Land Resources of the Morehead–Kiunga Area, Territory of Papua and New Guinea

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PART I. INTRODUCTION TO THE MOREHEAD–KIUNGA AREA

By K. Paijmans*

I. General

The survey area is a long and narrow strip of approximately 11,760 sq miles in western Papua, lying adjacent to the international border with West Irian. It is bounded to the east by long. 141°50′E., to the north by the 6°S. parallel, and to the south by the coast (Fig. 1).

The object of the survey was the mapping and description of the area at reconnaissance level by a team consisting of a geomorphologist (D. H. Blake), a pedologist (P. Bleeker), and a plant ecologist (K. Paijmans, the leader of the team).

The survey area contains parts of two administrative subdistricts, Morehead and Kiunga, and the administrative centres situated within it are Kiunga, Morehead, Lake Murray Patrol Post, and the recently established Patrol Post at Weam.

II. Historical Background

In this section a brief account is given of the explorations that have led to the discovery and naming of some of the main geographic features of the area. This is followed by a summary of the main political events and administrative actions that have affected the survey area.

The mouth of the Fly River was discovered by H.M.S. *Fly* in 1842, during the charting of the western side of the Gulf of Papua. However, the interior of western Papua was not explored by white men until 1876, when Luigi Maria D'Albertis steamed up the Fly River to a point upstream from the junction of the Black and Palmer Rivers, some 580 miles inland. On his way back Signor D'Albertis turned into the Ok Tedi River at Snake Point, later named D'Albertis Junction, but about 30 miles above the junction rapids forced him to return. He renamed the Ok Tedi River the Alice River after Alice Robertson, the wife of the then Premier of New South Wales. D'Albertis's contact with the population was not a happy one. He put the natives to flight with rifle salvoes and explosions of dynamite charges, and fired rockets into their villages, with the result that later explorers invariably met a hostile population. The Strickland River was first explored in 1885 by Captain H. C. Everill; Lake Murray was not discovered until 1913, when G. M. Massey Baker, travelling up the Strickland River, turned into the Herbert River and reached the lake, which he named after J. H. P. Murray, who was then Lieutenant-Governor of Papua (Souter 1964).

The Dutch had proclaimed sovereignty over West New Guinea in 1848. In 1884 the eastern half of New Guinea was subdivided by agreement between Britain and Germany and the southern part became a British protectorate. The boundary between the British and Netherlands possessions was established by the Anglo–Dutch

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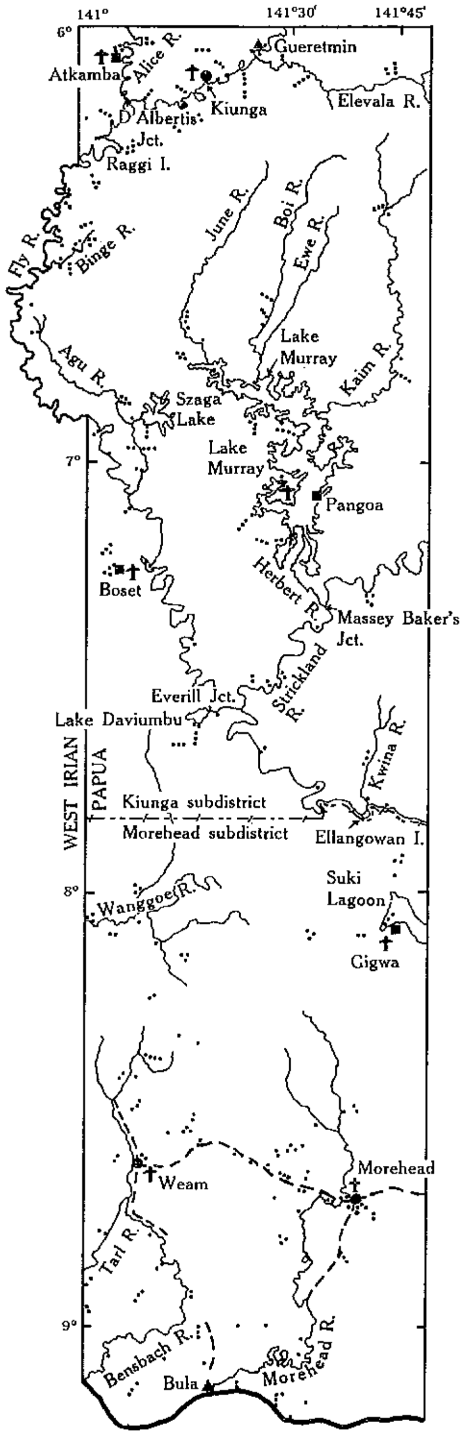

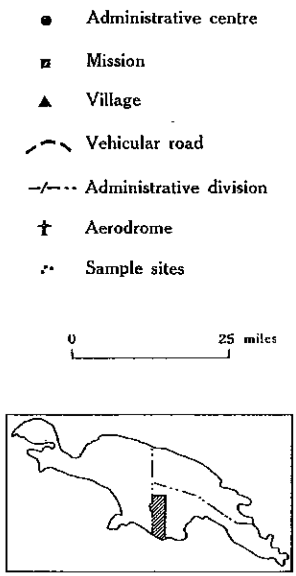

Fig. 1.—Settlement and communications in the Morehead–Kiunga area, and sites sampled by the survey.

boundary treaty of 1895. In 1906 the Papua Act came into force, placing British New Guinea under Australian control and renaming it Papua. In 1962 the Netherlands government handed over the administration of West New Guinea to a United Nations Temporary Executive Authority, and a year later Indonesia acquired full administrative responsibility over the area.

The Western Division of Papua was established in 1889 by Sir William MacGregor, then Administrator of British New Guinea, with headquarters at Mabaduan on the mainland. Four years later the headquarters were moved to Daru by the Resident Magistrate (Clune 1943), and Daru has been the headquarters of the now Western District ever since.

The international border had never been properly delineated on the ground before the joint Australian–Indonesian border survey of 1967, and existing Dutch and Australian maps show the border in different positions. Up to the late 1940s border villages, including the large village of Boset, were occasionally visited by both Australian and Dutch patrols. The Dutch, with the consent of the Netherlands government, ceased patrolling the Boset Lagoon region from Merauke after regular Australian patrols had started from Lake Murray Patrol Post, established in 1947. The Dutch Catholic missionaries, however, who had founded Boset, stayed on, and as late as 1956 locally controlled evangelization and education. Malay was used as the teaching language by the Dutch missionaries and is still the lingua franca in the Boset area. The effect of the international border on the development of the administration is dealt with by van der Veur (1966).

III. Settlement

The population density in the area averages just over 1 person per 2 sq miles. Concentrations of native settlement occur near Kiunga and Atkamba, along the middle Fly, and around Lake Murray and Suki Lagoon; other areas, for instance the thickly forested region between Lake Murray and the Fly and Elevala Rivers, are almost uninhabited. The sparseness of population in the southern part of the area may be due partly to adverse conditions, i.e. swampiness during the wet season and lack of drinking water in the dry. Another reason, dating back to before the establishment of administrative control, may be the depopulation caused by the Tugeri, a group of head-hunters who lived west of the Bensbach River and who carried out raids on neighbouring tribes east of the border. These raids only ceased after the Dutch had established an administrative post among the Tugeri at Merauke in 1902 and had pacified the area during the following three years (Souter 1964).

Two missions, the Unevangelized Fields Mission and the French–Canadian Roman Catholic Mission, are active in the area. The former has mission posts at Atkamba on the Alice River, Pangoa on the shore of Lake Murray, and Gigwa in Suki Lagoon, and the latter has mission posts at Kiunga and Boset.

The only Europeans living in the area are Administration officers and missionaries.

IV. Communications

There are very few roads in the area. A road network is present in the south, centred on Morehead, but the roads are impassable in the wet season. The main road connects Weam and Morehead with a wharf on the Wassi Kussa River some 20 miles south-east of Morehead. Other roads run southward from Morehead, north-west from Weam, and north from Bula on the coast. None of the rivers are bridged, and vehicles on the Weam–Morehead road cross the Morehead River at Morehead by ferry. Other land communication is by means of native tracks between villages. In the southern part of the area it is possible in the dry season to walk long distances; towards the end of the wet season movement is mostly by canoe.

Airstrips are maintained by the Administration at Morehead, Weam, and Kiunga, and by missions at Boset, Atkamba, Pangoa, and Suki Lagoon. Only the strip at Morehead is suitable for DC3 aircraft. A regular twice-a-week air service runs between Port Moresby and Daru but does not serve any of the airstrips in the survey area.

Daru is the only port along the coast of south-western Papua, and off shore the seas are shallow (less than 6 ft at low tide) to a distance of 1–3 miles (Anon. 1942). The entrances to the two main coastal rivers in the survey area, the Bensbach and Morehead, are blocked by mud bars which can only be negotiated by shallow draught vessels at high tide. The Bensbach River, strongly meandering and rather narrow, is navigable for small launches of 6 ft draught to Wando, and in the wet season to Weam. The Morehead River, much wider than the Bensbach and not so strongly meandering, is navigable by launches up to 40 miles upstream from Morehead. Neither of the two rivers is much used by vessels. Supplies for Morehead and Weam are brought in mainly by air, and by boat and vehicle via the Wassi Kussa River and the road connecting with Morehead.

Transport on the lakes and lagoons is mostly by canoe and speed-boat. Small launches serve Lake Murray and the lower courses of the rivers flowing into it.

Kiunga on the Fly River is accessible to vessels of up to 100 tons and drawing up to 8 ft, but is near the limit of navigation for such craft. During the season of south-easterly winds a tidal bore commonly occurs at new and full moons. It consists of a series of rapidly advancing waves up to 6 ft high gradually decreasing in size towards the limit of tidal influence at Ellangowan Island north of Suki Lagoon. Other navigational hazards common on the Fly and also on the Strickland River are hidden snags in the form of uprooted trees, sand bars which are often only just submerged, and the extremely rapid rise and fall of flood-waters.

V. Survey Procedure

As in previous surveys undertaken by the Division of Land Research the work was carried out in three stages, firstly, air-photo interpretation and preliminary mapping, secondly, field sampling, and, thirdly, compilation of data and report writing. The first stage was carried out in Canberra from April to July 1967. The area was mapped into preliminary mapping units, each showing a distinct photo pattern of land form and vegetation. The aerial photography available, taken by Adastra Airways Pty. Ltd., between 1960 and 1967, ranged in scale between 1:36,000 and 1:86,000. The westernmost part of the area, comprising about 60 sq miles within the westward bulge of the Fly River, was not covered by photography and a few minor gaps occurred in the central part of the area.

Field work was carried out in August–October 1967. The team made joint observations at 322 sites (Fig. 1), their distribution over the area being governed by accessibility and intricacy of photo pattern. A helicopter, supplied by Helicopter Utilities Pty. Ltd., of Sydney, was used in the southern and northern parts of the area; in the central part, two 18-ft dinghies powered by 35-h.p. outboards served to transport the team to various points from which traverses on foot were made. A work-boat was used to move base camp. Messrs. V. G. Dawson and P. A. Healy were in charge of logistics during the first and the second half of the period of field work respectively, and were aided by native assistants from Madang District under the leadership of Gabi-Momo. Mr. R. Pullen, of the Herbarium Australiense, was in the area during the same period for the purpose of collecting botanical material. Mr. R. Miniotas carried out levelling traverses near Bula, Morehead, and Weam.

On return to Canberra, re-examination of the air photos in the light of the field data, and combination of some of the preliminary mapping units led to the establishment of 20 land systems, each with a typical and recurring pattern of land form, soil, and vegetation. The period November 1967–August 1968 was spent in describing the land systems and in writing the report. The maps accompanying this report are based partly on the Boigu, Fly River, Lake Murray, and Raggi 1:250,000 sheets, and partly on the New Guinea Border Special 1:100,000 sheets, numbers 6 and 7. These maps were printed in 1966 by the Royal Australian Survey Corps.

VI. Acknowledgments

The cooperation of the Administration of the Territory of Papua and New Guinea in supplying and transhipping transport is gratefully acknowledged, as are the assistance and facilities made available by District Commissioner F. A. Bensted at Daru, and members of his staff at Kiunga, Lake Murray, and Morehead.

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PART II. SUMMARY DESCRIPTION OF THE MOREHEAD–KIUNGA AREA

By K. PAIJMANS,* D. H. BLAKE,* and P. BLEEKER*

I. INTRODUCTION

In western Papua, west of long. 142° 30′ E., the central mountain chain of New Guinea is flanked by a low-lying tract of land stretching from the base of the foothills in the north to the coast in the south. Within this low-lying tract is the Morehead–Kiunga area, measuring 225 miles from north to south and up to 65 miles from east to west (Fig. 2).

The survey area ranges in altitude from sea level in the south to about 300 ft in the north-east, has a maximum relief of about 200 ft, and consists of low ridges and plateaux, broad major flood-plains, narrow minor valleys, and many swamps and lakes. It is traversed by the Fly River, the longest river in New Guinea, and contains the lower courses of the Strickland and Alice (Ok Tedi) Rivers, the main tributaries of the Fly. The largest lake in the area is Lake Murray, which drains into the Strickland River via the Herbert River; of the other major lakes the most important are Boset Lagoon (also called Lake Wam and Lake Herbert Hoover), Suki Lagoon, and Lake Daviumbu (Fig. 1).

The southern part of the area is unique in the Territory of Papua and New Guinea for its wideness and flatness, and the landscape strongly resembles that of coastal and adjacent areas of northern Australia. The predominance of tea-tree or paperbark (*Melaleuca* spp.) and the commonness of termitaria strengthen the similarity. In the Morehead–Kiunga area large numbers of deer roam the coastal plain and adjacent areas, whereas in northern Australia it is the water buffalo that thrives in similar country. Both animals are introduced and have multiplied abundantly in their new environments.

II. REGIONAL DESCRIPTION

(*a*) *Climate*

The survey area lies within two climatic zones. The southern part lies within a zone having a tropical savannah or subhumid tropical type of climate. This region stretches from near the mouth of the Fly River in the east to beyond Merauke in West Irian (Fig. 2). Here the annual rainfall is about 75 in., of which over 75% is received in a wet season lasting from December to May, the remainder falling in a dry season from June to November. As a result of the monsoonal climate, savannah and monsoon forest types of vegetation predominate (Plates 9–11). The northern part of the survey area lies within the wet tropical climatic zone which covers most of New Guinea.

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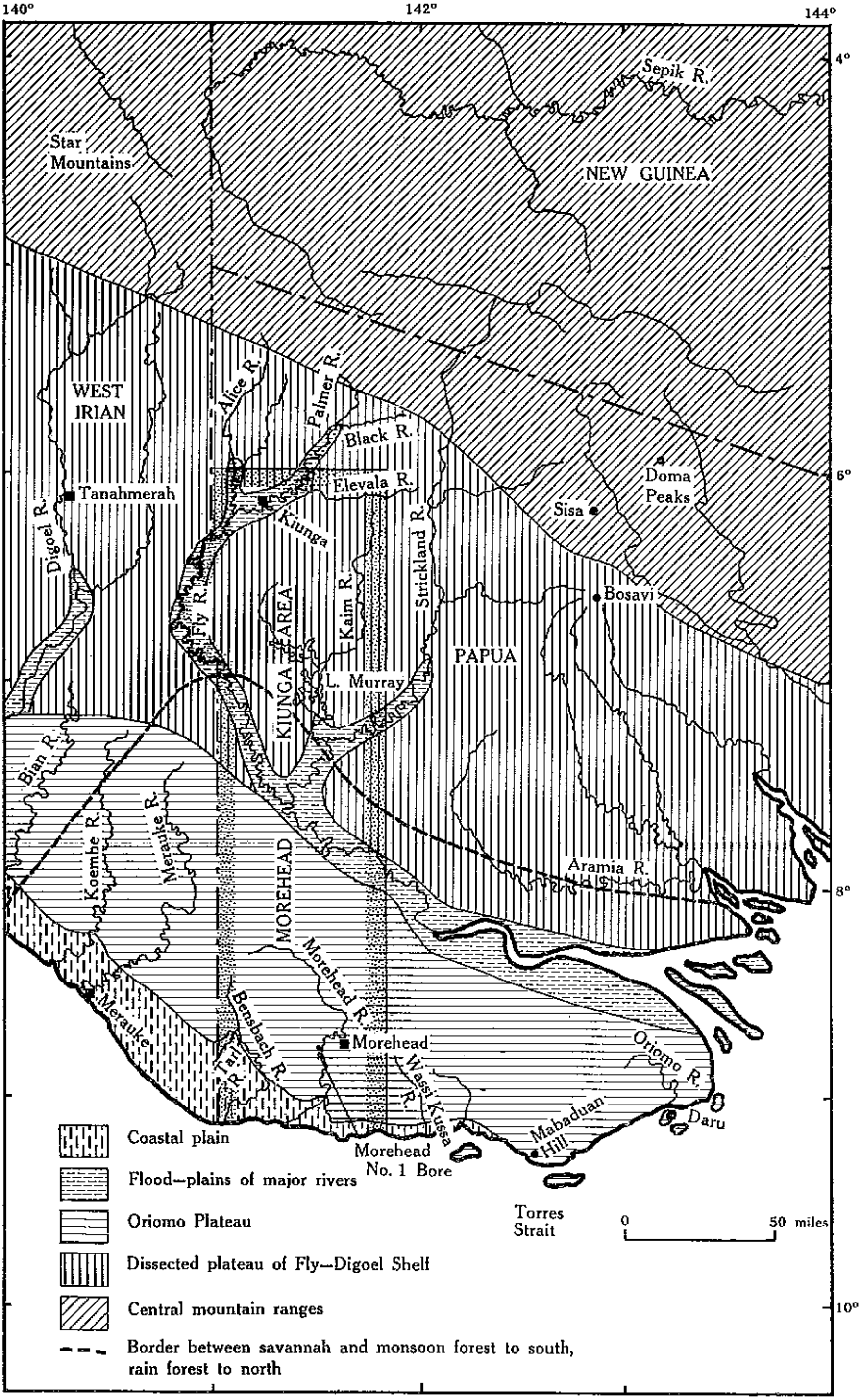

Fig. 2.—Regional setting of the Morehead-Kiunga area.

Here an annual rainfall of about 175 in. is almost equally spread over the year and rain forest is the predominant type of vegetation (Plate 11, Fig. 2; Plate 14, Fig. 1). In the central part of the survey area there is a transition zone where an annual rainfall between 100 and 150 in. is seasonally distributed, but not so markedly as in the south. During the wet season north-westerly winds prevail, whereas the dry season is characterized by south-easterly winds.

(b) *Land Form, Soil, and Vegetation*

For the purpose of a regional description it is convenient to divide the area into four geographic regions: the coastal plain; the flood-plains of the Fly River and its tributaries; the Oriomo Plateau, a low undissected flat to slightly undulating plateau; and the intricately dissected plateau of the Fly–Digoel Shelf. The coastal plain and the Oriomo Plateau lie in the monsoon climate zone, whereas the flood-plains of the Fly River and its tributaries and the dissected plateau lie mostly within the wet tropical climate zone. The topographic contrast between the undissected Oriomo Plateau in the south and the dissected plateau of the Fly–Digoel Shelf in the north may be due mainly to climatic factors such as difference in total annual rainfall and seasonality of rainfall. The coastal plain and the river flood-plains have young alluvial soils, while on the Oriomo Plateau and the Fly–Digoel Shelf the soils are strongly developed. A marked textural contrast in the soils on the Oriomo Plateau may be due to rainfall seasonality.

Land form, soils, and vegetation of the four geographic regions are briefly described below.

(i) *The Coastal Plain*.—This consists of flats and low beach ridges and swales along the coast and a back plain inland and is crossed by the flood-plains of the Morehead and Bensbach Rivers. It ranges in width from less than 300 ft to over 12 miles and is mostly less than 10 ft above mean sea level. It is crossed by the Morehead and Bensbach Rivers. Most of the flats are flooded or inundated by fresh water in the wet season, but flats nearest to the coast are subject to tidal inundation. The soils of the flats are very poorly drained marine clays ranging from strongly alkaline near the coast to neutral or weakly acid further inland. Mangrove occurs on tidal flats while elsewhere mixed woodland, littoral forest, and man-induced *Imperata* grassland are found. The beach ridges have well-drained sandy soils and littoral forest and *Imperata* grassland; the swales have soils and vegetation similar to those of the non-tidal flats. The inland back plain is almost completely inundated during the wet season. It largely dries out in the dry season although some parts remain swampy. Soils here are leached and non-calcareous clays with a weakly acid to neutral soil reaction, and the vegetation mainly consists of low sedge–grassland, locally with scattered *Pandanus* trees (Plate 1). The flood-plains of the Morehead and Bensbach Rivers consist of permanent to seasonal swamps which have organic soils and very poorly drained acid alluvial clay soils. The vegetation consists of reeds and tall sedges in permanent swamp (Plate 3, Fig. 1); low swamp grassland and *Melaleuca* swamp forest in semi-permanent to seasonal swamp (Plate 2, Fig. 1; Plate 3, Fig. 2); and, on slightly higher ground, *Melaleuca* savannah and *Imperata* grassland (Plate 2, Fig. 2).

(ii) *The Flood-plains of the Fly River and its Tributaries.*—The Fly River and its main tributaries the Strickland and Alice Rivers have wide flood-plains consisting of meander scroll complexes flanked by back swamps and lakes (Plate 4, Fig. 2; Plate 5), many of which extend several miles up tributary valleys. The flood-plains have extremely low gradients: for instance, near Kiunga, 500 miles upstream from its mouth, the Fly River is only 60 ft above sea level (Anon. 1965). Levees on river banks are low and discontinuous and the flood-plains are frequently and deeply flooded, the back swamps being under water for most of the year. Deposition of alluvial material has proceeded more rapidly in the valleys of the major rivers than in the tributary valleys, and this has led to the blocking of the latter and the formation in them of numerous lakes and swamps. The largest of the lakes, Lake Murray, occupies the flooded valley of the Herbert River and covers almost 300 sq miles (Plate 11, Fig. 2; Plate 12).

