (D)	G-Q Gading with Quarry (D); Sa Semporna (D)		
LAKE BEDS (LB) RIVERINE PLAINS (RP) and COASTAL PLAINS (CP)						Limau-Lucia (LB)	S Sapang (RP); Bg Balung (RP); T Tanjong (CP); Freshwater Swamp (LB RP CP); Mangrove Swamp (CP)

Roads
Major Tracks
Minor Tracks
Watercourses
Villages
Hill or Mountain Summit
Centre of Aerial Photograph
Major Trigonometrical Station
Minor " "

SHEET INDEX



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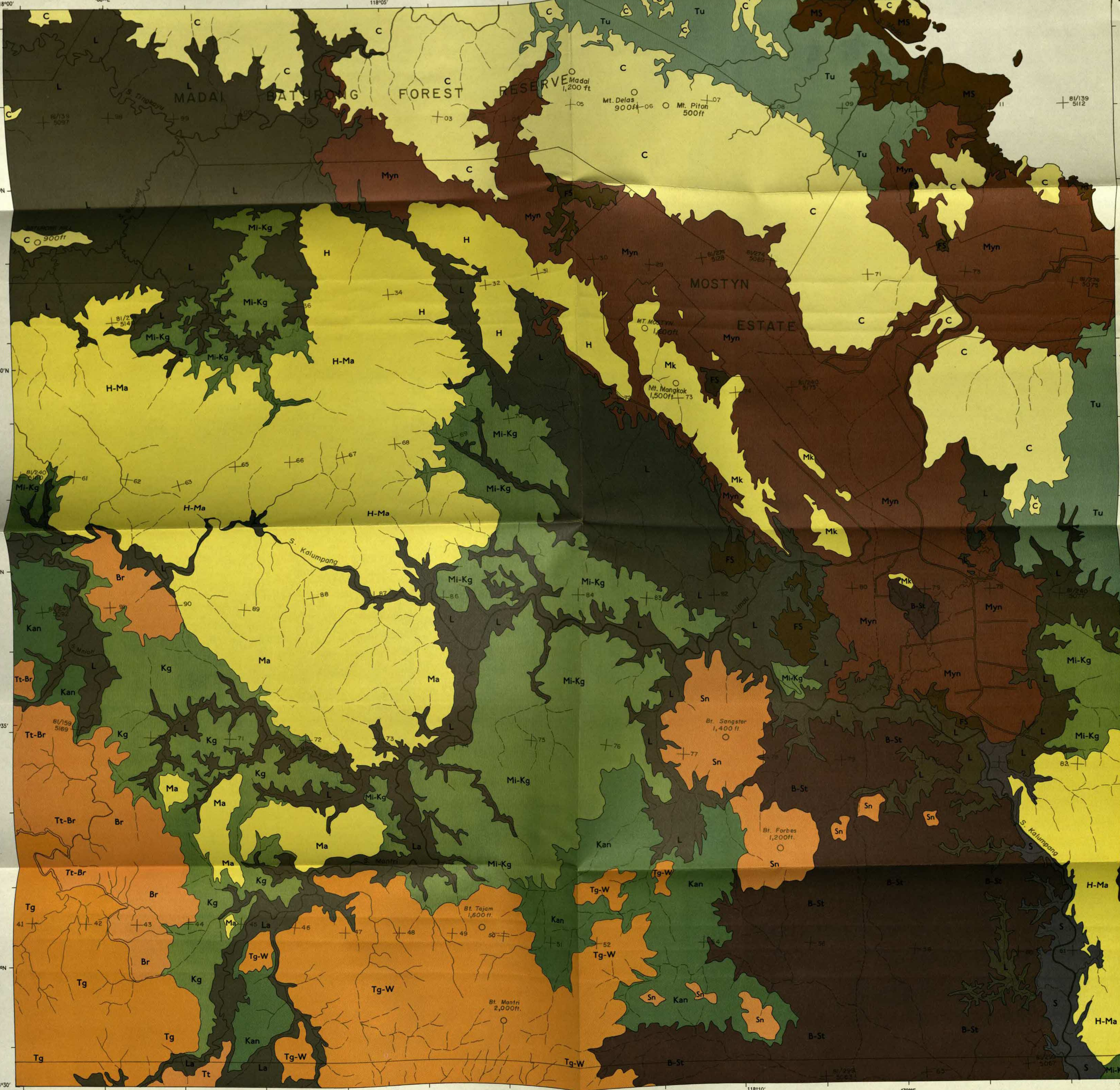
NORTH BORNEO 1:50,000 (Approx)

MOSTYN SOIL MAP

SHEET 4/118/5 (NORTH B-50 / W-I-SW)



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SCALE 1:50,000

Mile 1 ¾ ½ ¼ 0 1 2 3 4 5 Miles

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Soil survey carried out by T.R. Paton, 1953-1959.
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	PRE UPPER EOCENE	MIOCENE	EARLY PLIOCENE	LATE PLIOCENE	LATE PLIOCENE/QUATERNARY	QUATERNARY	RECENT
HILLS and MOUNTAINS	C Cook	H, Mk, Ma, H-Ma Malatai	Tt, Br, Sn, Tt-Br Besar	Tg, W, Mia, Tg-W Tajong		Tr, Bi Bombalai	
RIDGE COUNTRY (R) or HIGH PLATEAU (P)	Tu Tinkayu (R)	Kg, Mi, Mi-Kg Kalumpang (R)		Kan, A, A-Kan Kinabutan	Q-A-Kan Quarry with Apas (R)	Qn, Myn, Ta, ... and combinations Table (P)	
COASTAL PLATFORM DEPOSITIONAL (D) EROSIONAL (E)		B-St Sipit (E)	Kn, K, M Kawa (E)	G, Kta Gading (D)	G-Q, Sa Gading with Quarry (D) Semporna (D)		
LAKE BEDS (LB) RIVERINE PLAINS (RP) and COASTAL PLAINS (CP)						L, La Limau-Lucia (LB)	S Sapang (RP); Bg Balung (RP); T Tanjong (CP); Fs Freshwater Swamp (LB RP CP); Ms Mangrove Swamp (CP)

Roads
Major Tracks
Minor Tracks
Watercourses
Villages
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SHEET INDEX

4/117/8	4/118/5	4/118/6	4/118/7
4/117/12	4/118/9	4/118/10	4/118/11

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