The scroll complexes mostly have very poorly drained to swampy alluvial clay soils and the back plains have a mixture of organic soils and sloppy alluvial clay. The flood-plains of the Fly and Strickland Rivers, downstream from the bulge into West Irian and Massey Baker's Junction respectively, are characterized by extensive stretches of swamp grass, broken only by thin strips of swamp forest and water-logged open rain forest on scroll ridges; *Melaleuca* swamp savannah is typical of the back plains (Plate 8, Fig. 2). The flood-plains of the Fly and Strickland Rivers further upstream, and of the Alice River, are less severely flooded, and here open rain forest predominates on the scroll complexes (Plate 6, Fig. 2) and swamp forest and swamp woodland commonly with sago characterize the back plains. Downstream from Ellangowan Island, tidal influence along the Fly River is indicated by the occurrence of alkaline subsoils and of *Sonneratia* mangrove on river scrolls.

(iii) *The Oriomo Plateau.*—This plateau is bounded in the south by the coastal plain and in the north by the flood-plains of the Fly River. It is mainly less than 100 ft above sea level. Streams, the most important of which are the Morehead and Bensbach Rivers, are widely spaced and generally have open V-shaped valleys; narrow flood-plains are present locally. The highest part of the plateau is an east–west-aligned ridge on which Morehead is situated. This is the Morehead Ridge, up to 50 ft above the surrounding plain and up to 180 ft above sea level. However, the main watershed, from which flow the Morehead, Bensbach, and Wanggoe Rivers, lies some 30 miles north of the Morehead Ridge and is mostly less than 100 ft above sea level. South of the Morehead Ridge the plateau slopes very gradually down to the coastal plain; much of this part of the plateau is inundated in the wet season (Plate 9, Fig. 2). The remainder of the plateau consists of watershed areas and slightly undulating terrain. The watershed areas are generally flat and have very slowly permeable subsoils, hence they are inundated during the wet season; the undulating country is generally better drained and not subject to inundation. Soils on the plateau are grey and reddish brown sandy loams and loamy sands overlying red and grey mottled clay subsoils. Many soils contain lateritic concretions, particularly those on the Morehead Ridge. The vegetation consists of *Melaleuca* savannah near the coastal plain, low sedge–grassland, monsoon scrub, and low mixed savannah on the watershed areas and tall mixed savannah and monsoon forest on the undulating terrain (Plate 10, Fig. 2; Plate 11,

Fig. 1). Grassland and savannah areas are burnt every dry season. Termite mounds are a characteristic feature of the open savannah (Plate 10, Fig. 1).

(iv) *The Dissected Plateau of the Fly–Digoel Shelf*.—This plateau ranges in altitude from 40 ft above sea level in the south-east to 300 ft above sea level in the north-east, and it is crossed by the broad flood-plains of the Strickland, Alice, and upper Fly Rivers. In marked contrast to the Oriomo Plateau, it consists of innumerable closely spaced ridges and valleys with an intricately dendritic drainage pattern. The main valleys have flat swampy flood-plains traversed by meandering sluggish rivers. Slumping, gullying, and tunnelling are common features in the northern part. Under influence of the wet tropical climate the soils are leached and deeply weathered. Uniform-textured well-drained red clays with an acid soil reaction predominate on hill slopes and ridge crests, although some crests have imperfectly drained soils with red and grey mottles in the subsoil. Valley floors have mainly organic soils and strongly gleyed alluvial soils. The vegetation on the ridge crests and hill slopes consists of tropical lowland rain forest, very rich in species but rather poor in timber volume. Sago swamp woodland, commonly with emergent *Campnosperma* trees, occurs in the valley bottoms. A striking feature of the forests is the commonness of members of the Dipterocarpaceae.

(*c*) *Present Land Use*

Most of the land in the survey area is used only for hunting. Limited subsistence agriculture in the coastal area and on the Oriomo Plateau is centred around Morehead, Weam, and widely scattered small villages on the better-drained parts of the southern area. Yam (*Dioscorea* sp.) is the staple crop, and each village has one or two coconut groves.

The population in the central part of the survey area is centred around Lake Murray and Boset Lagoon and exists mainly on sago and the products of fishing and hunting; subsistence agriculture is of minor importance. The main source of cash income used to be the sale of crocodile hides. However, many years of over-shooting have substantially reduced the numbers of crocodiles, and the income from the sale of skins has dwindled.

In the northern part of the survey area the staple diet is still sago, but subsistence agriculture is fairly widespread around the population centres of Kiunga and Atkamba. In recent years plantations of high-yielding rubber varieties have been established near many villages under the guidance of the Department of Agriculture.

(*d*) *Fauna*

The coastal plain is very rich in wildlife. Many years ago the Dutch released a number of sambur deer near Merauke (Willey 1965), and these have multiplied and moved into western Papua, so that about 38,000 deer now roam the plains between the Morehead and Bensbach Rivers. Their tracks criss-cross the coastal plain and converge towards islands of shrubbery within the grass (Plate 1, Fig. 1). In addition to deer, large numbers of wallabies and pigs live on the grassy flood-plains of the Bensbach, Tarl, and Wanggoe Rivers.

The swamps, lakes, and rivers, especially on the coastal plain and along the middle Fly, are an El Dorado for thousands of waterfowl, and many of the lakes and smaller rivers abound with fish, of which barramundi (*Lates calcarifer*) and a large catfish of the family Tachysuridae are particularly common.

Crocodiles used to be abundant, but indiscriminate shooting has greatly reduced their numbers. Although the crocodile does not yet seem to be in danger of extinction, measures for controlled shooting are urgently required.

Non-magnetic termitaria up to 14 ft high, probably of *Nasutitermes triodiae* (F. J. Gay, personal communication), are plentiful in the open, poorly drained, but not swampy areas of the Oriomo Plateau, and a black termite (*Hospitalitermes papuanus**) was on many occasions seen marching in armies through the rain forests. *Nasutitermes triodiae* has also been recorded in the Northern Territory of Australia, but *Hospitalitermes papuanus* seems to be strictly Malaysian. Mounds of the bush hen (brush turkey?) are common throughout the forests.

Mosquitoes abound throughout the area, especially in the middle Fly, but there appears to be no evidence of a particularly high incidence of malaria. In the wooded portions of the southern area the team was continuously harassed by green ants. At the time of survey there were no leeches in the monsoon forest, and they were only very locally common in the rain forest. Scrub mites abound on some abandoned village sites.

(*e*) *Land Use Potential*

The main factors limiting potential agricultural production in the area are acid and infertile soils, poor drainage, flooding and inundation hazards, difficult land communications because of numerous swamps, and, in the southern part, seasonal drought stress. The forests in the central and northern parts of the area have a low potential mainly because of low timber volume but also because of access problems.

On the positive side, some 7000 sq miles are rated as moderately to highly suitable for the cultivation of tree crops. Rubber is already being planted in the north, and the cultivation of oil palm in the centre and teak in the south might be considered. An area of 2900 sq miles in the northern part of the Oriomo Plateau is rated moderately suitable for arable crops, and some 3600 sq miles on the coastal plain and the Oriomo Plateau near permanent water supplies are moderately suitable for irrigated rice. Many of the lakes and rivers in the area, particularly in the central part, could be used for fish and crocodile farms. The grasses of the natural pastures in the south have a low nutrient value for cattle, but as these pastures feed large numbers of deer it is likely that they could also support water buffaloes. Under suitable management, such animals could help overcome the shortage of locally produced meat in the Territory of Papua and New Guinea. An additional potential industry is tourism in the southern part of the area, where abundant wildlife roams plains that are readily accessible in the dry season.

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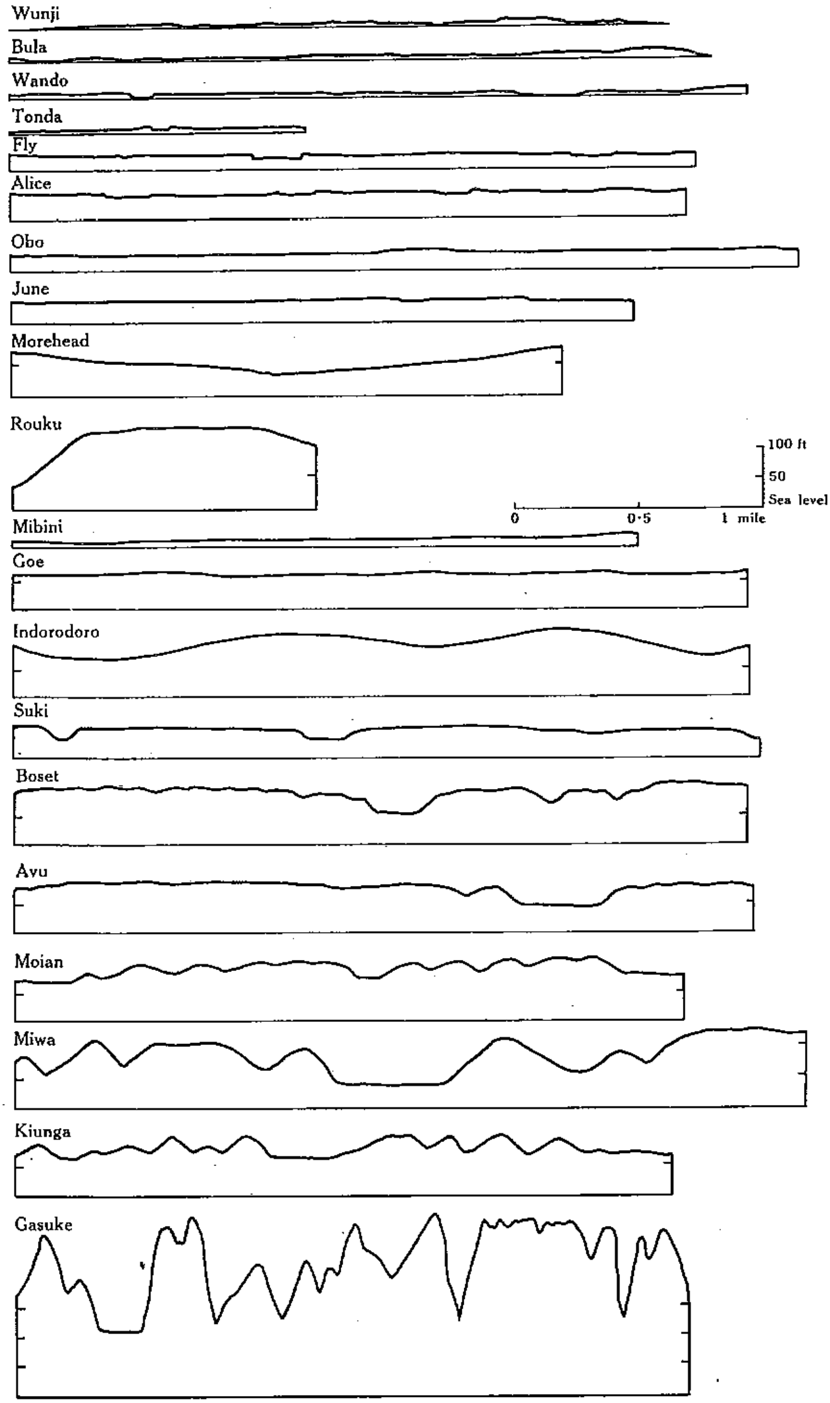

Fig. 3.—Typical cross-sections of the land systems.

PART III. LAND SYSTEMS OF THE MOREHEAD–KIUNGA AREA

By K. Paijmans,* D. H. Blake,* and P. Bleeker*

I. Introduction

The area has been mapped as 20 land systems (Christian and Stewart 1953), each of which consists of a recurring pattern of land forms, soils, and vegetation. The land systems were initially recognized as distinctive patterns on air photographs, and were later checked by examining selected sites in the field.

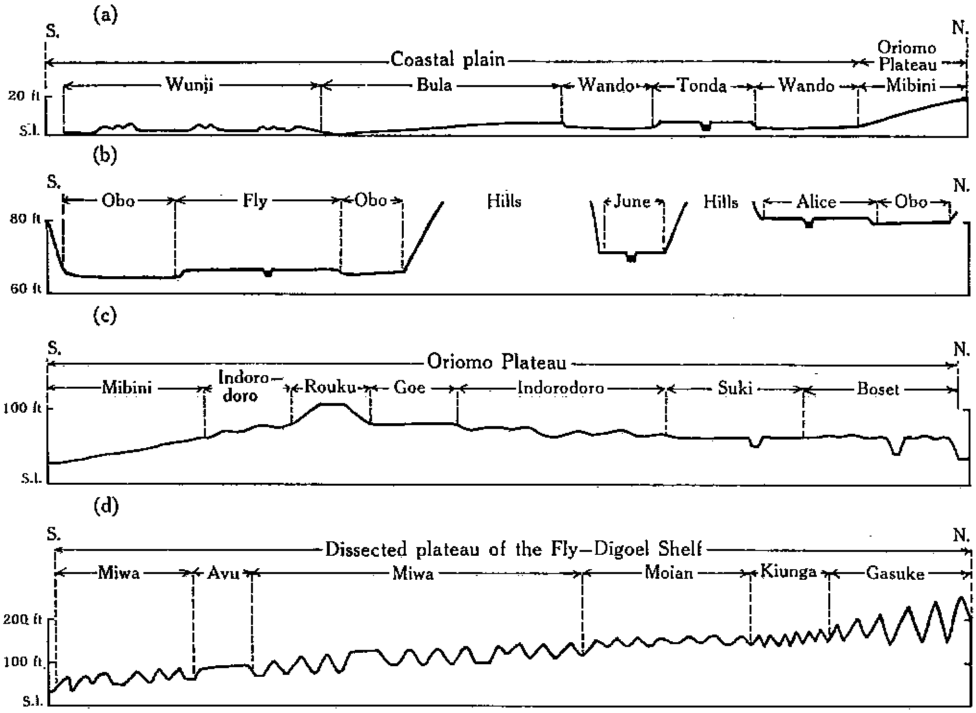

Fig. 4.—Diagrammatic sections showing the topographical relationships of the land systems in the four geographical units. (*a*) Land systems of the coastal plain; (*b*) land systems of the Fly River and its tributaries; (*c*) land systems of the Oriomo Plateau; (*d*) land systems of the dissected plateau of the Fly–Digoel Shelf.

The land systems are described in tabulated form and illustrated by sketch plans and cross-sections. More detailed information on land forms, soils, vegetation, and land use capability can be obtained from Parts V–VIII of the report.

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TABLE 1

DIAGNOSTIC FEATURES OF LAND SYSTEMS

Land System	Geology	Main Land Forms	Altitude (a.s.l.) (ft)	Relief (ft)	Characteristic Slope	Grain (ft)	Predominant Soil	Predominant Vegetation	Drainage	Flooding and Inundation
Coastal plain										
Wunji	Littoral sand, silt, and clay	Non-tidal and tidal flats; low beach ridges and swales	0–5	< 5	< 1 in 1000	—	Weakly acid to neutral over alkaline marine clay	Littoral forest and woodland	Largely very poorly drained	Large parts inundated in wet season
Bula	Clay and silt	Plain	2–20	< 5	< 1 in 1000	—	Strongly gleyed alluvial clay, weakly acid over alkaline or acid over weakly acid	Sedge–grassland	Poorly to very poorly drained	Largely inundated in wet season
Wando	Alluvial clay and silt	Swampy flood-plain	2–30	< 10	1 in 1000	—	Organic soils, and strongly gleyed alluvial clay, acid to strongly acid	Herbaceous swamp vegetation, *Melaleuca* swamp forest, low swamp grassland	Swampy to very poorly drained	Permanently inundated or inundated in wet season
Tonda	Alluvial clay and silt	Flood-plain	5–15	< 10	1 in 500	—	Strongly gleyed alluvial clay commonly with a thick dark topsoil, acid to strongly acid	*Imperata* grassland, *Melaleuca* swamp forest	Poorly drained	Probably flooded and inundated for less than 3 months a year
Flood-plains of the Fly River and its tributaries										
Fly	Alluvial clay, silt, and sand	Swampy alluvial plain	10–70	< 10	< 1 in 1000	—	Strongly gleyed alluvial clay loam and clay, weakly acid to neutral	Open rain forest, tall swamp grassland	Swampy to poorly drained	Frequent and deep flooding and inundation

Alice	Alluvial clay, silt, sand, and gravel	Alluvial plain	70–100	< 10	< 1 in 1000	—	Strongly gleyed alluvial clay loam and clay, weakly acid	Open rain forest	Poorly drained	Frequent flooding and inundation
Obo	Alluvial clay and peat	Back swamp	10–80	< 5	< 1 in 1000	—	Organic soils and strongly gleyed alluvial clay loam and clay, weakly acid to acid	*Melaleuca* swamp savannah, swamp grassland, swamp woodland	Swampy	Prolonged flooding and inundation
June	Alluvial clay	Flood-plain	25–80	< 5	< 1 in 500	—	Strongly gleyed alluvial clay loam to clay, strongly acid	Swamp forest	Very poorly drained to swampy	Frequent flooding and inundation
Undissected plateau (Oriomo Plateau)										
Morehead	Pleistocene clay	Broad shallow valleys	10–90	20–80	2–3°	—	Loamy sand to loam overlying mottled clay loam to clay	Sedge–grassland, *Melaleuca* savannah	Imperfectly drained	Partly flooded in wet season
Rouku	Clay	Broad ridge	30–150	30–100	1–2°	—	Loam overlying gravelly loam and clay loam, acid to strongly acid	Monsoon forest	Well drained	
Mibini	Alluvial clay	Smooth plain	5–50	< 5	< 1 in 1000	> 5000	Loam overlying mottled clay loam to clay, acid to strongly acid	*Melaleuca* savannah	Imperfectly to poorly drained	Large parts inundated in wet season
Goe	Clay	Flat to very gently undulating plains on watersheds	50–120	< 5	< 1 in 1000	—	Loamy sand and loam overlying mottled clay loam and clay, acid to strongly acid	Monsoon scrub and low mixed savannah	Imperfectly to poorly drained	Large parts inundated in wet season

TABLE 1 (*Continued*)

Land System	Geology	Main Land Forms	Altitude (a.s.l.) (ft)	Relief (ft)	Characteristic Slope	Grain (ft)	Predominant Soil	Predominant Vegetation	Drainage	Flooding and Inundation
Undissected plateau (Oriomo Plateau) (*Continued*)										
Indorodoro	Clay	Gently undulating plain	50–120	30–50	1–2°	2500	Sandy loam to loam overlying mottled clay loam and clay, acid to strongly acid	Monsoon forest and tall mixed savannah	Well to imperfectly drained	Locally inundated in wet season
Suki	Clay	Gently undulating to flat plain	10–70	20–30	1–2°	1500	Loam and clay loam overlying mottled clay, acid to strongly acid	Undulating terrain: monsoon forest and low mixed savannah	Well to imperfectly drained	
								Flat terrain: *Melaleuca* swamp forest and probably *Melaleuca* swamp savannah	Poorly drained	Inundated in wet season
Boset	Clay	Undulating plain	10–130	30–100	2°	1500	Loam to clay loam overlying mottled clay, acid to strongly acid	Monsoon forest	Well to imperfectly drained	
Dissected plateau of the Fly–Digoel Shelf										
Avu	Clay, silt, and sand	Flat to gently undulating plateau	40–90	30–40	1–2°	> 5000	Undulating terrain: clay loam overlying mottled clay, acid to strongly acid	Closed rain forest	Well to imperfectly drained	

							Flat terrain: clay loam overlying strongly gleyed clay, acid to strongly acid	*Melaleuca* savannah	Poorly to very poorly drained	Inundated in wet season
Moian	Clay, silt, and sand	Low ridges and flat swampy valley floors	60–130	20–50	5°	400	Ridges: clay loam overlying clay, acid to strongly acid	Closed rain forest	Well drained	
							Valley floors: organic soils	Sago–*Campnosperma* swamp woodland	Very poorly drained	Periodic brief flooding
Miwa	Clay, silt, and sand	Narrow ridges	10–200	30–100	8°	400	Clay loam to clay, acid to strongly acid	Closed rain forest	Well drained	
Kiunga	Clay, silt, sand, and gravel	Narrow ridges	70–170	20–80	10°	200	Red uniform-textured clay loam to clay, acid to strongly acid	Closed rain forest	Well drained	
Gasuke	Clay, silt, sand, and gravel	Narrow ridges	100–300	100–200	30°	250	Red or yellowish brown uniform-textured clay loam to clay, acid to strongly acid	Thin-stemmed closed rain forest	Well drained	

The land systems are numbered from 1 to 20 and are described in this order. They are arranged in four groups representing the four geographic regions briefly described in Part II, Section II(*b*). The order of the land systems within each group is based on geomorphic criteria the same as those shown in Table 1 and in the reference to the land system map. The diagnostic features of each land system are set out in Table 1, and typical cross-sections are presented in Figure 3. The topographic relationships of the land systems within the four main groups are shown diagrammatically in Figure 4. A brief explanation of some of the terms and concepts used in Table 1 and in the tabular land system descriptions is given in the following section.

II. Explanation of Land System Descriptions

(*a*) *Terrain Parameters*

Categorization of the terrain parameters altitude, relief, slope, and grain mainly follows that used in the report on lands of Bougainville and Buka Islands (Speight 1967). *Altitude* is the range in height above sea level within the land system. *Relief* is defined as the difference in height, within the land system, between ridge crest or summit and the nearest valley. The *characteristic slope* is the slope that is typical of the largest land unit in the land system. *Grain* is defined as half the average distance between major stream beds in the land system, assessed from air photographs.

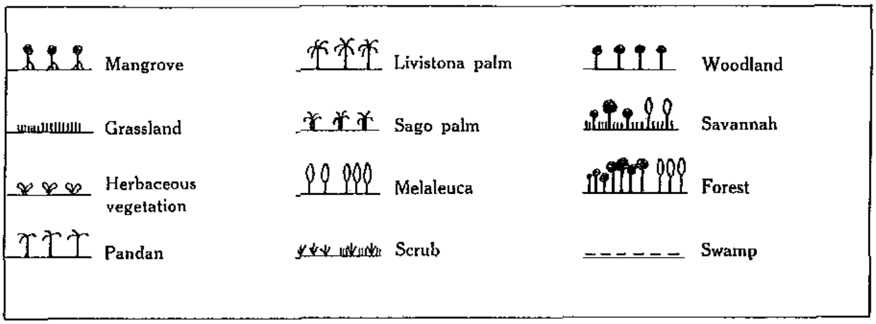


Fig. 5.—Key to the vegetation symbols used on the land system profiles.

(*b*) *Sketch Plans and Cross-sections*

The sketch plans and cross-sections, drawn by D. H. Blake, are diagrammatic representations showing the patterns and relationships of the different land units within the land systems. All plans are drawn on the same scale. The horizontal scale of the cross-sections is double that of the plans. The vegetation symbols, which are not to scale, are explained in Figure 5.

(*c*) *Land Units*

The description below the sketch plan correlates land form, soils, and vegetation of each land unit. The relative area of each land unit within a land system is an estimate assessed from air photographs.

In the Land Forms column, permanent swamps are defined as areas waterlogged all the year, semi-permanent swamps are waterlogged for more than 6 months a year, and seasonal swamps are waterlogged for less than 6 months a year. The term flooding is used for overflow of moving water which either erodes or deposits material; flooding generally lasts less than 15 days and mostly comes from nearby rivers. The term inundation is used for slowly rising and abating water on the land surface; it does not erode or deposit material and can be caused by rain, rising ground water, or spent flood-waters and it generally lasts more than 15 days.

In the Soils column, letters in brackets refer to the relevant soil family. Terms used are defined in Part VI, Section II.

In the Vegetation column, names of vegetation types are those used in Part VII.

In the Limitations column, the factors limiting potential agricultural land use are given as ratings which are defined in Appendix I.

At the bottom of each land system description an assessment is given of the potential of the land system for arable crops, tree crops, improved pastures, and irrigated rice. The assessment is based on the combined effect of all limiting factors, and the methods used are further discussed in Part VIII. The ratings for the soil nutrients nitrogen, available phosphate, and potassium are explained in Appendix II.

III. References

Christian, C. S., and Stewart, G. A. (1953).—General report on survey of Katherine–Darwin region, 1946. CSIRO Aust. Land Res. Ser. No. 1.

Speight, J. G. (1967).—Lands of Bougainville and Buka Islands, Papua–New Guinea. CSIRO Aust. Land Res. Ser. No. 20, 174–84.

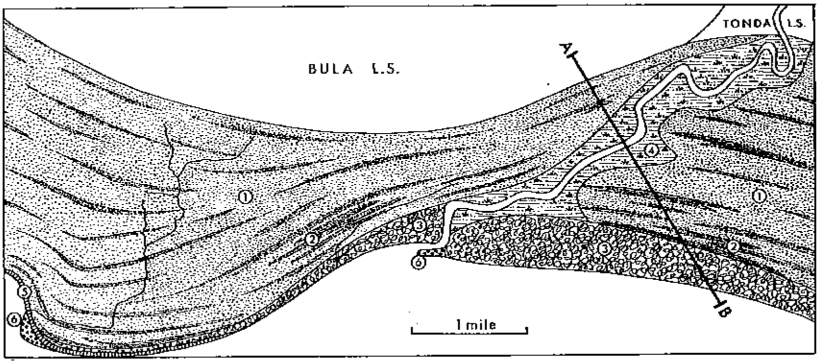
(1) Wunji Land System (144 sq miles)

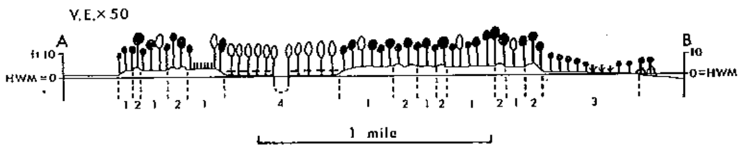
Coastal flats, beach ridges, and swales.

Geology.—Littoral sand, silt, and clay; Recent.

Geomorphology.—Littoral plains 0–7 miles wide; an inland complex of non-tidal flats and long low beach ridges and swales passing seawards into tidal flats, present beach ridges and beaches, spits, and offshore bars. Some narrow tidal creeks. Alluvial flats flank the lowermost courses of the Morehead and Bensbach Rivers. Normal spring tidal range about 12 ft.

Terrain Parameters.—Altitude: 0–5 ft. Relief: <5 ft. Characteristic slope: <1 in 1000. Grain: —.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	70	Non-tidal flats: 200–5000 ft wide, 1–3 ft above high-water mark	Marine clays: mainly weakly acid to neutral over alkaline, very poorly drained (EAHV1—3 obs., locally EAHV2—1 obs.)	Littoral forest and woodland; minor *Imperata* grassland	i2, w3, p4, d3, m2, t1, a1/4, c1, g2
2	10	Inland beach ridges and swales aligned parallel to coast: ridges 200–400 ft wide, 1–4 ft high, up to 5 ft above high-water mark; swales 50–200 ft wide, 0–2 ft above high-water mark	Ridges: sands to sandy loams, alkaline over strongly alkaline, well drained (IOEO—1 obs., MR—1 obs.) Swales: marine clays, weakly acid to neutral over alkaline, very poorly drained (EAHV1)		Ridges: p1, d1–2, m3, a4/6, g2 Swales: i2, w3, p4, d3, m2, t1, a1/4, c1, g2
3	15	Tidal flats: 200–5000 ft wide, at high-water mark	Marine clays: alkaline to strongly alkaline, very poorly drained (EAHV2—2 obs.)	Low *Rhizophora* forest, mangrove woodland, and scrub	f3, i1–3, w3, p4, d3, m2, t1, a4, c2, g2
4	3	Alluvial flats: 500–5000 ft wide, 0–3 ft above high-water mark	Probably alluvial clay loams to clays: weakly acid to weakly alkaline, poorly drained	Probably mainly *Melaleuca* swamp forest; *Nypa* palm along edges of rivers	No data
5	<1	Present beach ridge: up to 200 ft wide, up to 5 ft above high-water mark; locally small sand dunes	Probably medium and fine sands: alkaline	Mixed herbaceous beach vegetation	
6	<1	Present beaches, spits, and offshore bars		Bare	

Agricultural Potential.—Moderate for irrigated rice, low for improved pastures. Soil nutrient status (2 soils): nitrogen moderate, available phosphate low but very variable, potash high.
Observations.—8.

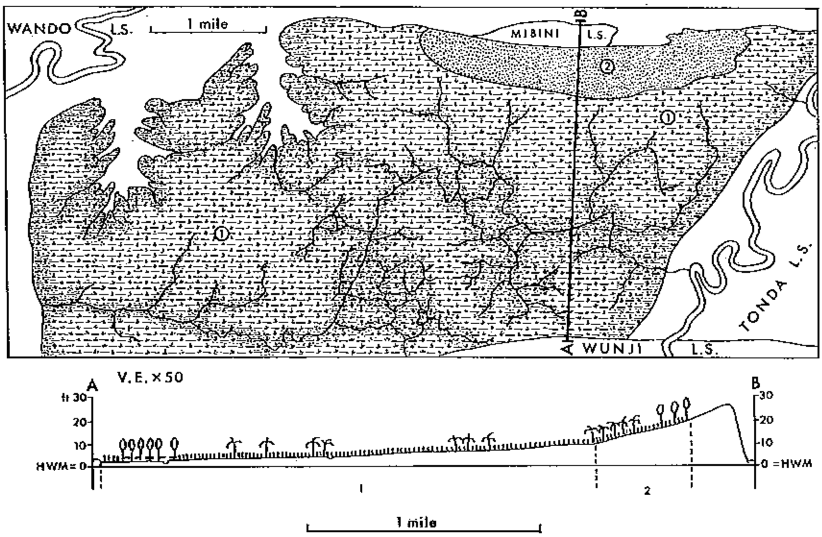
(2) Bula Land System (226 sq miles)

Plain with sedge–grassland and scattered *Pandanus* trees (Plate 1).

Geology.—Clay and silt; Recent.

Geomorphology.—Plain traversed by small tortuous channels that form an open to dense dendritic to reticulate drainage pattern; almost completely covered by standing water during wet season.

Terrain Parameters.—Altitude: 2–20 ft. Relief: <5 ft. Characteristic slope: <1 in 1000. Grain: —.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	85	Plain: 2–15 ft above high-water mark; semi-permanent swamps in shallow depressions; short slopes bordering permanent and semi-permanent swamps of Wando land system; slopes generally <1 in 1000; dense drainage pattern	Clays: weakly acid over weakly alkaline, also acid over weakly acid, poorly to very poorly drained (EAHV1—1 obs., EAHV4—1 obs.). Locally sandy clay loam overlying clay, acid over neutral, poorly drained (AAAM—1 obs.)	Low, locally mid-height, grassland with abundant sedges and scattered *Pandanus* trees; *Melaleuca* swamp forest; *Melaleuca* savannah in east	i3–4, w2–3, p4, d3, m2, locally a2, g2
2	15	Plain: 10–20 ft above high-water mark; surface with reticulate pattern of cracks up to 1 ft deep and wide; no well-defined drainage channels; slopes <1 in 100	Clays: acid over neutral, poorly drained (EAHV3—3 obs.)	Low to mid-height strongly tussocky sedge-grassland with *Pandanus* trees; *Melaleuca* savannah	i2, w2, p4, d3, m2, t1, a2, g2, u2

Agricultural Potential.—Low for irrigated rice, very low for improved pastures.
Observations.—5.

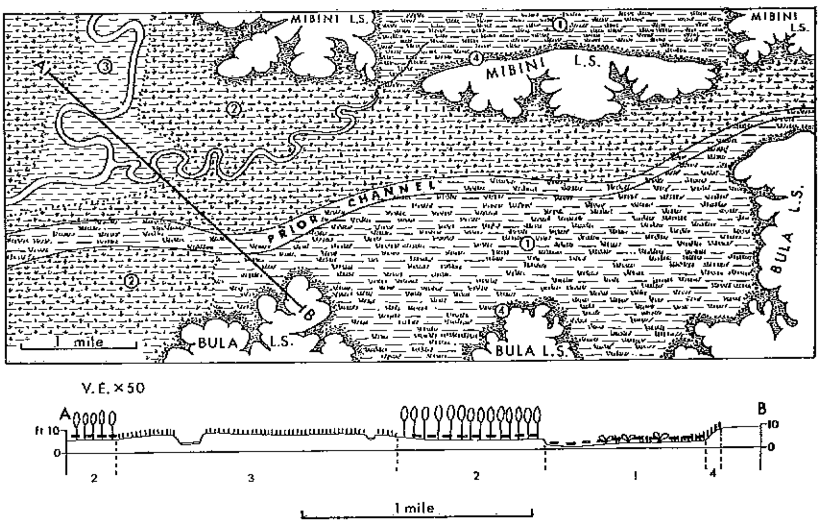
(3) Wando Land System (388 sq miles)

Permanent to seasonal swamps associated with Morehead, Bensbach, and Wanggoe Rivers and tributaries (Plate 2, Fig. 1; Plate 3).

Geology.—Alluvial clay and silt, local peat; Recent.

Geomorphology.—Swampy flood-plains of meandering rivers and swampy prior river channels. Most swamps have irregularly indented margins where bordered by higher plains of adjacent land systems. Main river channels are normally less than 200 ft wide.

Terrain Parameters.—Altitude: 2–30 ft. Relief: <10 ft. Characteristic slope: 1 in 1000. Grain: —



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	40	Permanent swamp; back swamp up to 2 miles wide; also prior channels, up to 3000 ft wide	Organic soils (H1—2 obs.)	Tall sedge; aquatic vegetation; open water	i5, w4, p4, d2, m1, a2, g2
2	40	Semi-permanent swamp; up to 2 miles wide, locally slightly undulating with up to 3 ft microrelief; slopes <1 in 500	Alluvial clays: locally with thick dark topsoils, acid to strongly acid, very poorly drained (EAHO7—4 obs., locally IAU2—1 obs.)	Mainly tall, occasionally low, *Melaleuca* swamp forest	i4, w3, p5, d2–3, m2, a2 and a5, g1
3	10	Seasonal swamps: microrelief of broad shallow depressions <2 ft deep; slopes <1 in 1000; discontinuous levees up to 3 ft high along main river channels	Alluvial clay loams overlying clays: thick dark topsoils present, strongly acid, poorly drained (IAU1—6 obs.)	Low swamp grassland (*Pseudoraphis* sp.), usually with widely scattered low *Barringtonia* trees; on levees, gallery woodland and *Melaleuca* savannah	f2, i3–4, w2, p4 d2, m2, a5, g1
4	10	Swamp margins: intermittently flooded and bordered by higher plains of adjacent land systems; slopes up to 5°	Alluvial clays: acid over strongly acid, poorly to very poorly drained (EAHO7—1 obs., EAHO4—1 obs., EAHAt1—1 obs.) Clay loams and loams overlying clays: thick dark topsoils present, strongly acid, poorly to very poorly drained (UAU—3 obs.)	Low swamp grassland; also *Melaleuca* swamp forest	f2, i3, w2–3, p4, d2, m2, a2/5 and a5, g2

Agricultural Potential.—Very low for irrigated rice. Soil nutrient status (1 soil in unit 4): nitrogen moderate to low, available phosphate very low, potash low.
Observations.—19.

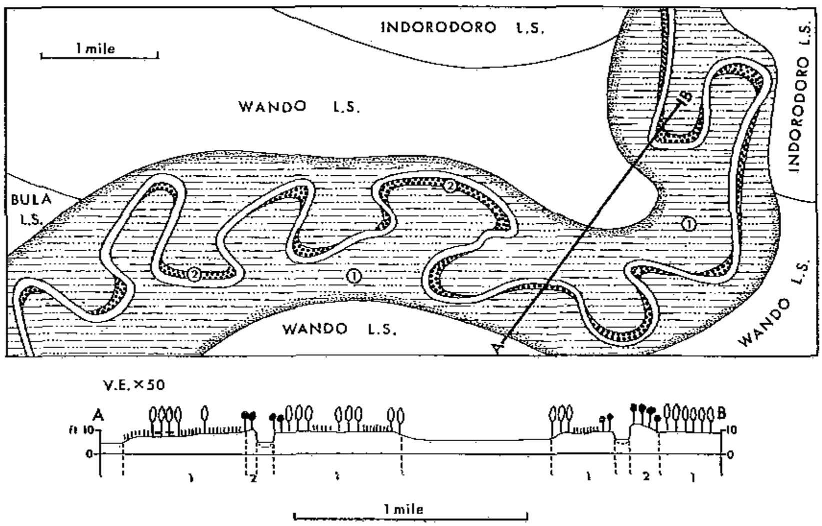
(4) Tonda Land System (50 sq miles)

High flood-plains of lower Morehead and Bensbach Rivers (Plate 2, Fig. 2).

Geology.—Alluvial clay and silt; Recent.

Geomorphology.—High flood-plains along tidal reaches of Morehead and Bensbach Rivers, probably flooded for less than 3 months a year; discontinuous low levees border river channels; river banks generally vertical, locally terraced.

Terrain Parameters.—Altitude: 5–15 ft. Relief: <10 ft. Characteristic slope: 1 in 500. Grain: —.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	>95	Flood-plain: surface smooth or with broad depressions less than 2 ft deep; 5–12 ft above mean river level; slopes up to 1 in 100	Mainly alluvial clays: commonly with thick dark topsoils, acid to strongly acid, poorly to very poorly drained (IAU1—2 obs., EAHO7—1 obs.)	*Imperata* grassland, *Melaleuca* swamp forest, minor gallery woodland	f2, i2, w2–3, p4, d2, m2, a2 and a5, g2
2	<5	Levees: up to 300 ft wide and 3 ft above back plain; slopes generally <1°	Alluvial clays: acid, poorly drained (BAHO7—1 obs.)	Gallery woodland	f2, w2, p4, d3, m2, t1, a2, g1

Agricultural Potential.—Low for improved pastures and irrigated rice, very low for arable crops. Soil nutrient status (2 soils): nitrogen moderate, available phosphate very low, potash high.
Observations.—4.

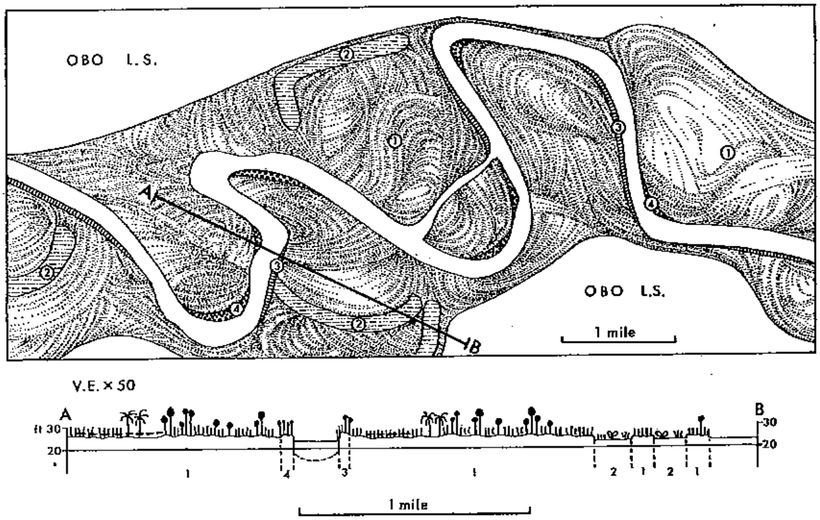
(5) Fly Land System (539 sq miles)

Scroll complexes of the Fly and Strickland Rivers, with tall swamp grassland and open rain forest and very poorly drained to swampy alluvial soils (Plate 4, Fig. 2; Plate 5; Plate 6, Fig. 1).

Geology.—Alluvial clay, silt, and sand; Recent.

Geomorphology.—Alluvial plains consisting largely of scroll complexes, with oxbows, low levees, and present scrolls, subject to prolonged flooding. Main river channels 1000–4000 ft wide. Fly River tidal downstream from Ellangowan Island.

Terrain Parameters.—Altitude: 10–70 ft. Relief: <10 ft. Characteristic slope: <1 in 1000. Grain: —.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	90	Scroll complexes: patterns of crescentic ridges and swales; maximum local relief 5 ft	Alluvial clay loams to clays: mainly weakly acid to neutral, poorly drained to swampy (EAA1—5 obs., EAHO2—4 obs., EAHO1—2 obs., EAHO6—2 obs.). Where influenced by tides, acid over alkaline or alkaline throughout (EAHO5—2 obs.). Locally organic soils (H1—1 obs.)	Open rain forest, climber thicket, tall swamp grassland	f6, i3–4, w2–4, p4, d2, m2, a1. Where influenced by tides, a2/4 and a4
2	5	Oxbows: up to 2000 ft wide	Alluvial clay loams to clays: neutral, swampy (EAA1—1 obs.)	Open water, aquatic vegetation, climber thicket, tall swamp grassland	f6, i5, w4, p5, d3, m2, a1
3	<5	Levees: discontinuous; up to 150 ft wide; 2–6 ft local relief	As unit 2, but weakly acid to neutral, poorly drained (EAHO2—4 obs., EAHO—1 obs.)	Open rain forest, swamp forest, climber thicket, tall swamp grassland	f6, i3, w2, p4, d2, m2, a1/3
			Loams, silt loams, and clay loams: variable soil reaction, imperfectly to well drained (EUHA1—1 obs., EUHA3—1 obs., EUHO1—1 obs.)	Open rain forest	f6, i1, w1, p4 or p2, d1 and d2, m2; locally a1 and a1/4
4	<5	Present scrolls: ridges and swales with up to 6 ft local relief; ridge crests up to 150 ft apart	Alluvial silt loams to clays: neutral, very poorly drained (EAHO1—1 obs.). Where influenced by tides, neutral over alkaline (EAHO2)	Seral forest of *Timonius* or *Althoffia*; pure low stands of *Sonneratia* where influenced by tide	f6, i3, w3, p4, d3, m2, a1 and a1/4

Agricultural Potential.—Nil. Soil nutrient status (3 soils): nitrogen moderate to low, available phosphate very high to very low, potash high to moderate.
Observations.—25.

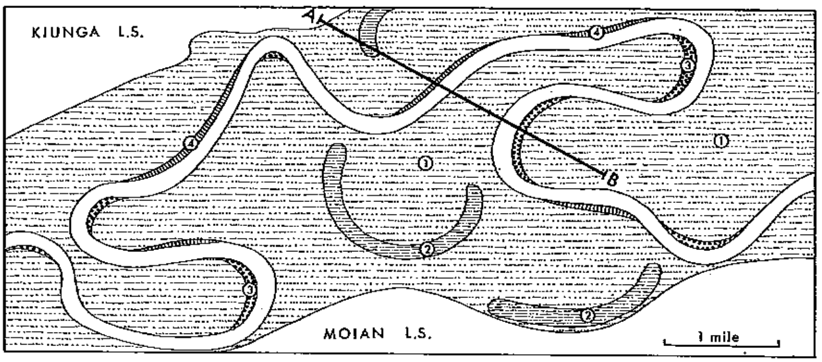
(6) Alice Land System (117 sq miles)

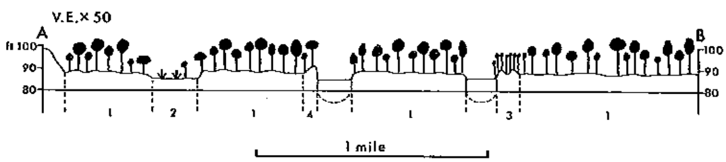
Alluvial plains of Alice, upper Fly, and lower Elevala Rivers, with open rain forest and poorly drained alluvial soils (Plate 6, Fig. 2; Plate 7, Fig. 1).

Geology.—Alluvial clay, silt, sand, and gravel; Recent.

Geomorphology.—Alluvial plains with oxbows, low levees, and present scrolls, subject to frequent flooding. Main river channels 700–2000 ft wide.

Terrain Parameters.—Altitude: 70–100 ft. Relief: < 10 ft above mean river level. Characteristic slope: < 1 in 1000. Grain: —.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	90	Alluvial plains: slopes <1 in 1000	Alluvial silty clay loams to clays: weakly acid to neutral, poorly drained to swampy (EAHO2—1 obs., EAA1)	Open rain forest	f6, i3–4, w2–4, p5, d2, m2, locally a1
2	5	Oxbows: up to 2000 ft wide	As unit 1, but swampy (EAA1)	Climber thicket; minor open water	f6, i5, w4, p5, d3, m2, locally a1
3	<5	Present scrolls: ridges and swales with up to 6 ft local relief; ridge crests up to 150 ft apart	Alluvial silt loams to silty clay loams: neutral to alkaline, on ridges imperfectly drained, on swales poorly drained (ridges EUHA1—2 obs.; swales EAHO1)	Seral forest of *Timonius*	f6, locally i3, w1 and w2, p2–4, d2, m2, a3–4
4	<5	Levees: discontinuous, 5–10 ft above mean river level, up to 200 ft wide	Mainly sandy loams to silt loams merging into clay loams to clays: neutral, well to imperfectly drained (EUHO1—2 obs., EUHA1—1 obs.)	Open rain forest; locally garden regrowth	f6, p4, d2, m2, a1

Agricultural Potential.—Very low for irrigated rice. Soil nutrient status (1 soil): nitrogen low, available phosphate very high, potash high.
Observations.—6.

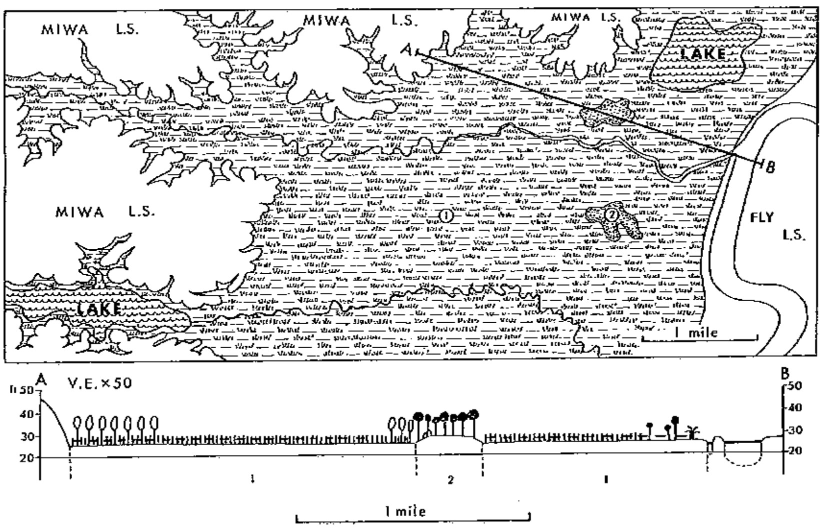
(7) Obo Land System (1094 sq miles)

Back swamps of major rivers, and associated blocked valley swamps (Plate 7, Fig. 2; Plate 9, Fig. 1).

Geology.—Alluvial clay and peat; Recent.

Geomorphology.—Extensive swamps behind Fly and Alice land systems consist of back swamps of major rivers and swamps in valleys blocked by alluvial lobes. Minor low poorly to imperfectly drained rises within swamps. Numerous lakes and irregular open water channels.

Terrain Parameters.—Altitude: 10–80 ft. Relief: < 5 ft. Characteristic slope: < 1 in 1000. Grain: —.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	95	Swamps: under water for at least 8 months of the year	Organic soils: acid to weakly acid or acid to strongly acid, swampy (H1, H2, H3—each 2 obs.). Alluvial silty clay loams to clays; locally with thick dark topsoils, weakly acid to neutral, swampy (EAA1—6 obs., IAU2—3 obs.)	*Melaleuca* swamp savannah, tall and mid-height swamp grassland, swamp woodland (locally with sago and *Campnosperma*), climber thicket	f6, i5, w4, p4, d1–2, m1, a2
2	5	Low rises: up to 4 ft high, probably flooded for less than 8 months of the year	Alluvial clay loams to clays: acid to strongly acid, also weakly acid, imperfectly drained (EUHA2—1 obs., EUHA3—1 obs.)	Swamp forest; locally mid-height swamp grassland	f6, i3, w1, p4, d2, m2, commonly a2 and a5

Agricultural Potential.—Nil. Soil nutrient status (2 soils): nitrogen high to moderate, available phosphate moderate to high, potash moderate to low.
Observations.—17.

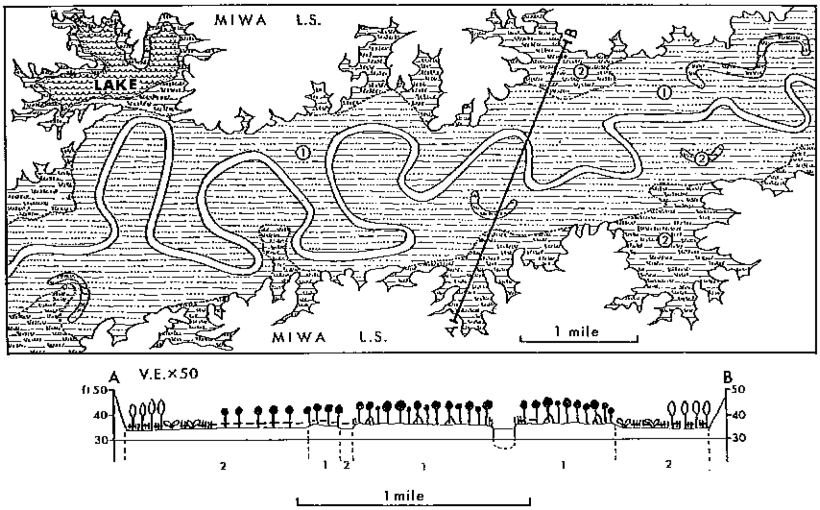
(8) June Land System (159 sq miles)

Flood-plains of minor rivers, with swamp forest (Plate 8).

Geology.—Alluvial clay; Recent.

Geomorphology.—Flood-plains up to 8000 ft wide along meandering river channels up to 300 ft wide, backed by low hills of Miwa land system. Small lakes and swamps common in tributary valleys blocked by river alluvium.

Terrain Parameters.—Altitude: 25–80 ft. Relief: <5 ft. Characteristic slope: <1 in 500. Grain: —.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	80	Back plains: subject to frequent flooding; slopes <1 in 500, levees up to 2 ft high locally present; microrelief (less than 4 ft) of mounds and depressions common	Alluvial clay loams to clays: strongly acid, very poorly drained to locally swampy (EAHO4—7 obs., EAA3—1 obs.)	Swamp forest	f6, i3–4, w3, locally w4, p4–5, d2, m2, a5
2	20	Back swamps and prior channels: probably flooded for at least 8 months of the year	Probably alluvial clays: strongly acid, swampy (EAA3). Probably also organic soils: acid, swampy (H1)	Swamp woodland, *Melaleuca* swamp savannah, tall sedge swamp vegetation	f6, i5, w4, p4, m1, a5, d1–2

Agricultural Potential.—Nil. Soil nutrient status (2 soils): nitrogen moderate, available phosphate very low, potash moderate.
Observations.—8.

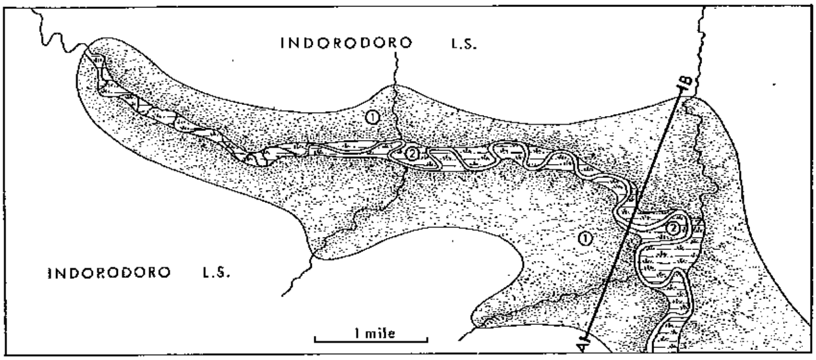
(9) Morehead Land System (122 sq miles)

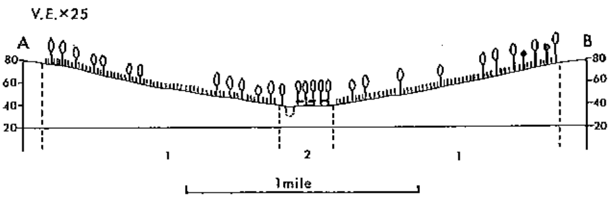
Broad shallow valleys of Morehead and Bensbach Rivers.

Geology.—Clay; Pleistocene. Alluvial clay: Recent.

Geomorphology.—Generally broad shallow valleys with narrow flood-plains in valley floors, 20–140 ft below adjacent Rouku and Indorodoro land systems.

Terrain Parameters.—Altitude: 10–90 ft. Relief: 20–80 ft. Characteristic slope: 2–3°. Grain: —.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	80	Valley sides: slopes generally 1–5°, locally (at Morehead and Weam) up to 20°	Loams and silt loams overlying sandy clay loams and mottled clays: acid over strongly acid, imperfectly drained (UOP3—1 obs., UAPO2)	Low sedge–grassland and stunted *Melaleuca* savannah	Locally e1, w1, p5, d1–2, m2, a2/5, g2
2	20	Flood-plain: up to 3000 ft wide; includes small back swamps and discontinuous levees up to 4 ft high	Alluvial clays: acid over strongly acid, poorly drained (EAHO7—3 obs.) Also loams to silty clay loams overlying clays: thick dark topsoils present, mainly strongly acid, poorly to very poorly drained (IAU1—2 obs., IAU3—1 obs.)	*Melaleuca* savannah *Melaleuca* swamp forest	f3, i2, w2–3, p5, d2, m2, a2/5

Agricultural Potential.—Very low for improved pastures and irrigated rice. Soil nutrient status (1 soil): nitrogen, available phosphate, and potash very low.
Observations.—7.

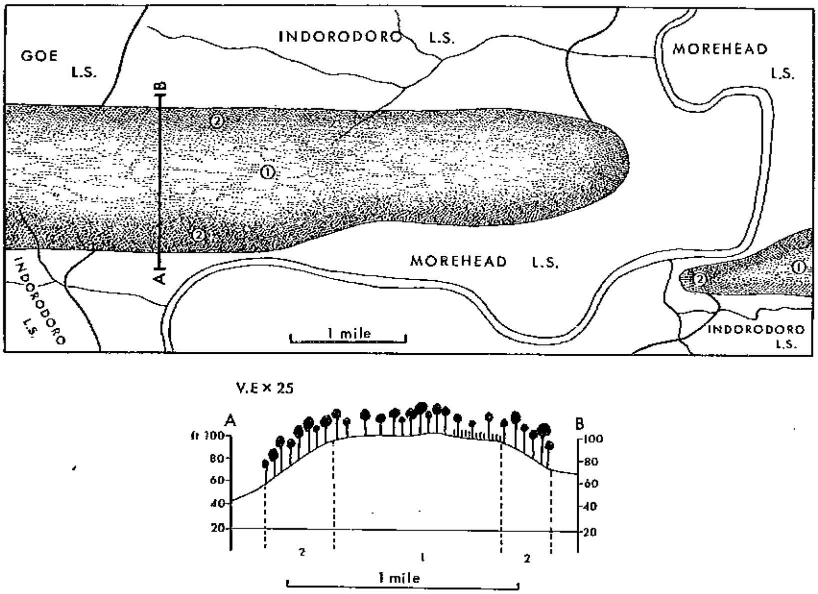
(10) Rouku Land System (50 sq miles)

Broad low ridge with monsoon forest.

Geology.—Clay; Pleistocene.

Geomorphology.—Low E.–W. ridges up to 1¾ miles wide, minor incised valleys up to 40 ft deep. Traversed by entrenched Morehead River.

Terrain Parameters.—Altitude: 30–150 ft. Relief: 30–100 ft. Characteristic slope: 1–2°. Grain: —.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	75	Ridge crest: up to 5000 ft wide, flat to gently undulating, slopes 0–2°	Sandy loams to loams merging into red gravelly loams to gravelly clay loams: acid to strongly acid, well drained (OAPO—5 obs., OAPM—1 obs.)	Monsoon forest and woodland, mixed savannah	p1–2, m2–3, a2 and a5, g2–3
2	25	Side slopes: up to 2000 ft long, slopes generally <5°, locally up to 15°	As unit 1 (OAPO—1 obs.)		Locally e1–2, p1–2, m2–3, a2 and a5, g3

Agricultural Potential.—High for tree crops, moderate for arable crops and improved pastures, low for rice. Soil nutrient status (3 soils): nitrogen moderate to low, available phosphate and potash very low.
Observations.—7.

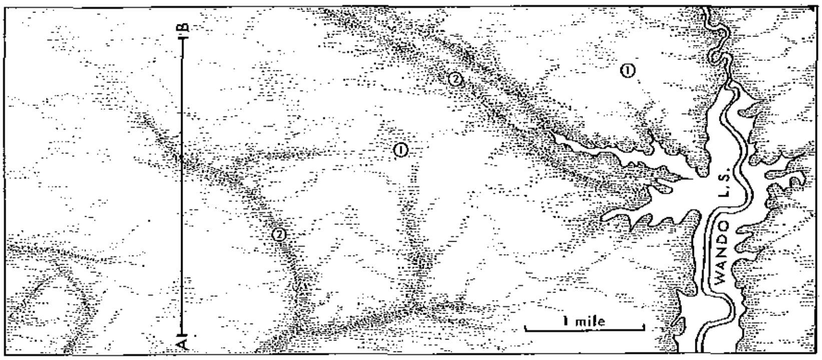
(11) Mibini Land System (753 sq miles)

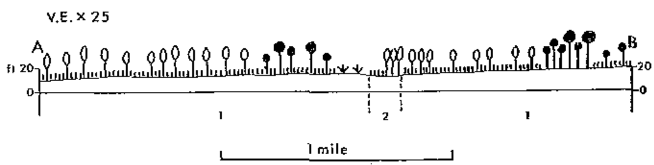
Smooth plain with Melaleuca savannah (Plate 3, Fig. 1; Plate 9, Fig. 2).

Geology.—Clay; Pleistocene and Recent.

Geomorphology.—Smooth plain up to 30 miles wide and rising from less than 10 ft near coast to 50 ft inland where it merges into Morehead, Rouku, Goe, and Indorodoro land systems. Minor broad drainage depressions and alluvium-filled prior channels. Traversed by Morehead, Bensbach, and Tarl Rivers. Widely spaced small creeks and, near coast in south-east, an E.–W. freshwater channel up to 700 ft wide.

Terrain Parameters.—Altitude: 5–50 ft. Relief: <5 ft. Characteristic slope: <1 in 1000. Grain: >5000 ft.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	95	Plains: slopes <1 in 1000; include alluvium-filled prior channels; *termite mounds up to 12 ft* high locally common; large parts water-covered during wet season	Sandy loams to silt loams merging into clay loams to clays: acid to strongly acid, imperfectly to poorly drained (UOP3, UAPO2—each 3 obs., locally UUP1 and UOTO2—each 1 obs.). Clay loams over clays: acid over neutral, imperfectly to poorly drained AAAM—3 obs.). Locally alluvial clays: with thick dark topsoils (IAU1—1 obs., IAU3—1 obs.)	*Melaleuca* savannah; minor monsoon forest, mixed savannah, woodland, and scrub	Locally f3, commonly i3–4, locally w1–2, p4, d1, m2–3, a2 and a5, locally a2/1, g2
2	5	Broad drainage depressions: up to 3000 ft wide and 4 ft deep; water-covered for 3–6 months	Alluvial clay loams overlying clays: thick dark topsoils present, strongly acid, poorly drained (IAU1—2 obs.). Locally silt loam and sandy loam merging into sandy clay: acid over alkaline, poorly drained (AAAO—1 obs.)	Low grassland, *Melaleuca* swamp forest	i4, w2, p4–5, d2, m2, a5 and a2/6, g1–2

Agricultural Potential.—Low for tree crops, improved pastures, and irrigated rice, very low for arable crops. Soil nutrient status (3 soils): nitrogen low, available phosphate and potash very low.
Observations.—16.

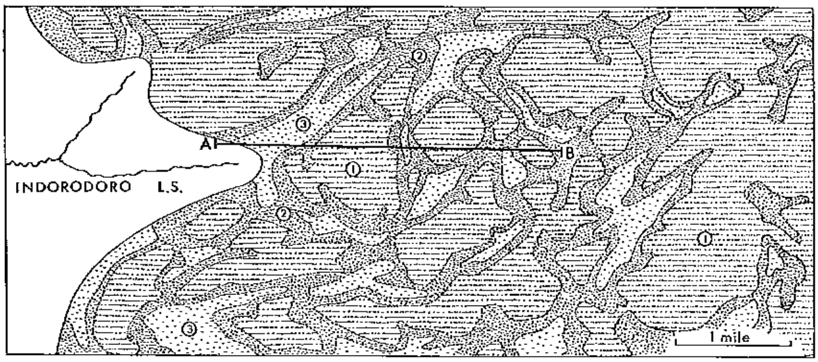
(12) Goe Land System (617 sq miles)

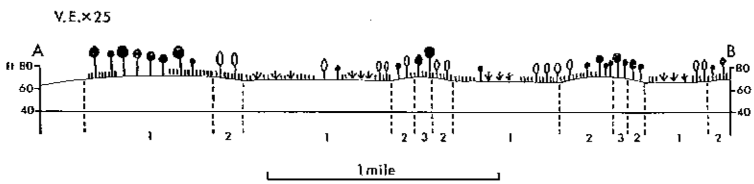
Flat plains on watersheds, with monsoon scrub (Plate 10).

Geology.—Clay; Pleistocene.

Geomorphology.—Poorly drained plains on watersheds, flat to slightly undulating, with broad shallow depressions and generally narrow, slightly sinuous rises. Flat parts and depressions inundated in wet season. Few surface drainage channels.

Terrain Parameters.—Altitude: 50–120 ft. Relief: <5 ft. Characteristic slope: <1 in 1000. Grain: —.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	50	Plains and broad depressions: up to 3 ft deep; slopes 0 to 1 in 1000; termite mounds up to 12 ft high locally present	Loamy sands to silt loams merging into clay loams and clays: acid to strongly acid, poorly to imperfectly drained (UAPO2—4 obs., UAPU1—3 obs., locally UAU—1 obs.)	Monsoon scrub; stunted *Melaleuca–Banksia* savannah along margins of unit	i3–4, w1–2, locally w3, p4, d1, m2, a2 and a5, g1–2
2	30	Slopes and low rises: less than 5 ft high; slopes up to 1 in 100; termite mounds up to 15 ft very common	As unit 1, but mainly imperfectly drained (UAPU1—2 obs., UAPO2—1 obs.)	*Melaleuca* savannah; low mixed savannah	Commonly i2, w1, p4, d1, m2, a2 and a5, g1–2
3	20	As unit 2, but termite mounds sparse	As unit 1, but well drained (UOTU—2 obs., UUP1—1 obs.)	Tall mixed savannah; minor woodland and monsoon forest	p4, d1, m2, a2 and a5, g1–2

Agricultural Potential.—Moderate for irrigated rice, low for arable crops and improved pastures, very low for tree crops. Soil nutrient status (2 soils): nitrogen moderate to very low, available phosphate and potash very low.
Observations.—14.

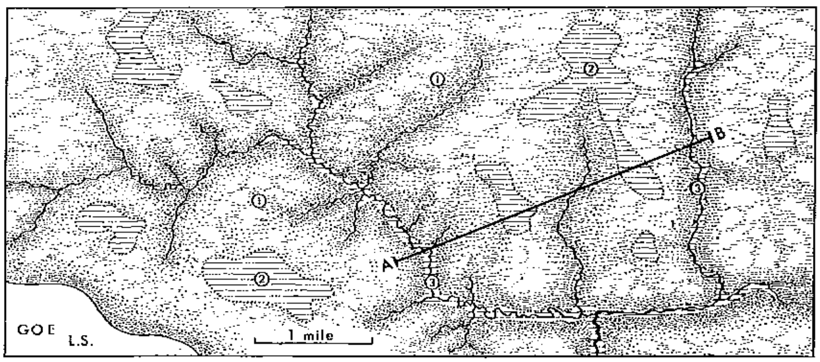
(13) Indorodoro Land System (1569 sq miles)

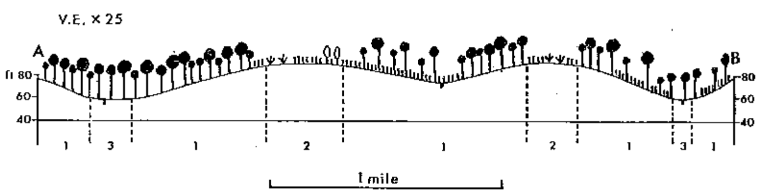
Gently undulating terrain drained by small creeks, with monsoon forest and tall mixed savannah (Plate 11, Fig. 1).

Geology.—Clay; Pleistocene.

Geomorphology.—Slightly undulating plains with dendritic drainage patterns of mostly seasonally dry meandering creeks less than 30 ft wide, incised up to 15 ft. Minor poorly drained flat areas occur on local watersheds.

Terrain Parameters.—Altitude: 50–120 ft. Relief: 30–50 ft. Characteristic slope: 1–2°. Grain: 2500 ft.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	80	Gently undulating plain: slopes generally 0–2°, locally up to 5°; termite mounds up to 12 ft high locally common	Loamy sands to silt loams merging into clay loams to clays: acid to strongly acid, well drained, locally imperfectly drained (UOP3—8 obs., UOTU—3 obs., UUP1, UOTO2—each 2 obs., UUT—1 obs., locally UAPO2—3 obs. and UAPU—2 obs.). Locally sandy loams to loams merging into red gravelly clay loams: acid to strongly acid, well drained (OAPO—2 obs.)	Mainly monsoon forest and tall mixed savannah; also low mixed savannah; minor low grassland	Locally w1–2, p4, locally p2, d1, m2, a2 and a5, g1–2
2	15	Flat plains on local watersheds: gradient 0 to 1 in 1000; termite mounds up to 12 ft high locally common	As unit 1, but poorly drained (UAPO 2—8 obs., locally UAU—1 obs.)	Monsoon scrub; low *Melaleuca–Banksia* savannah along margins of unit	i3–4, w2, p4, d1, m2, a2 and a5, g1–2
3	5	Floors of minor valleys: up to 500 ft wide	As unit 1, but well to imperfectly drained (UOP3—2 obs., UUP1—1 obs.). Also uniform-textured loams: acid to strongly acid, well to locally imperfectly drained (IODO2—2 obs., locally IODA—1 obs.)	Gallery woodland	f3, locally w1, p4 and p2, locally d1, m2, a2 and a5, g2

Agricultural Potential.—Moderate for arable crops, tree crops, improved pastures, and irrigated rice. Soil nutrient status (4 soils): nitrogen very low to moderate, available phosphate very low, potash very low to low.
Observations.—38.

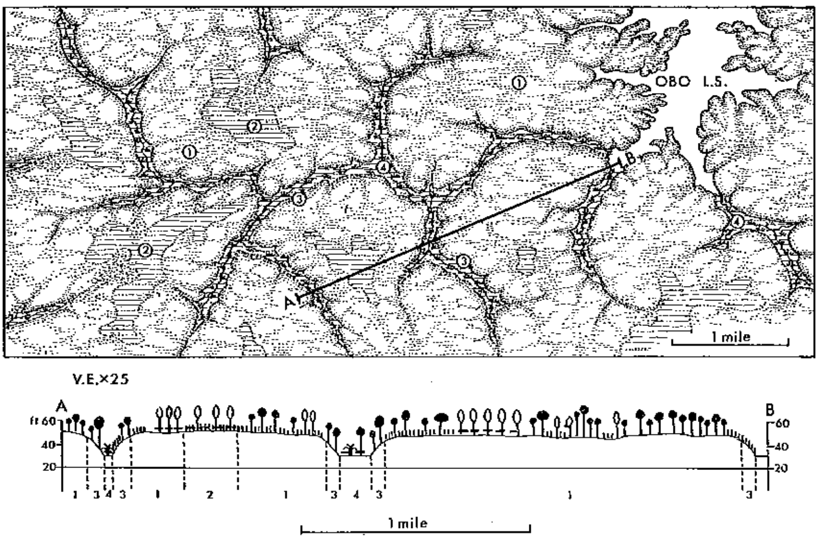
(14) Suki Land System (980 sq miles)

Flat to gently undulating plain with poor monsoon forest (Plate 9, Fig. 1).

Geology.—Clay; Pleistocene. Minor alluvial clay and peat; Recent.

Geomorphology.—Flat to gently undulating plain with areas of poor drainage. Dendritic drainage pattern with main creeks in narrow flat-bottomed valleys. Short relatively steep slopes on valley sides and bordering Obo land system.

Terrain Parameters.—Altitude: 10–70 ft. Relief: 20–30 ft. Characteristic slope: 1–2°. Grain: 1500 ft.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	70	Flat to gently undulating plains: slopes 0–2°	Loams merging into clay loams to clay: acid to strongly acid, well to locally imperfectly drained (UOP1—3 obs., UAPO1—1 obs.)	Poor monsoon forest, *Melaleuca* swamp forest; locally low mixed savannah and *Imperata* grassland	Locally w1, p4, d1, m2, a2 and a5, g2
2	15	Flat plain: slopes probably <1 in 500	Probably as unit 1, but mainly poorly drained (UAPO1 and 2)	Probably *Melaleuca* swamp savannah	Probably f3, i3–4, w2, p4, d1, m2, a2 and a5, g1–2
3	10	Slopes: up to 200 ft long, 2–12°, convex	As unit 1 (UOP1—3 obs.), but locally UOP2—1 obs. and UOTU—1 obs.	Poor monsoon forest; locally low mixed savannah and *Imperata* grassland	e1–2, p4, d1, m2, a2 and a5, g3–4
4	5	Flat valley floors: up to 1000 ft wide, slopes <1 in 100	Probably organic soils (H2). Alluvial clay loams and clays: very poorly drained to swampy (EAA2)	Swamp woodland with sago and *Campnosperma*	Probably f3, i5, w3–4, p5, d3, m2, a2 and a5, g1

Agricultural Potential.—Moderate for arable crops, tree crops, improved pastures, and irrigated rice. Soil nutrient status (1 soil): nitrogen moderate, available phosphate very low, potash low.
Observations.—9.

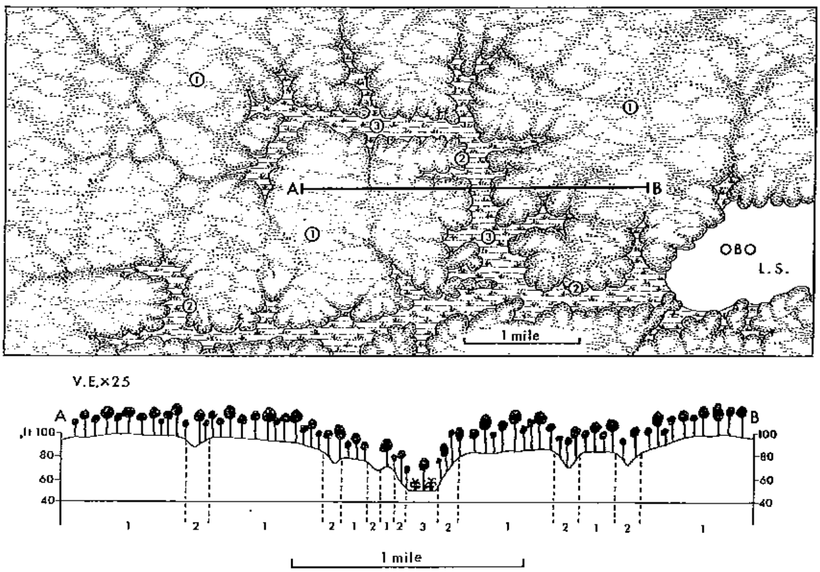
(15) Boset Land System (301 sq miles)

Undulating plain with monsoon forest.

Geology.—Clay; Pleistocene. Minor alluvial clay and peat; Recent.

Geomorphology.—Undulating plains with incised narrow flat-bottomed valleys. Short relatively steep slopes on valley sides and bordering Obo land system.

Terrain Parameters.—Altitude: 10–130 ft. Relief: 30–100 ft. Characteristic slope: 2°. Grain: 1500 ft.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	85	Undulating plain: slopes 0–3°	Loams to clay loams merging into clay loams to clays: locally thick dark topsoils present, acid to strongly acid, well to imperfectly drained (UAPO1—3 obs., UOP1, UUP1—each 2 obs.)	Monsoon forest	Locally e1, locally w1, p4–5, d1, m2, a2 and a5, g1
2	10	Short slopes: 150–600 ft long, 3–10°, convex	As unit 1 (UOP2, UOTO2—each 2 obs.)	Monsoon forest, in the west commonly with bamboo	Commonly e1–2, locally w1, p4, d1, m2, a2 and a5, g3–4
3	5	Flat-bottomed valleys: up to 1200 ft wide, incised up to 100 ft; slopes <1 in 100	Alluvial silty clay loams and clays: acid, swampy (EAA2—2 obs.). Also organic soils (H3—1 obs.)	Swamp woodland with sago and *Campnosperma*	f3, i3–4, w4, p1/4 and p4, locally d2, locally m1, a2, g1

Agricultural Potential.—Moderate for arable crops, tree crops, improved pastures, and irrigated rice. Soil nutrient status (2 soils): nitrogen moderate, available phosphate and potash very low.
Observations.—14.

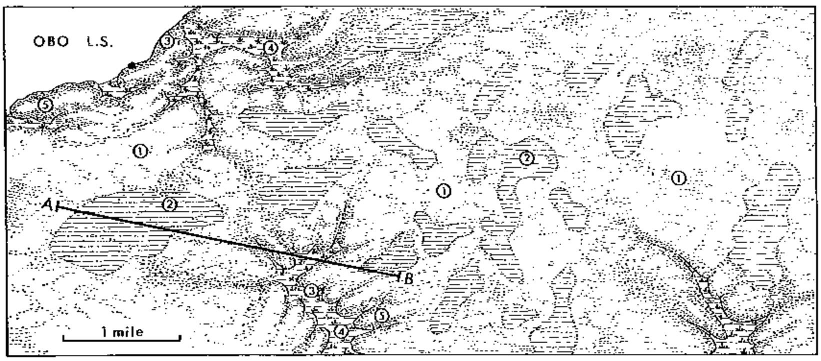
(16) Avu Land System (50 sq miles)

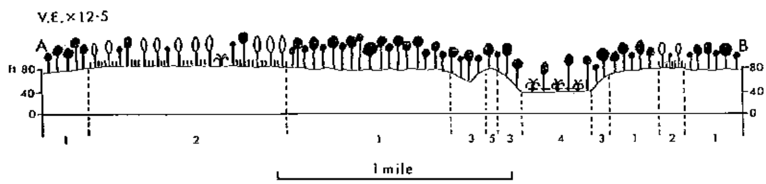
Slightly undulating to flat, low plateau with closed rain forest and *Melaleuca–Casuarina* savannah.

Geology.—Clay, silt, and sand; Pleistocene. Minor alluvial clay and peat; Recent.

Geomorphology.—Slightly undulating to flat plateau with marginal low ridges and narrow valleys. Some river cliffs along Strickland River. Irregular areas of poor to very poor drainage occur on plateau.

Terrain Parameters.—Altitude: 40–90 ft. Relief: 30–40 ft. Characteristic slope: 1–2°. Grain: >5000 ft.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	70	Gently undulating plateau surface: slopes 0–2°	Clay loams overlying clays or uniform-textured clay loams to clays: acid to strongly acid, well to imperfectly drained (IODX, UOP1 and 2, UAPO1)	Closed rain forest	Locally w1, p4, d1, m1, a2 and a5, g3
2	20	Flat plateau surface: slopes <1 in 100	As unit 1, but mainly poorly to very poorly drained (UAPO1—1 obs.)	*Melaleuca* savannah mixed with *Casuarina*, rain forest species, and some sago	i1–2, w2–3, p4, d1, m1, a2 and a5, g3
3	5	Hill slopes: 3–10°	Loams overlying clay loams: acid to strongly acid, well drained (UOTO1—2 obs.)	As unit 1	e1–2, p4, d1, m1, a2 and a5, g4
4	5	Flat valley bottoms: up to 1000 ft wide, slopes <1°	Organic soils (H2—1 obs.). Probably also alluvial clays: acid, swampy	Swamp woodland: *Campnosperma*–sago	i5, w4, p3 and p5, d2, a2, g1
5	<5	Ridge crests: up to 200 ft wide, slopes 0–3°	As unit 3	As unit 1	p4, d1, m1, a2 and a5, g3

Agricultural Potential.—Moderate for arable crops, tree crops, and improved pastures, low for irrigated rice. Soil nutrient status (3 soils): nitrogen high to low, available phosphate very low, potash very low to low.

Observations.—4.

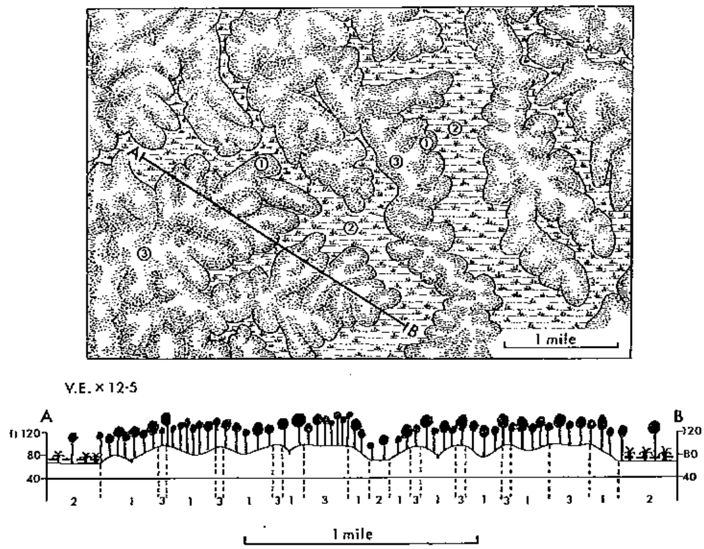
(17) MOIAN LAND SYSTEM (291 SQ MILES)

Intricate pattern of valleys and low ridges with latosols and rain forest (Plate 13, Fig. 2).

Geology.—Clay, silt, and sand; Pleistocene. Alluvial clay and peat; Recent.

Geomorphology.—Random reticulate pattern of valleys and low ridges with an intricate dendritic drainage network. Subdued relief with gentle hill slopes. Numerous swampy flat valley floors. Gullies, pits, and sink-holes up to 15 ft deep locally common on ridges.

Terrain Parameters.—Altitude: 60–130 ft. Relief: 20–50 ft. Characteristic slope: 5°. Grain: 400 ft.



Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	65	Hill slopes: up to 400 ft long, slopes 2–15°, average 5°	Loams to clay loams merging into clays: acid to strongly acid, well drained (UOTO1, UOP1—each 2 obs.). Also uniform-textured clay loams to clays, acid to strongly acid, well drained (IODX—2 obs., IODO1—1 obs.)	Closed rain forest, in many places dense and thin-stemmed; *Vatica* common	e1–3, p4, d1, m1, a2 and a5, commonly g4
2	20	Flat valley floors: up to 2000 ft wide, slopes <1 in 100	Organic soils (H2—2 obs.). Also undifferentiated soils: fine textured, acid to strongly acid, very poorly to imperfectly drained (EAHO3—2 obs., EUHA2—1 obs.)	Swamp woodland, commonly with *Campnosperma* and sago; open rain forest on less poorly drained sites	Locally f3, i5 or i2–3, w1–4, p1 and p4, locally d2, a2 and a5, g1
3	15	Ridge crests: average width 100 ft, gently undulating, slopes 0–2°	As unit 1 (UOTO1—3 obs., UOP1, UOP2—each 1 obs.)	As unit 1	p4, d1, m1, a2 and a5, g3

Agricultural Potential.—High for tree crops, moderate for improved pastures, low for arable crops, very low for irrigated rice. Soil nutrient status (3 soils): nitrogen moderate to low, available phosphate very low, potash low to very low.
Observations.—17.

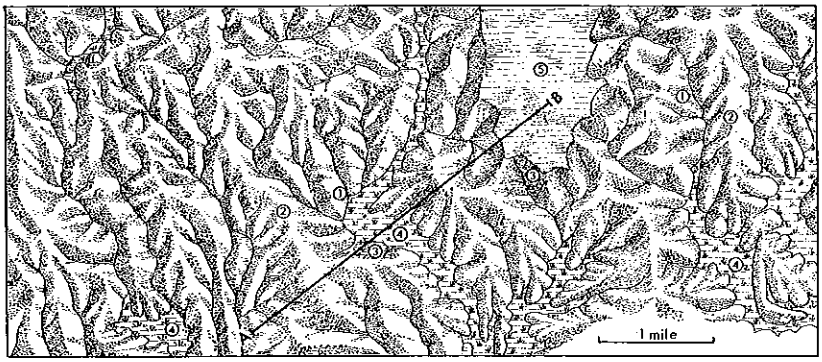
(18) Miwa Land System (3317 sq miles)

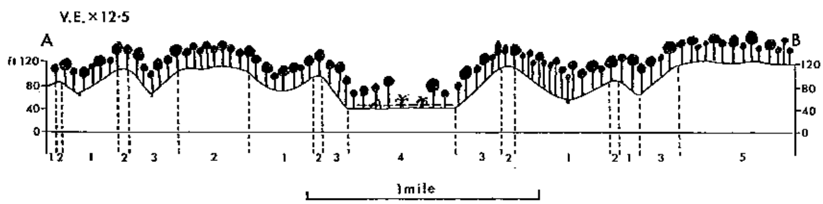
Intricate pattern of low ridges and narrow valleys, with latosols and closed rain forest (Plate 11, Fig. 2; Plate 12, Fig. 2; Plate 13, Fig. 1).

Geology.—Clay, silt, and sand; Pleistocene. Minor alluvial clay and peat; Recent.

Geomorphology.—Random reticulate pattern of narrow ridges and minor undulating plateaux with a closely spaced dendritic drainage network consisting of flat-bottomed major valleys and narrow V-shaped tributary valleys.

Terrain Parameters.—Altitude: 10–200 ft. Relief: 30–100 ft. Characteristic slope: 8°. Grain: 400 ft.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	55	Hill slopes: 3–15°, average 8°; up to 600 ft long, convex, straight, locally stepped; gullies and pits up to 12 ft deep occasionally present	Clay loams to clays: acid to strongly acid, well drained, locally imperfectly drained (IODX—9 obs., locally IODP—2 obs., UOTO1—7 obs., UOP2—6 obs., UOP1, UUP2—each 2 obs., UUT, UAP1—each 1 obs.)	Closed rain forest, locally very dense and thin-stemmed; minor monsoon forest in south and south-west	e1–3, locally w1, p4, d1, m1, a2 and a5, locally g3–4
2	15	Ridge crests: 50–200 ft wide, average 100 ft; gently undulating slopes 0–3°; knolls up to 4 ft high locally present	Loams to clay loams merging into clays, and uniform-textured clay loams to clays: acid to strongly acid, well to imperfectly drained (UOP2—8 obs., UOTO1, UUP2, and UAPO1—each 2 obs., UAPU2, UOP1, and UUT—each 1 obs., IODX—5 obs., IODP—1 obs.)		Locally e1, locally w1, p4, d1, m1, a2 and a5, g3
3	15	Hill slopes: 15–40°, average 25°; up to 150 ft long, generally straight	As unit 1, but well drained (IODX—3 obs., UOTO1—2 obs., UOP1—1 obs.)		e4–6, p4, d1, m1, a2 and a5
4	10	Flat valley floors: generally <1200 ft wide; slopes <1°	Alluvial clay loams to clays: acid to strongly acid, very poorly drained to swampy (EAA3—5 obs., EAHO3—3 obs.); locally imperfectly drained (EUHA2, EUHA3—each 1 obs.). Organic soils (H2)	Sago-*Campnosperma* swamp woodland, swamp forest	Locally f3, locally i5 and i2–3, commonly w3–4, locally w1, p1 and p4–5, locally d2, locally m1, a2 and a5, g1
5	5	Plateaux: up to 6 miles wide (west of Lake Murray); undulating; slopes 0–3°	Clay loams merging into clays: thick dark topsoils commonly present, acid to strongly acid, well to imperfectly drained (UUP2—2 obs., locally UOP2)	Closed rain forest	As unit 1

Agricultural Potential.—High for tree crops, moderate for improved pastures, low for arable crops. Soil nutrient status (15 soils): nitrogen moderate to low, available phosphate very low, potash low to very low.
Observations.—71.

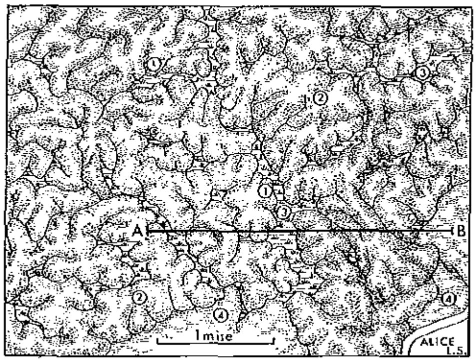
(19) Kiunga Land System (318 sq miles)

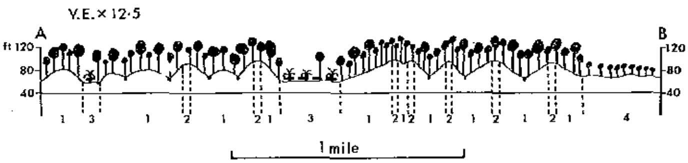
Highly intricate pattern of low narrow ridges and valleys, with latosols and rain forest (Plate 14).

Geology.—Clay, silt, sand, and gravel; Pleistocene. Minor alluvial clay and peat; Recent.

Geomorphology.—Random reticulate pattern of narrow ridges with a highly intricate dendritic drainage network consisting of narrow flat-bottomed and V-shaped valleys. Minor undulating terrain near major rivers. Gullies, pits, and sink-holes up to 12 ft deep common on ridges.

Terrain Parameters.—Altitude: 70–170 ft. Relief: 20–80 ft. Characteristic slope: 10°. Grain: 200 ft.





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	70	Hill slopes: up to 400 ft long; slopes 3–25°, average 10°, small slumps locally common	Loams to clay loams merging into clays, and uniform-textured clay loams to clays: acid to strongly acid, well drained (IODX—5 obs., UOTO1—2 obs.)	Closed rain forest, locally dense and thin-stemmed; *Vatica* common; patches of garden regrowth and secondary forest	e1–5, p4, d1, m1, a2 and a5
2	15	Ridge crests: generally <60 ft wide, gently undulating; slopes 0–3°	As unit 1 (UOTO1—4 obs., UOP2—1 obs., IODX—1 obs., IODO1—1 obs.)		Locally e1, p4, d1, m1, a2 and a5, locally g4
3	10	Flat valley floors: up to 300 ft wide; slopes <1 in 100	Organic soils (H2—2 obs.). Also alluvial clay loams to clays: acid, mainly very poorly drained to swampy (EAA2, EAHO3—each 1 obs., locally EUHA2—1 obs.)	Swamp woodland, commonly with *Campnosperma* and sago	Locally f3, locally i5 and i2–3, w2–4, p1 and p4–5, locally d2 and m1, a2 and a5, g1
4	5	Undulating terrain: slopes 0–4°	As unit 1 (IODX—4 obs., locally UOP2, UOTO1—each 1 obs.)	As unit 1	As unit 2

Agricultural Potential.—Moderate for tree crops, low for arable crops and improved pastures, very low for irrigated rice. Soil nutrient status (5 soils): nitrogen moderate to low, available phosphate very low, potash low to very low.
Observations.—25.

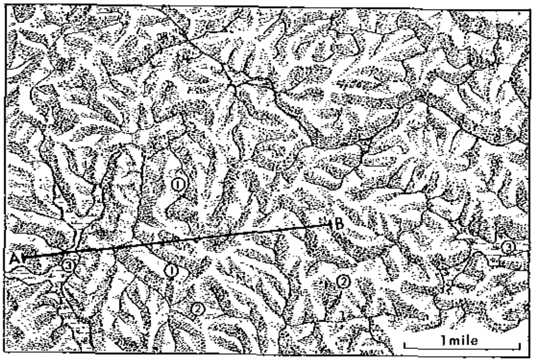
(20) Gasuke Land System (134 sq miles)

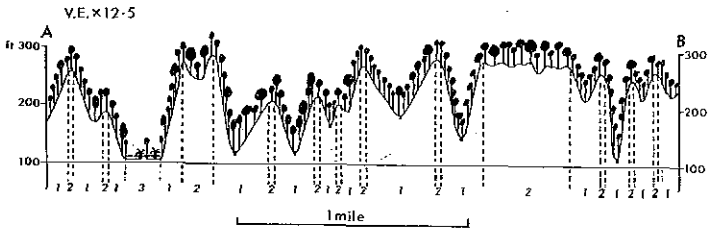
Steep-sided narrow ridges with dense thin-stemmed rain forest.

Geology.—Clay, silt, sand, and gravel overlying feldspathic sand; Pleistocene. Minor alluvial clay and peat; Recent.

Geomorphology.—Random reticulate pattern of narrow steep-sided ridges and narrow V-shaped valleys, with an intricate dendritic drainage network; minor flat-bottomed valleys; traversed by Elevala River.

Terrain Parameters.—*Altitude: 100–300 ft. Relief: 100–200 ft.* Characteristic slope: *30°*. Grain: *250 ft.*





Unit	Area (%)	Land Forms	Soils	Vegetation	Limitations
1	85	Hill slopes: generally 25–35°, but ranging from 5 to 40°; uneven surface consisting of interconnecting gullies and spurs with up to 10 ft microrelief; slumping common	Uniform-textured clay loams to clays: acid to strongly acid, well to locally imperfectly drained (IODO1—2 obs., IODX—1 obs., locally IODA—1 obs.)	Dense thin-stemmed rain forest; *Vatica* very common and locally dominant	e1–6, locally w1, p4, d1, m1, a2 and a5
2	15	Ridge crests: <100 ft wide, undulating; slopes 0–5°	Loams to clay loams overlying clays, and uniform-textured clay loams to clays: acid to strongly acid, well to imperfectly drained (UOTO1, UAPO1—each 1 obs., IODX—1 obs.)		Locally e1, locally w1, p4, d1, m1, a2 and a5, g3–4
3	<5	Flat valley floors: generally <1000 ft wide; slopes <1°; creeks up to 10 ft deep	Organic soils (H2). Alluvial clay loams to clays: acid, well drained (Elevala valley) to swampy (EAHO3, EUHO2—1 obs.)	Swamp woodland: *Campnosperma*-sago, open rain forest in Elevala valley	Locally f3, locally i5 and i2–3, commonly w1–4, p1 and p4–5, locally d2 and m1, a2, g1

Agricultural Potential.—Low for tree crops, very low for arable crops and improved pastures. Soil nutrient status (1 soil): nitrogen low, available phosphate and potash very low.
Observations.—8.

PART IV. CLIMATE OF THE MOREHEAD–KIUNGA AREA

By J. R. McAlpine*

I. Introduction

Within the area surveyed there are few climate stations and those that do exist have kept rainfall records for only a few years. However, the area forms part of a larger region (Fig. 6) to which it is climatically similar, and fortunately this larger region possesses climate stations with somewhat longer and more comprehensive records of the various climatic elements. It is from a consideration of these data that the climate of the area is inferred. However, as the data from the western sector were recorded only during the period of Dutch administration and the remaining data are more recent, it has been impossible to establish a suitable standard period for spatial comparison of climate elements.

(a) *Principal Climatic Features*

The climate of the area may be classified under the Köppen (1931) or Thornthwaite (1931) systems respectively, as varying from a tropical savannah (*Aw*) or subhumid tropical type (*CA'r*) in the south to a tropical rain forest (*Af*) or wet tropical type (*AA'r*) to the north.

Mean annual rainfall ranges from 60–80 in. per annum on the coast to 170–180 in. in the northern part of the survey area near the foothills of the central mountain ranges of New Guinea. This south-to-north, coast-to-mountain, rainfall gradient is more marked in June–October, the drier months, than in the remainder of the year and the southern part has a fairly marked seasonal distribution of rainfall. By contrast, temperature ranges between seasons and places are very limited. Mean annual temperature is 80°F, the range of mean monthly temperature through the year varies by only 5 degF and the mean diurnal range is about 15 degF. These temperature characteristics are similar at both coastal and inland stations.

(b) *Climatic Controls*

The major climatic controls operating in the tropical south-west Pacific are described and discussed by Brookfield and Hart (1966). Briefly, these consist of the seasonal latitudinal movements of two major surface air masses which are separated by a discontinuous intertropical convergence zone (ITCZ). These two air masses are the perturbation belt of westerly-moving vortical circulations to the north, referred to in previous literature as the "north-west season", and the south-east trade wind belt to the south. The latter dominates from June to September and is relatively drier than the air masses of the perturbation belt, the influence of which is greatest from December to March. The south-east trades are associated with surface winds of greater velocity and directional stability. Wind roses for Port Moresby, which probably give

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a reasonable approximation to the coastal situation in the survey area, clearly illustrate this contrast (Fitzpatrick 1965). The transition from the dominance of one system to the other takes place during April–May and October–November.

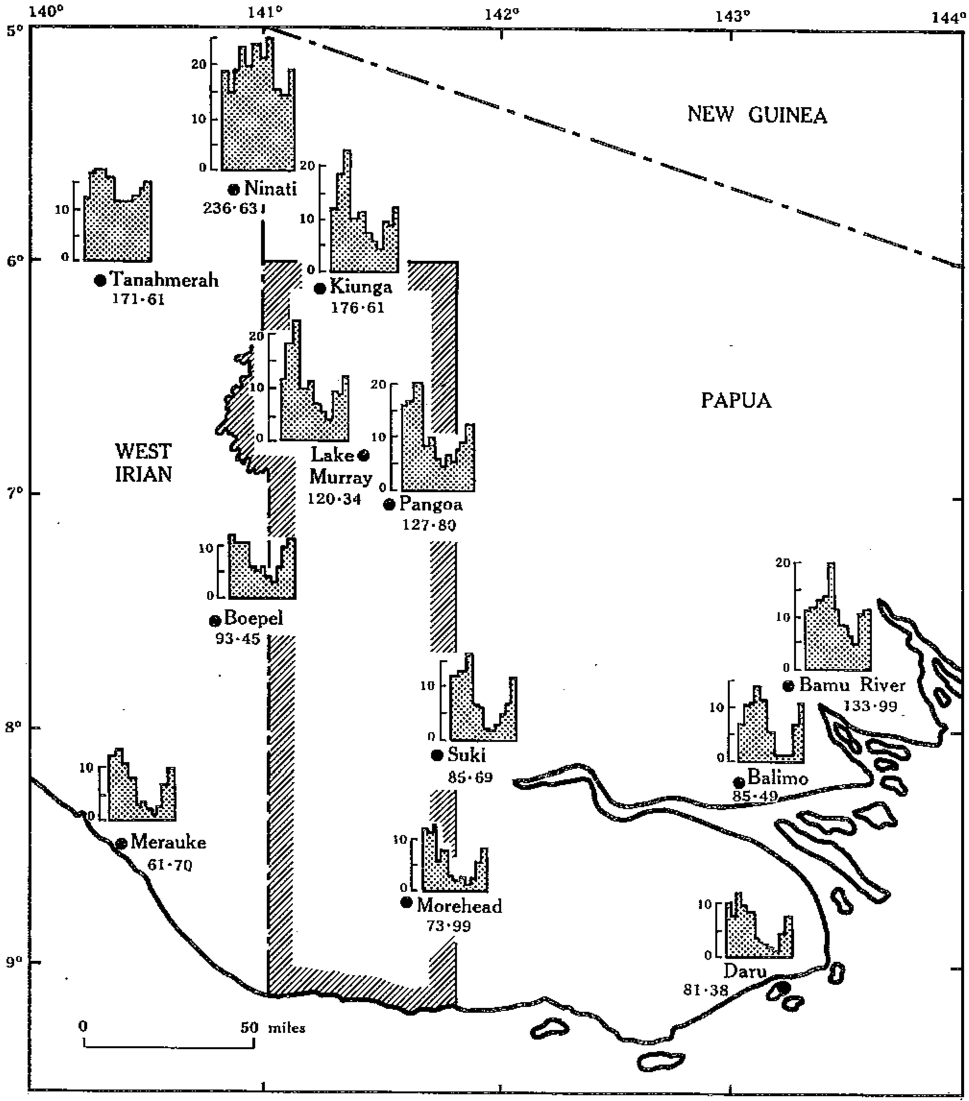

Fig. 6.—Rainfall distribution (in.) (January–December) in the Fly River region.

The broad regional controls are modified locally in two ways. Firstly, as the area lies in the south-east corner of the south-west Pacific the controls will be affected by factors connected with the weather patterns of northern Australia, including the cyclonic disturbances of that area. Secondly, it will be affected by the presence of local circulations induced by topography, especially in the north of the area surveyed, and the differential heating of land and sea masses.

TABLE 2

MEAN MONTHLY AND ANNUAL RAINFALL (INCHES) FOR 13 STATIONS

Station	Period of Records	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Atkamba	1962–67	17·72	14·08	26·50	15·17	16·00	14·30	9·08	13·07	14·00	14·15	9·40	14·07	177·63
Balimo	1958–61	7·82	10·53	10·45	13·61	11·73	5·74	1·91	1·45	2·62	2·76	6·85	10·02	85·49
Bamu River	1955–61	11·62	12·64	14·20	14·72	20·31	11·08	7·54	5·16	7·52	6·07	11·49	11·64	133·99
Boepel*	1941–57	12·24	10·83	10·98	10·20	6·69	4·88	4·92	3·54	3·31	5·51	9·33	11·02	93·45
Daru	1894–67	10·98	9·97	13·06	12·53	8·82	3·90	3·58	2·11	1·65	2·21	4·40	8·17	81·38
Kiunga	1963–67	18·19	19·09	28·04	12·69	15·04	13·05	8·64	15·92	10·61	11·42	11·86	12·06	176·61
Lake Murray	1964–67	11·15	17·95	22·54	8·52	11·91	6·34	3·61	6·78	4·03	8·84	7·76	10·91	120·34
Merauke*	1951–60	9·49	11·85	8·99	7·33	3·48	2·30	1·77	0·76	0·57	0·91	4·15	9·70	61·70
Mindiptana*	1959–60	11·96	15·56	12·58	12·09	14·17	15·06	16·75	15·81	15·08	11·66	10·01	14·26	164·99
Morehead	1964–67	11·90	11·58	12·74	5·45	7·60	2·72	2·35	3·02	1·38	1·82	5·33	7·90	73·99
Ninati*	1951–60	19·06	15·76	16·72	19·39	24·44	20·47	25·39	21·63	25·45	15·37	14·95	18·00	236·63
Pangoa	1962–67	16·49	16·87	20·30	9·42	11·27	6·09	4·18	7·18	5·53	7·88	9·74	12·85	127·80
Suki	1962–67	12·74	12·79	16·54	6·82	6·23	2·25	2·40	2·62	2·69	3·65	5·50	11·44	85·69
Tanahmerah*	1937–60	13·90	15·39	17·00	16·89	16·04	11·87	11·27	11·54	14·54	13·24	14·25	15·67	171·60

*Data obtained from Brookfield and Hart (1966).

II. General Climatic Characteristics

(a) Rainfall

Mean monthly and annual rainfall for 14 stations together with the relevant length of record is given in Table 2, and the spatial distribution of this rainfall is shown by histograms in Figure 6. Mean annual rainfall varies near the coast from 62 in. at Merauke in the west to 74 in. at Morehead and to 82 in. at Daru in the east. Northwards from the coast rainfall increases to 85 in. at Suki and Balimo, to 95 in. at Boepel, to 130 in. at Bamu and Pangoa, and to 170 in. at Tanahmerah and Kiunga. Closer to the main central ranges rainfall increases to over 235 in. per annum at Ninati.

Table 3

PERCENTAGE FREQUENCY OF RAIN DAYS PER QUARTER WITH RAINFALL WITHIN SPECIFIED CLASSES

Station and Quarter	Class (in./rain day)					
	0·01–0·24	0·25–0·99	1·00–1·99	2·00–3·99	4·00–5·99	≥6·00
Balimo						
Dec.–Feb.	39·4	42·2	11·6	6·4	0·4	0
Mar.–May	42·8	38·4	12·5	5·4	0·9	0
June–Aug.	69·6	23·9	4·8	1·5	0·2	0
Sept.–Nov.	52·6	31·3	11·6	4·2	0·3	0
Daru						
Dec.–Feb.	41·1	39·3	12·9	5·5	0·1	0
Mar.–May	48·8	32·5	10·9	5·8	1·9	0
June–Aug.	83·3	12·8	2·5	1·0	0·4	0
Sept.–Nov.	74·2	15·5	5·2	4·7	0·4	0
Mindiptana						
Dec.–Feb.	27·1	45·5	16·4	9·6	1·1	0·2
Mar.–May	25·5	46·0	18·8	7·7	1·8	0·2
June–Aug.	25·9	44·7	17·9	9·4	1·7	0·3
Sept.–Nov.	22·5	44·2	20·1	11·2	1·8	0·2
Tanahmerah						
Dec.–Feb.	30·3	43·3	14·7	10·2	1·5	0
Mar.–May	37·4	38·7	14·2	8·5	0·9	0·3
June–Aug.	39·4	41·4	10·1	7·5	0·7	0·9
Sept.–Nov.	29·2	40·2	19·2	8·7	2·3	0·4

This northward and inland increase in annual rainfall is associated with a decrease in rainfall seasonality. Compared with other areas in New Guinea the southern part of the area has a fairly marked seasonal rainfall distribution, the wettest month on average at Merauke possessing 20 times the rainfall of the driest. This factor decreases to 8 at Daru and further decreases inland to about 4 at Boepel and to less than 2 at Tanahmerah. The highest monthly falls occur in the south during March with minimums being recorded during September–October. Harmonic analysis indicates that this single monthly maximum of rainfall per year in the south is replaced by a double maximum in the north (Fitzpatrick, Hart, and Brookfield 1966).

TABLE 4

TEMPERATURE CHARACTERISTICS AT TWO STATIONS

Temperature (°F)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						Daru (19 yr of records)							
Mean maximum	89·6	89·2	88·6	87·1	86·3	84·4	83·2	83·7	85·1	87·8	90·0	90·5	87·1
Mean	81·9	81·6	81·1	80·5	80·2	78·6	77·6	78·1	79·2	81·0	82·4	82·4	80·4
Mean minimum	74·3	74·0	73·6	73·9	74·2	72·9	72·1	72·5	73·2	74·2	74·9	74·4	73·7
Mean diurnal range	15·3	15·2	15·0	13·2	12·1	11·5	11·1	11·2	11·9	13·6	15·1	16·1	13·4
Extreme maximum	93·6	92·7	91·5	90·6	89·0	86·9	87·5	86·4	88·6	90·7	93·2	94·2	
Extreme minimum	71·6	71·3	70·6	69·8	70·9	68·2	65·7	68·6	69·5	69·5	70·1	71·2	
						Tanahmerah (5 yr of records)*							
Mean maximum	90·1	89·4	90·0	88·9	87·4	85·5	84·2	84·9	86·7	89·6	91·0	90·1	88·2
Mean	81·6	81·2	81·5	81·6	80·6	79·1	78·2	78·1	79·2	80·6	82·0	82·0	80·5
Mean minimum	73·2	73·0	73·0	73·2	73·9	72·7	72·1	71·2	71·4	71·6	72·9	73·8	72·7
Mean diurnal range	16·9	16·4	17·0	15·7	13·5	12·8	12·1	13·7	15·3	18·0	18·1	16·3	15·5
Extreme maximum	95·5	95·5	95·4	93·7	92·1	89·6	89·2	90·3	92·8	97·5	96·6	96·4	
Extreme minimum	67·0	69·1	68·9	69·1	69·3	66·7	66·6	66·2	66·2	63·7	68·0	68·7	

*Data from Nederlands–Nieuw Guinea Meteorologisch en Geofysisch Bur. (1962).

Lengths of available records at all stations except Daru are inadequate to express annual rainfall variability. At Daru, variability as measured by the standard deviation as a percentage of mean is 22%; in terms of rank variation median annual rainfall is 81 in. per annum, the ninth decile is 110 in., and the first 51 in.

No direct measure of rainfall intensity is available. Table 3 gives an indication of this characteristic based on daily rainfall data. On the coast daily falls of over 6 in. have not occurred in the periods considered and falls of between 4 and 6 in. are uncommon. Inland the percentage of falls of over 4 and 6 in. appears to increase significantly. In terms of the seasonal distribution of heavy and light falls there is little contrast inland but near the coast there are proportionately more lighter falls during the July–September quarter than at other times of the year.

Persistency of rainfall also differs somewhat between coastal and inland areas. An analysis of consecutive periods of rainy and rainless days indicates that at Daru and Tanahmerah the average length of rainy periods is about the same, being 2–3 days for all quarters of the year. However, the average duration of periods of rainless days at Daru is 2 days between January and March and 4–6 days from July to December, while at Tanahmerah it is 2–3 days throughout the year.

(*b*) *Temperature*

Data concerning temperature characteristics are available for Daru, Tanahmerah, Merauke, and Balimo. Table 4 gives these data for Daru and Tanahmerah, which can be regarded as typical coastal and inland stations respectively. Mean annual and monthly temperature characteristics are essentially constant over the whole area and the ranges given in the discussion below are for interstation variation. In annual terms the mean temperature is 80°F, mean maximum is 87–88°F, and mean minimum 73–74°F. In seasonal terms mean monthly temperatures vary from 78°F in July to 82°F in December with the range of mean maxima slightly higher at 7 degF and mean minima slightly lower at 3 degF. Mean annual diurnal temperature range is 13–16 degF with a seasonal variation of 5–6 degF. The only significant spatial difference in temperature regimes occurs in relation to extreme temperature records which are slightly greater inland than on the coast. Yet even in this characteristic the equable nature of the temperature regime is demonstrated, as at no station does the difference between the extreme and mean ranges exceed 8 degF.

(*c*) *Other Climatic Characteristics*

Mean monthly relative humidity, evaporation, and duration of sunshine are presented in Table 5. Mean annual relative humidity is about 85% over the whole area and exhibits only slight seasonality, varying from about 90% in July to 80–85% in January. This seasonal contrast is almost absent at Merauke. Evaporation has been estimated from the mean monthly maximum and minimum temperatures, vapour pressure, and day length (Fitzpatrick 1963). Mean estimated evaporation varies between stations from 55 to 60 in. a year and between seasons from 3–4 in. in July to 6–7 in. in January.

TABLE 5

OTHER CLIMATIC CHARACTERISTICS

Characteristics and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Relative humidity													
Balimo*	80	82	82	85	85	86	86	85	84	84	81	82	84
Daru*	80	80	82	85	86	84	89	88	89	87	88	88	85
Merauke†‡	82	84	85	85	85	85	83	81	80	81	82	81	83
Tanahmerah†‡	85	86	86	89	88	89	90	89	87	86	85	86	87
Evaporation (in.)													
Balimo	6·66	5·48	5·38	4·11	4·00	3·36	3·53	3·91	4·68	5·83	7·05	7·04	60·98
Daru	6·79	5·80	5·80	4·47	4·00	3·72	3·13	3·47	3·78	5·08	5·55	6·17	57·70
Merauke	5·58	4·64	4·43	4·20	3·91	3·83	3·85	4·44	5·03	6·04	6·02	5·80	57·77
Tanahmerah	5·66	5·33	5·24	4·57	3·42	3·23	2·88	3·55	4·25	5·51	5·96	5·52	55·12
Sunshine (hr/day)													
Merauke‡	6·3	5·6	5·7	6·2	6·2	6·4	5·4	5·8	7·5	8·0	8·8	6·4	6·5
Tanahmerah‡	5·6	5·4	5·4	5·3	4·6	2·7	2·7	2·0	3·7	5·8	5·7	4·9	4·5

* Average index of mean relative humidity.

† Average relative humidity at 6.30, 12.30, 18.30 hr.

‡ Data from Nederlands–Nieuw Guinea Meteorologisch en Geofysisch Bur. (1962).

Mean daily duration of sunshine per month data are available for Merauke and Tanahmerah. The figures are higher for the coastal station Merauke for all months of the year and the difference is particularly marked from July to September. Mean annual total hours of sunshine is 1639 hr at Tanahmerah and 2385 hr at Merauke. These figures should possibly be taken as conservative as the source from which they have been copied indicates that the Campbell–Stokes recorders used may have been partially obscured by shade in either the early morning or late afternoon.

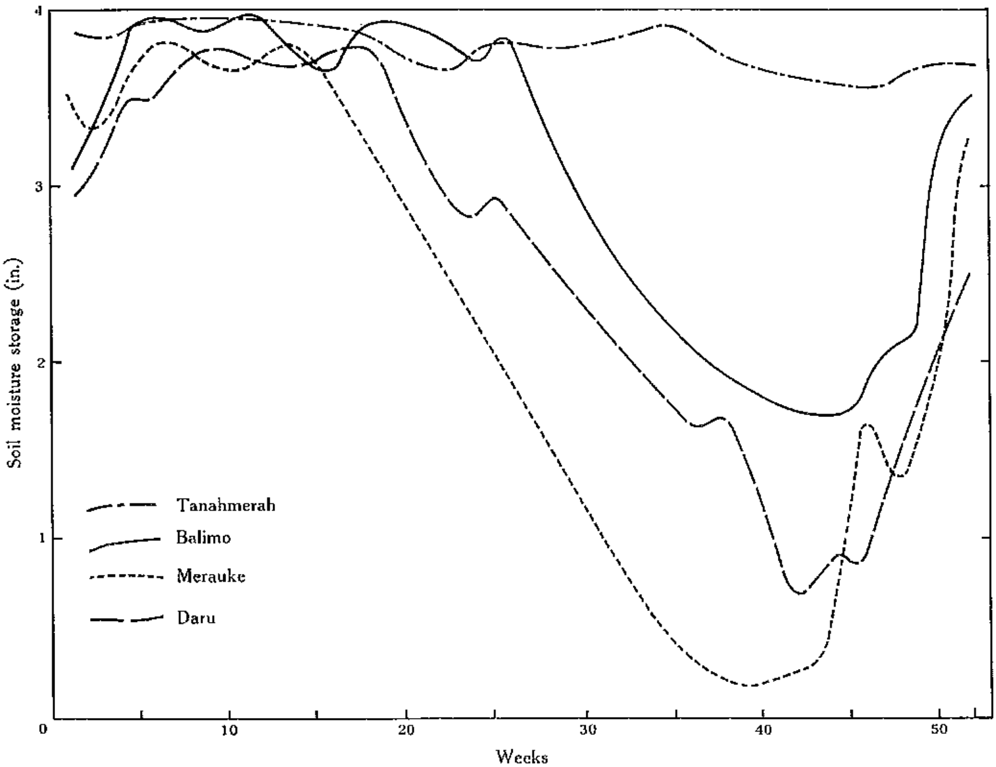

Fig. 7.—Average weekly soil moisture storage at four stations.

III. Plant Growth and Water Balance

This section deals with the relation of water balance to plant growth as expressed by fluctuations in levels of soil moisture storage. The measurement of these fluctuations is based on a water balance model similar to that developed by Slatyer (1960). The model is designed to give estimates of week-to-week changes in available soil moisture. These estimates have been obtained with the aid of computer processing using estimated evapotranspirational withdrawals and weekly rainfall inputs. The assumptions in applying the model are that actual evapotranspiration (ET) is related to estimated evaporation (E) from an Australian standard tank evaporimeter (Fitzpatrick 1963) by the relationship $ET = 0 \cdot 8E$ for those weeks with storage plus rainfall exceeding $2 \cdot 50$ in. and by $ET = 0 \cdot 4E$ below this level. The model may tend to underestimate evapotranspiration losses when the upper parts of an otherwise dry soil profile receive weekly rains of less than 2·50 in. and to overestimate it during weeks without rainfall when stored soil water in the upper profiles is nearing depletion. However, these variations are not likely to introduce large errors in a general assessment over a number of years. Soil moisture storage capacity is assumed to be 4 in., a conservative estimate for the area. Run-off is assumed to occur only when this soil moisture storage is filled. This model, using weekly data, has been applied to obtain an evaluation of the differences in soil moisture regimes within the area which are not apparent from a more general examination based on mean monthly rainfall and evaporation data.

TABLE 6

PERCENTAGE FREQUENCY OF WEEKS WITH SOIL MOISTURE STORAGE AT SPECIFIED LEVELS PER SEASON

(a, storage full; b, storage 1–49% depleted; c, storage 50–99% depleted; d, storage empty)

Station and Storage Level	Percentage Frequency (wk) Dec.–Feb.	Mar.–May	June–Aug.	Sept.–Nov.	Mean Annual Water Surplus (in.)
Balimo					51
a	65	78	35	16	
b	25	22	45	26	
c	9	0	20	44	
d	0	0	0	14	
Daru					39
a	50	57	14	5	
b	26	40	41	18	
c	21	3	43	46	
d	3	0	2	31	
Merauke					28
a	50	46	5	7	
b	34	49	24	4	
c	14	5	50	32	
d	2	0	21	57	
Tanahmerah					120
a	88	85	80	70	
b	11	14	19	29	
c	1	1	1	1	
d	0	0	0	0	

The weekly changes in soil moisture levels that are indicated by the application of this model have been averaged for four stations and the results presented in Figure 7. This clearly indicates the differentiating effect of seasonality of rainfall in terms of soil moisture storage regimes between coastal and inland areas. Soil moisture deficits from July to October are much more marked on the coast (e.g. Merauke) than at inland stations, and deficits decrease in amount and duration the further inland the station is situated. The short records of the rainfall stations in the survey area have been examined using the same model and this analysis reveals that the Morehead regime is probably transitional between that of Merauke and Daru, that the Suki regime is very similar to that of Balimo, while the Pangoa regime is transitional between those of Balimo and Tanahmerah.

These curves represent only average weekly conditions and do not in themselves portray the risk of serious soil water deficits that might influence plant growth and production. The percentage frequency distribution of various levels of soil moisture deficits for the stations illustrated in Figure 7 are presented by seasons in Table 6. It can be seen that weekly occurrences of complete depletion of soil moisture storage are common during September–November at Merauke and Daru, uncommon at Balimo, and not recorded inland at Tanahmerah. Records are too short to give a reliable estimation of the distribution of the duration of soil moisture droughts (i.e. complete depletion). However, the records indicate that droughts usually vary in length from 5 to 10 weeks at Daru, from 6 to 20 at Merauke, and from 1 to 3 at Balimo, although all three stations, especially the last, have some years with no droughts. In contrast to these droughtless years, 1965, with its extremely dry "dry season", had a drought that lasted 12 weeks at Balimo and 10 weeks at Daru. Even as far inland as Pangoa estimates revealed a 9-week drought.

The residual term in the water balance model, after evapotranspirational and soil moisture storage requirements have been met from weekly rainfall, is water surplus. This may be regarded as an estimate of a combination of surface run-off and deep percolation. The average annual water surplus varies from 28 in. at Merauke on the coast to 120 in. inland at Tanahmerah. Estimates for other stations are given in Table 6.

IV. Acknowledgment

Mrs. A. Komarowski prepared and tabulated the data used in this report.

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PART V. GEOLOGY AND GEOMORPHOLOGY OF THE MOREHEAD–KIUNGA AREA

By D. H. Blake*

I. Introduction

The Morehead–Kiunga area lies within a low-lying tract of land extending from the foothills of the central mountain chain of New Guinea in the north to the coast in the south. The area ranges in altitude from sea level in the south to about 300 ft in the north-east, has a maximum relief of about 200 ft, and consists topographically of low ridges and plateaux, broad major flood-plains, narrow minor valleys, and many swamps and lakes. It is traversed by the Fly River, the longest river (about 700 miles long) in New Guinea, and contains the lower courses of the Strickland and Alice (Ok Tedi) Rivers, the main tributaries of the Fly.

Several geological and geophysical investigations have been carried out in the area by the Australasian Petroleum Company Pty. Ltd. This work included the drilling of a bore, the Morehead No. 1, to a depth of 8087 ft near Morehead (Fig. 2). The results of the investigations are described in various unpublished reports, and have been summarized by the Australasian Petroleum Company Pty. Ltd. (1961). The general geology of the area has been discussed by Stanley (1925), Carey (1938), van Bemmelen (1949), Montgomery, Glaessner, and Osborne (1950), Glaessner (1950), Smith (1965), and Thompson and Fisher (1967).

II. Relief, Land Forms, and Drainage

The survey area comprises four main geographic regions (Fig. 2, and geology and geomorphology map): these are, from south to north: the coastal plain; the Oriomo Plateau, a low undissected plateau area; the flood-plains of the Fly River and its tributaries; the dissected plateau of the Fly–Digoel Shelf.

The land forms are developed on unconsolidated sediments of mostly Quaternary age, and are variously affected by tectonic, weathering, slope, fluvial, and littoral processes. The Quaternary sediments are composed largely of unstable minerals that are highly susceptible to chemical weathering, and the volume of material removed in solution during denudation is possibly as large as that removed in the solid state.

(a) *The Coastal Plain*

The coastal plain lies mostly less than 10 ft above mean high tide level and ranges in width from less than 300 ft to over 12 miles. It consists of tidal flats and present beaches backed by non-tidal flats and a series of low beach ridges and swales,

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behind which is a flat and mainly swampy back plain (Plate 1, Fig. 1). Small sand dunes up to 3 ft high are locally developed on headlands. Off shore there are extensive mud and sand banks, locally up to 3 miles wide, which are bared at low tide. Along the coast the normal maximum tidal range is probably about 12 ft, similar to that at Merauke, West Irian (Anon. 1961), although in abnormal conditions such as king tides combined with strong on-shore winds the tidal range could be as large as 16 ft.

Apart from a small area more than 10 ft above high-water mark north-east of Bula, almost the whole of the coastal back plain is flooded during the wet season. However, most of the back plain dries out during the dry season, when it has an intricate reticulate to dendritic network of narrow drainage channels. Other parts consist of permanent and semi-permanent swamps which have deeply indented margins where they are bordered by slightly higher seasonally dry plains (Plate 3, Fig. 1).

The coastal plain is traversed by the highly sinuous meandering channels of the Bensbach (Plate 2, Fig. 1) and Morehead Rivers and the much less sinuous channel of the Tarl River. The highly sinuous channels are locally flanked by relatively narrow flood-plains (Plate 2, Fig. 2) 2–6 ft higher than the adjoining plains. Downstream the mouths of both the Bensbach and Morehead Rivers are blocked by mud bars which can only be negotiated by shallow-draught vessels at high tide. Also present on the coastal plain are permanently swampy channels that probably represent former channels of the Morehead and Tarl Rivers.

At the present time the coast is being prograded by wave action, which forms beach ridges of material derived by longshore drift from the east, and by stabilization of littoral clays by mangroves to form tidal flats. The coastal back plain is being aggraded by clay deposition during seasonal flooding of the Morehead and Bensbach Rivers.

(*b*) *The Oriomo Plateau*

The Oriomo Plateau (Carey 1938), also known as the Merauke Ridge (van Bemmelen 1949), is a low broad ridge that extends from Oriomo, near Daru, in the east to the Digoel River, West Irian, in the west. In the survey area the Oriomo Plateau is a mostly flat to very slightly undulating featureless plain generally less than 100 ft above sea level. To the south the plateau descends very gradually down to the coastal plain while it is bounded to the north, except near Boset in the north-west, by the valley of the Fly River. The southern and western margins of the plateau are deeply indented by swampy flood-plains of streams on the coastal plain (Plate 3, Fig. 1), and the northern edge of the plateau is incised by several creeks draining northwards to the Fly (Plate 9, Fig. 1). The highest part of the plateau is an east–west-aligned ridge near Morehead which rises 50 ft above the surrounding plain and up to 180 ft above sea level. It is significant that this ridge, here called the Morehead Ridge, does not coincide with the main watershed of the plateau from which flow the Morehead, Bensbach, and Wanggoe Rivers. This watershed lies over 30 miles north of the Morehead Ridge, and is much lower; the source of the Morehead River, for example, is only 80 ft above sea level (Montgomery, Glaessner, and Osborne 1950).

Streams on the Oriomo Plateau are widely spaced and mostly flow in open V-shaped valleys, rarely more than 30 ft deep, which have side slopes of less than 3°;

narrow flood-plains are locally present. An exception is the valley of the Morehead River near Morehead Patrol Post, where the river has cut through the Morehead Ridge. Here the valley is about 120 ft deep and has side slopes of 5–10°.

Deep mature weathering profiles occur on the flat and very slightly undulating surfaces of the Oriomo Plateau, and pisolitic laterites are developed on the Morehead Ridge. Fluvial processes are active locally and include down-cutting by many of the small streams, lateral erosion of river banks during meander migration, and deposition of sediment on narrow flood-plains. Some gullying occurs on the rare slopes that are greater than 10°. The effect of slope wash is indicated by a general paucity of leaf litter on gentle slopes.

(c) *Flood-plains of the Fly River and its Tributaries*

(i) *General*.—The Fly River and its main tributaries, the Strickland and Alice Rivers, have highly sinuous meandering channels on flood-plains that range in width from 3 to 10 miles (Blake and Ollier 1971). The flood-plains in the immediate neighbourhood of the channels are made up of interlocking groups of meander scrolls, or "scroll complexes", and have numerous ox-bow lakes and swamps representing abandoned meanders (Plate 4, Fig. 2; Plate 5). Flanking the scroll complexes are extensive back swamps and lakes, many of which extend several miles up tributary valleys (Plate 9, Fig. 1). The back swamps are slightly lower than the adjacent scroll complexes and are under water for most of the year.

The Fly River ranges in width from 450 to 3000 ft and in depth (Stanley 1925) from less than 12 ft to over 40 ft. The average discharge upstream from Everill Junction is probably in the order of 20 million gallons per minute (Stanley 1925) and the average mid-stream velocity is probably between 2 and 3 knots. The gradient of the river is extremely low, and 500 miles upstream near Kiunga the river is only 60 ft above sea level (Anon. 1965). The Strickland River is 700–2000 ft wide and probably has an average depth of over 30 ft. It has a steeper gradient than the Fly and is faster-flowing, having an average mid-stream velocity of about 6 knots. The discharge and water level of both rivers are extremely variable, both seasonally and from year to year, and flood-waters commonly rise up to 6 ft above the top of the river banks. The rivers carry large amounts of sediment in suspension and are always murky.

Several alluvial islands, of which the best known are probably Ellangowan Island and Raggi Island, occur in the Fly and Strickland Rivers. These islands have been formed where flood-waters have cut new river channels across the scroll complexes, thus isolating parts of the flood-plain.

The meander scrolls forming the scroll complexes are long and narrow, gently curving, parallel ridges of uniform height, separated from one another by narrow depressions. The crests are up to 6 ft above the adjacent depressions, up to 5 ft above mean river level,* and are generally less than 200 ft apart. The ridges represent point bars formed by the deposition of sediment against the inner banks of meanders as the meanders migrated laterally across the flood-plain. Changes of course by the rivers during floods have caused new groups of scrolls to be built up which cut across the old scrolls and so form scroll complexes.

* Mean river level = average river level in October 1967.

The channels of the main rivers are flanked in places by discontinuous low levees that are generally less than 6 ft above mean water level.

The flood-plains of the Fly, Strickland, and Alice Rivers have been considerably aggraded with material brought down from the mountains to the north. However, the smaller tributary streams have catchments restricted to the Fly–Digoel Shelf, and they carry insufficient material to aggrade their valleys at the same rate as the major rivers. The tributary valleys have therefore become blocked by alluvial deposits of the major rivers and this has led to the formation of blocked-valley lakes and swamps, a characteristic feature of the area. On the geology and geomorphology map these blocked-valley lakes and swamps are shown separately from the rest of the back swamps.

The blocked-valley lakes and swamps are connected to the major rivers by narrow and highly sinuous channels through which water flows either from the tributary valley into the major river or vice versa, depending on where the water level happens to be higher. Hence when the Fly and Strickland Rivers are in flood they overflow into the lakes, while at low water they receive water from them.

The main fluvial processes active on the flood-plains are lateral erosion of river banks during meander migration, deposition of sediment on point bars and in channels, deposition in times of flood of over-bank sediments on levees, scroll complexes, and back swamps, and deposition of sediments in lakes.

(ii) *Lake Murray*.—Lake Murray (Plate 11, Fig. 2; Plate 12, Fig. 1) covers an area of almost 300 sq miles and is the largest blocked-valley lake in the area. The lake is connected to the Strickland River by the Herbert River, which passes through permanent grass swamps at the southern end of the lake before crossing scroll complexes to join the Strickland River at Massey Baker's Junction.

In October 1967, the average depth of water in Lake Murray was about 22 ft. The floor of the lake is remarkably flat except along the axis of the valley, where depths up to 30 ft were sounded. The water level of the lake normally rises and falls about 10 ft annually, rising in the wet season and falling in the dry. In abnormally dry years, such as 1965, the water level falls 20 ft or more, and the lake almost disappears.

The Lake Murray catchment area covers about 2900 sq miles and ranges in altitude from about 250 ft above sea level on the Elevala River–Kaim River divide to about 35 ft above sea level, the mean water level of Lake Murray. The main rivers flowing into the lake are the June, Boi, and Kaim, the flood-plains of which show many of the features of the Fly and Strickland flood-plains, including lakes formed in blocked tributary valleys. These three rivers on entering Lake Murray are bordered by lines of grass swamp (Plate 12, Fig. 1) which are presumed to be growing on underwater silt and clay jetties. Upstream from Lake Murray the flood-plains locally have a hummocky microrelief of up to 4 ft, consisting of irregular mounds and hollows up to 60 ft across; the origin of this microrelief is not known.

(*d*) *Dissected Plateau of the Fly–Digoel Shelf*

The Fly–Digoel Shelf (Glaessner 1950; Smith 1965), or Fly–Digoel Depression as it is also called (van Bemmelen 1949; Montgomery, Glaessner, and Osborne 1950), extends northwards from the Oriomo Plateau to the foothills of the central mountain ranges. The characteristic landscape here, in marked contrast to that of the Oriomo Plateau, consists of closely spaced narrow ridges and valleys (Plate 11, Fig. 2) with only minor areas of undulating plateaux. The relief ranges from 25 ft in the south-east to 200 ft in the north-east. The drainage pattern is intricately dendritic. Ridge crests are generally less than 100 ft wide (Plate 13, Fig. 1) and side slopes range from 3 to 35° (Plate 13, Fig. 2). Valleys, except at their heads, have flat swampy flood-plains (Plate 14, Fig. 1) ranging in width from a few feet to over 1000 ft. The flood-plains have very low gradients and are traversed by highly sinuous meandering channels of sluggish rivers such as the Elevala, Binge, Kaim, and Kwina.

A general concordance of ridge summit levels indicates that the Fly–Digoel Shelf is an intricately dissected low plateau that rises northwards from 40 ft above sea level in the south-east to 300 ft above sea level in the north-east. This dissected plateau is crossed by the broad flood-plains of the Strickland, Alice, and upper Fly Rivers, which are incised up to 100 ft below the plateau surface.

On the dissected plateau, slope processes are dominant, but weathering and fluvial processes are also important. Five types of slope processes have been observed: slumping, soil creep, gullying, tunnelling, and slope wash. Slumping is rarely evident except in the north-east, where small slumps up to 20 ft deep occur on slopes of over 25°. Soil creep, comprising slow mass movement affecting only the soil layer, may be important but none of the common indications of rapid soil creep were seen. Small gullies are very common on slopes of over 10° and generally start within 100 ft of ridge crests; the gullies have side slopes of over 30° and are up to 15 ft deep. Closely related to gullying is tunnelling, which is very common on hill slopes in the northern part of the dissected plateau, especially near Kiunga: here holes up to 15 ft deep and 100 ft long are connected to one another by tunnels, some of which are over 50 ft long. The tunnels are not caused by textural differences in the subsoil, which is clay throughout, and it seems probable that they are formed by solution or disaggregation of some of the clay minerals. Slope wash due to the erosive action of rain-drops and surface run-off not concentrated as streams may be important (Ruxton 1967), as is shown by the generally sparse leaf litter cover, which is continually being removed by slope wash, and by the exposure of tree roots on ridge crests and side slopes, leading to the formation of small steps facing downslope.

Deep and mature weathering profiles have been formed on ridge crests, undulating plateaux, and most hill slopes, and in these situations red clay soils predominate. A catena relationship between land forms and soils is generally apparent: on ridge crests red subsoils occur, except where drainage is impeded, when red and grey mottled subsoils are developed; on side slopes, which are well drained, red subsoils are always present; at the bottom of side slopes there are young and strongly gleyed colluvial soils; and on valley floors young alluvial and organic soils are developed.

Active down-cutting by streams is taking place only in the heads of valleys. On flat valley floors lateral erosion of river banks occurs during meander migration, and in times of flood over-bank sediments are deposited on the narrow flood-plains.

III. Stratigraphy

Almost all of the Morehead–Kiunga area is covered by unconsolidated clay, silt, sand, and gravel of Pleistocene to Recent age. These sediments are underlain by

Jurassic, Cretaceous, and Tertiary rocks overlying crystalline basement. The only "hard" rocks cropping out are mudstones of possibly Pliocene age exposed near Weam. Information on the subsurface geology is available from the Morehead No. 1 bore, from gravity, seismic, and aero-magnetic surveys, and from stratigraphical sections exposed in the mountains to the north (Australasian Petroleum Company 1961).

(*a*) *Crystalline Basement*

A seismic velocity survey in the Morehead No. 1 bore indicated that crystalline basement, probably granite, lies at a depth of about 8300 ft. The basement is thought to lie at a comparable depth throughout most of the area except in the north-east, where it is overlain by at least 18,000 ft of Mesozoic and younger rocks. The crystalline basement, consisting of Upper Carboniferous granite (Richards and Willmott 1970), is exposed on the coast near Mabaduan (Fig. 2), 60 miles east of the survey area, and is probably a northerly extension of the Australian Platform.

(*b*) *Mesozoic*

The oldest sedimentary rocks known in the area are feldspathic sandstones of Jurassic age, which were encountered at depths of 7265–8087 ft at the bottom of the Morehead No. 1 bore. Overlying the Jurassic are nearly 4000 ft of Cretaceous sand and mudstone, making a total of about 5000 ft of Mesozoic rocks. Geophysical surveys have shown that the Mesozoic thickens to over 6000 ft south of Morehead in a narrow sedimentary basin known as the Morehead Basin. North of Morehead the Mesozoic decreases in thickness to about 3000 ft near Lake Murray, before increasing again to about 5000 ft in the north-east.

(*c*) *Miocene*

In the Morehead No. 1 bore the Mesozoic succession is overlain by about 3000 ft of Miocene limestone, sand, and mudstone.

(*d*) *Pliocene*

Rocks which are probably of Pliocene age occur in the north-east corner of the area, where over 10,000 ft of Pliocene terrestrial sediments are present in a closed sedimentary basin known as the Strickland Basin, and probably also in the south near Weam and Morehead.

Near Weam, pale grey sandy mudstones, informally named the Bensbach beds, are exposed on the banks of the Bensbach and Tarl Rivers. The mudstones, which are unfossiliferous, are hard and brittle when unweathered. They are made up of 20–30% quartz grains, averaging 0·1 mm in diameter, enclosed in an extremely fine-grained clayey matrix. Indistinct subhorizontal bedding, brought out by differential erosion of more resistant layers, is visible in exposures subject to subaerial erosion, but underwater rock surfaces are smooth and rounded. The mudstones are overlain by grey clay.

Mudstones probably similar to those of the Bensbach beds were encountered in the Morehead No. 1 bore at depths of 68–228 ft, underlying clay and overlying Upper and Middle Miocene limestone. The nearest known exposures of comparable rocks are on the banks of the Wassi Kussa, about 30 miles south-east of Morehead, where hard grey clayey sandstone crops out.*

(e) *Pleistocene*

Pleistocene sediments crop out on the Oriomo Plateau and on the ridges and undulating plateaux of the Fly–Digoel Shelf. Most of the sediments consist of deeply weathered alluvial deposits which are reddish to red and pale grey mottled on exposed surfaces: these sediments are informally named the Lake Murray beds. In the northern part of the area the Lake Murray beds are seen to unconformably overlie up to 30 ft of grey carbonaceous sediments, informally named the Kiunga beds, which in turn unconformably overlie an unknown thickness of sands, informally named the Elevala beds (Plate 14, Fig. 2).

(i) *Elevala Beds.*—The Elevala beds consist of massive cross-bedded medium- to coarse-grained alluvial sands which are well exposed along the Elevala River, along the Fly River near Kiunga, where they are overlain unconformably by Kiunga beds, and along the Fly River in West Irian, 30 miles NNW. of Boset, where they are overlain unconformably by Lake Murray beds. The sands are composed of lithic fragments (over 60%), quartz (less than 10%), opaque minerals, and crystal fragments of plagioclase, hornblende, augite, and biotite derived from andesitic volcanics. Most of the lithic grains are shale fragments, but some are of andesitic lava. The volcanic material in the sand may be derived from extinct andesitic volcanoes, such as Doma Peaks, Sisa, and Bosavi, situated over 50 miles to the east of the survey area (Fig. 8), which may have been active when the Elevala beds were laid down.

(ii) *Kiunga Beds.*—The Kiunga beds are exposed along the Fly River upstream from D'Albertis Junction, where they are overlain unconformably by Lake Murray beds. They consist of up to 30 ft of pale to dark grey thin-bedded clay, silt, and sand, and contain abundant plant fragments. A sample of carbonized wood (Gak–1691) from these beds at Gueretmin, on the Fly River upstream from Kiunga, has been dated by Dr. Kigoshi of Gakushuin University, Tokyo, at 27,100±1100 years before present by the carbon-14 method. The beds are interpreted as lacustrine or swamp deposits.

(iii) *Lake Murray Beds.*—The Lake Murray beds are best exposed around Lake Murray and where the Fly, Strickland, and Alice Rivers have cut into low ridges bordering their flood-plains. The beds have a maximum thickness of at least 100 ft. Exposures are deeply weathered and are red or red and grey mottled.

On the Oriomo Plateau the Lake Murray beds consist of pale grey clay. Further north they become coarser-grained, and around Lake Murray and on the banks of the Fly and Strickland Rivers south of latitude 6°30′S. they consist of well-stratified and locally cross-bedded sand and silt, as well as laminated clay. Further north still, near Kiunga, the beds consist mostly of cross-bedded sand and gravel. Weathered speci-

* Kicinski, F. M. (1957).—Appendix III, Morehead No. 1 Geol. Completion Rep. APC/PMB (unpublished).

mens of sand contain less than 50% quartz and are made up mostly of clay mineral aggregates. The gravel beds are commonly iron-stained and in places are cemented by iron oxide. They consist of well-rounded pebbles, up to 6 in. across, mostly of quartz, quartzite, chert, and siltstone.*

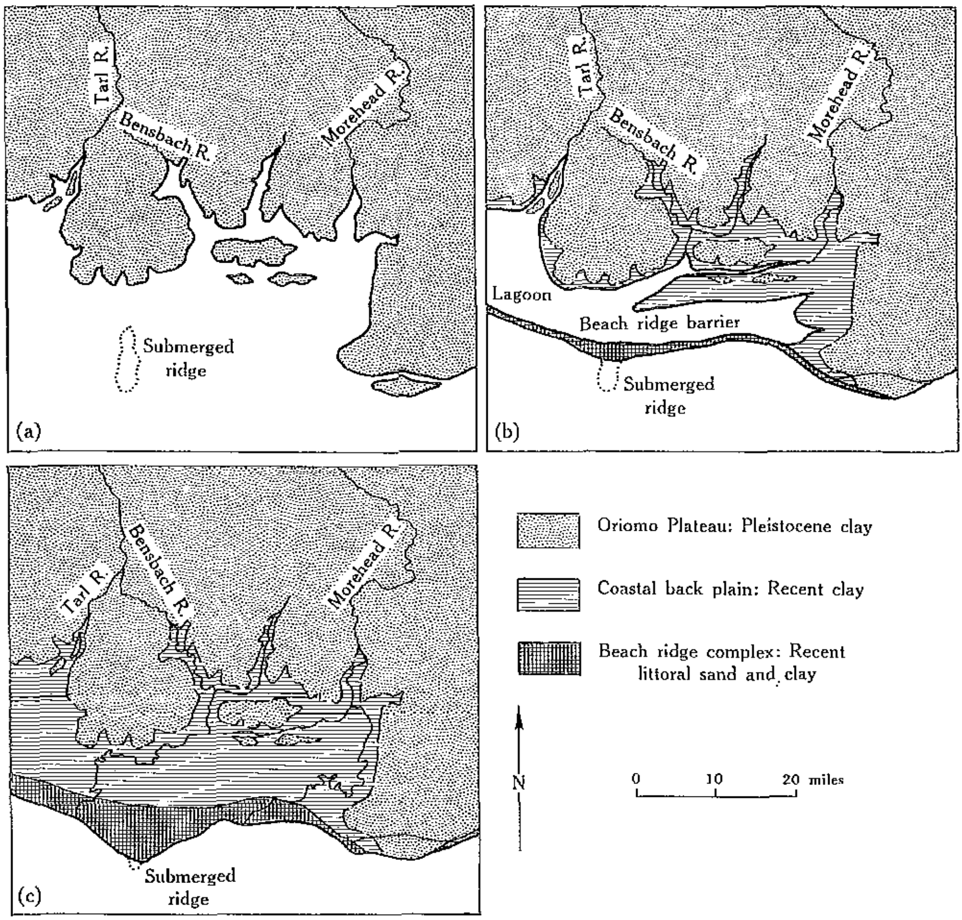

Fig. 8.—Development of the coastal plain in the Morehead–Kiunga area. (*a*) Initial stage; (*b*) intermediate stage; (*c*) present stage.

The Lake Murray beds are interpreted as mostly non-marine late Pleistocene alluvial sediments which were deposited on a broad piedmont alluvial plain by streams flowing southwards from the main mountain ranges. The gravel and most of the coarser sand are probably channel deposits, while most of the well-stratified fine sand, silt, and clay probably represents over-bank deposits. However, not all of the unit is non-marine, as foraminifera, including some of possibly Pliocene age, have

* Pebbles of silicified Miocene limestone and an ammonite fragment, possibly of Upper Jurassic age (?*Macrocephalites* sp.), were found in point bar gravels along the Elevala River: these gravels are almost certainly derived from gravel within the Lake Murray beds.

been found at depths greater than 15 ft in clay near Morehead:* the foraminifera indicate a littoral environment and show that at least some of the clay at this locality is marine, possibly deposited in coastal lagoons. Part of the Lake Murray beds in the south may be the same age as the Kiunga and Elevala beds in the north.

(iv) *Recent Sediments*.—Recent sediments occur on the coastal plain in the south and on the flood-plains of major and minor rivers.

Along the present coast are tidal flats formed of littoral clay and beaches and beach ridges formed of littoral sand; both clay and sand are calcareous. The littoral deposits pass inland into leached non-calcareous clay which forms the remainder of the coastal plain. Some of the non-calcareous clay was probably brought down by the Bensbach and Morehead Rivers and deposited in lagoons separated from the sea by beach-ridge barriers. The lagoons are now almost filled with sediments, although an additional very thin layer of alluvial clay is deposited during floods.

The flood-plains of the major and minor rivers consist of clay, silt, sand, and minor gravel. Gravel is present only in the north, where it forms point bar and other channel deposits in the Fly River upstream from D'Albertis Junction and similar deposits in the Alice and Elevala Rivers. The gravel is probably mostly derived from the Lake Murray beds. Elsewhere, channel deposits consist of sand which becomes increasingly finer-grained downstream. The over-bank deposits are mostly well stratified, and consist of fine sand, silt, and clay: clay predominates in back swamps and fine sand and silt are characteristic of levee deposits. Deltaic and lacustrine deposits of sand, silt, and clay occur where rivers enter lakes, and possibly underlie some of the channel and over-bank deposits of the lower Fly and Strickland Rivers.

IV. Structure

In contrast to most of New Guinea, which has been very active tectonically during the Cainozoic, the Oriomo Plateau and Fly–Digoel Shelf have formed part of a relatively stable shelf area from Jurassic times, and no major structures have been recognized in the survey area. However, there are some gentle flexures which were formed during the Mesozoic, Pliocene, and Quaternary.

Flexuring during the Mesozoic is indicated in the south by the presence of the Morehead Basin, which contains at least 6000 ft of Mesozoic sediments in contrast to only 3000 ft present near Lake Murray. During the Pliocene flexuring occurred in the north-east, where the Strickland Basin containing over 10,000 ft of Pliocene sediments was formed.

Quaternary flexures in the area are indicated by present summit levels and courses of streams (Blake and Ollier 1970). The Lake Murray beds, which occur throughout the survey area on the highest ground, are considered to have been deposited on a piedmont alluvial plain sloping consistently southwards at a low angle from the foothills of the central mountain chain down to the coast. The highest surface of this piedmont plain is represented by the summit level of the ridges and minor plateaux on the Fly–Digoel Shelf and by the summit surface of the Oriomo Plateau. At present this summit level surface slopes very gently from the north and

* Kicinski, F. M. (1957).—Appendix III, Morehead No. 1 Geol. Completion Rep. APC/PMB (unpublished).

north-east down to the south, to the valley of the Fly River downstream from Boset. From here the summit level surface rises southwards onto the main watershed of the Oriomo Plateau, before gradually descending to the south coast. This last general descent, however, is interrupted by the east–west Morehead Ridge which rises over 50 ft above the surrounding plain. These undulations of the originally flat piedmont surface indicate that gentle warping has occurred along a synclinal axis followed by the Fly River valley downstream from Boset, an anticlinal axis along the main watershed of the Oriomo Plateau, a minor synclinal axis north of Morehead, and an anticlinal axis along the Morehead Ridge (geomorphology and geology map). The latter anticline is cut by the Morehead River, which originates on the main watershed of the Oriomo Plateau and is the youngest structure recognized. The maximum relative uplift along the Morehead anticlinal axis is about 80 ft.

V. Geomorphic History

The present landscape of the survey area is considered to be the result of gentle warping and dissection within the last 27,000 years of the Plio–Pleistocene piedmont alluvial plain, accompanied by changes in sea level.

From the Jurassic to Upper Miocene, several thousand feet of marine shelf sediments, mainly shallow-water limestone, sandstone, and mudstone, were laid down on the stable platform which forms most of western Papua. This platform or shelf lies to the south of a tectonically mobile zone now represented by the central mountain chain of New Guinea. At the end of the Miocene a lowering of sea level caused the northern part of the platform, including most of the survey area, to become dry land, forming a broad flat plain only a few feet above sea level.

The orogenic activity that led to the formation of the central mountain chain in the mobile zone probably commenced in the Upper or Middle Miocene (Australasian Petroleum Company 1961) and reached its acme in the Pliocene, when the main structures were formed. The mountains probably attained their greatest elevations during the Upper Pliocene and Pleistocene. During the phase of maximum orogenic activity in the mobile zone, some tectonic warping affected the platform area to the south and led to the formation of the Strickland Basin, in which over 10,000 ft of terrestrial sediments of Pliocene age were laid down. In general, however, the platform remained stable during the Pliocene and Pleistocene, and it formed a piedmont plain on which alluvial sediments were deposited by streams draining southwards from the mountains. The youngest sediments to be deposited during this phase were the Lake Murray beds, the upper parts of which are less than 27,000 years old (the age of charcoal in the underlying Kiunga beds). These were deposited by streams graded to sea level at a coastline that was probably quite close to the present coastline; this is indicated by the occurrence within the Lake Murray beds near Morehead of both marine and probably terrestrial sediments. The position of the coastline at this time fluctuated with changes in sea level.

During the Upper Pleistocene, after the deposition of the Lake Murray beds, some gentle warping took place, forming the Oriomo Plateau by uplift along an anticlinal axis, the position of which is marked by the main watershed of the plateau. The average uplift along this axis was probably less than 50 ft. To the north of the

Oriomo Plateau, a corresponding synclinal axis lies along the valley of the Fly River downstream from Boset.

On the Fly–Digoel Shelf to the north of the Oriomo Plateau, streams became incised into the old alluvial plain. This incision was possibly caused by a relative lowering of sea level by 100–300 ft. As they were being incised, streams with head-waters in the mountains joined up to form three major rivers, the Alice River in the west, the Fly River in the centre, and the Strickland River in the east. The Alice River flowed southwards to D'Albertis Junction where it joined the south-westerly-flowing Fly River. From D'Albertis Junction the Fly River flowed south-west and south until it was diverted south-eastwards along the synclinal axis on the north side of the Oriomo Plateau. The Strickland River flowed south and south-west down to Everill Junction, on the synclinal axis, where it joined the Fly River. All three major rivers flowed in valleys that in places were probably incised at least 200 ft into the old alluvial plain. The former courses of the Fly and Strickland Rivers before they were diverted south-eastwards may be represented by the Baim and Merauke Rivers respectively in West Irian (Fig. 2).

On the Fly–Digoel Shelf between the major rivers the readily erodable nature of the sediments and the tropical climate with high annual rainfall combined to produce an incised dense drainage network.

On the Oriomo Plateau streams drained northwards from the main watershed to join the Fly River and southwards from the main watershed towards the sea. A much less dense drainage network was developed here than on the Fly–Digoel Shelf and little incision took place, probably because of the lower and more marked seasonality of rainfall. Rivers developed at this time on the Oriomo Plateau include the Morehead and Tarl Rivers which drain southwards from the main watersheds and the Wanggoe River which flows westwards to join the southerly-flowing Merauke River in West Irian.

After the establishment of the main drainage network on the Oriomo Plateau, further tectonic warping uplifted a ridge, the Morehead Ridge, along an east–west anticlinal axis crossing the Morehead River. Erosion by the Morehead River kept pace with the uplift, providing an example of antecedent drainage.

After being incised up to 200 ft into the old alluvial plain, the valleys of the Fly, Strickland, and Alice Rivers became filled with sediment brought from the mountains, forming flat swampy flood-plains with very low gradients. However, the smaller rivers in the area had much more restricted catchment areas and carried insufficient sediment to keep pace with the alluviation in the main valleys. The smaller valleys became dammed at their mouths by the alluvial deposits of the main rivers, and numerous blocked-valley lakes were formed. The largest of the blocked-valley lakes, Lake Murray, occupies the flooded valley of the Herbert River.

The aggradation of the valleys is probably partly due to a relative rise of sea level. This rise may be related to the world-wide marine transgression which began about 17,000 years ago and ended about 6000 years ago (Fairbridge 1961).

Any marine transgression that flooded the valleys of the Fly–Digoel Shelf would also have caused flooding of several hundred square miles on the south side of the Oriomo Plateau, including the lower courses of the Bensbach, Tarl, and Morehead

Rivers. However, these rivers were only locally incised and evidence of drowning is much less marked than in the northern part of the area.

A few thousand years ago, when the sea reached its present level, the coastline probably coincided with the inland limit of the present coastal plain (Fig. 8). Off shore the sea shelved very gently southwards. A submerged ridge, probably formed of hard and relatively resistant Bensbach beds, is thought to have existed just to the east of the present mouth of the Bensbach River.

Since that time a series of beach ridges have been built westwards from the coast east of the Morehead River to the submerged reef near the mouth of the Bensbach, and then north-westwards along the coast into West Irian. These beach ridges were formed by wave action depositing sand delivered by longshore drift from the mouth of the Fly River many miles to the east. The beach ridges enclosed a lagoon which at times became blocked off from the sea. This lagoon gradually filled up with sediment, part of which was brought in by the Morehead, Bensbach, and Tarl Rivers, producing the present coastal back plain.

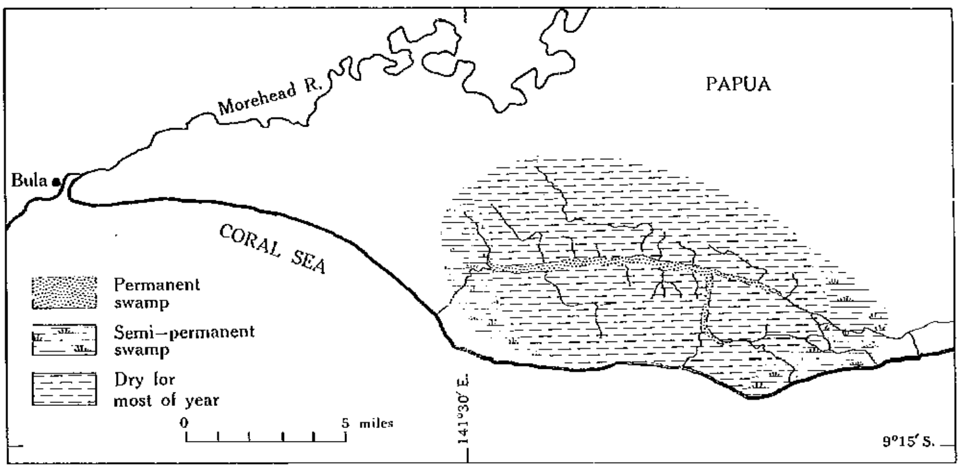

Fig. 9.—Permanently swampy channel east of the mouth of the Morehead River.

As the lagoon was filling up with sediment, the lower tidal courses of the Tarl and Morehead Rivers became silted up and were abandoned. The Tarl changed its course to flow down the Bensbach River, and the Morehead River developed an entirely new channel to the sea.

East of the Morehead River mouth there is a parallel-sided permanently swampy channel, over 10 miles long and up to 700 ft wide, blocked at both ends by semi-permanent swamps (Fig. 9). This channel lies 2–3 miles inland from, and more or less parallel to, the present coastline. It is suggested here that at one time the channel separated a small off-shore island, similar to those at the mouth of the Wassi Kussa further east, from the mainland. Eventually both ends of the channel became silted up, joining the island to the mainland but leaving the central part of the channel preserved as a permanent swamp.

VI. Land Forms and Land Systems

The relationship of land forms to land systems is set out in Table 1. Land systems on the Oriomo Plateau and on the dissected plateau of the Fly–Digoel Shelf consist predominantly of denudational land forms, while land systems on the coastal plain and on the flood-plains of the Fly River and its tributaries consist predominantly of aggradational land forms.

VII. Acknowledgment

The author greatly benefited from many discussions on the geomorphology of the area held with C. D. Ollier.

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PART VI. SOILS OF THE MOREHEAD–KIUNGA AREA

By P. BLEEKER*

I. INTRODUCTION

(a) General

The soils in the Morehead–Kiunga area are developed on Pleistocene to Recent detrital sediments and range from well-developed texture-contrast soils to undeveloped alluvial soils.

Because of relatively uniform parent material and also because of the small range in altitude and relief the soils vary less than in other surveyed areas in New Guinea. The main differences among soils appear to be due to climate and age.

Each of the four geographic regions in the area has a characteristic suite of soils. Young, very poorly drained, marine and alluvial soils are found on the coastal plain, and the flood-plains of major rivers have young, swampy, fluviatile soils. Texture-contrast soils have formed on Pleistocene sediments under the influence of a monsoonal climate on the Oriomo Plateau. Uniform-textured soils and soils with slightly finer-textured subsoils are characteristically developed on the Pleistocene sediments of the intricately dissected plateau of the Fly–Digoel Shelf, where the climate is less monsoonal.

The soils of the area have been subdivided into seven principal groups (orders). These are:

(1) Organic soils (histosols), which cover about 805 sq miles (7% of the area).

(2) Undifferentiated alluvial soils (entisols), which cover about 2125 sq miles (18%).

(3) Slightly to strongly developed soils with altered B horizons (cambic horizons) and/or acid to strongly acid thick dark topsoils (inceptisols), which cover about 1878 sq miles (16%).

(4) Slightly developed soils with weakly alkaline thick dark topsoils (mollisols), which cover about 7 sq miles ($<0 \cdot 1$%).

(5) Moderately developed soils with textural B horizons (argillic horizons), having a minimum pH $>5 \cdot 5$ and coarser-textured surface horizons (alfisols), which cover about 233 sq miles (2%).

(6) Moderately to strongly developed acid to strongly acid soils (maximum pH $5 \cdot 5$ in B horizon) with textural B horizons (argillic horizons) and coarser-textured surface horizons (ultisols), which cover about 5964 sq miles (51%).

(7) Strongly developed acid to strongly acid friable soils with no strong textural contrast or bleached A_2 horizons (oxisols), which cover about 211 sq miles (2%).

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TABLE 7

CLASSIFICATION OF THE SOILS

Classification according to 7th Approximation				Principal Profile Form (Northcote 1965)	Major Soil Group
Order	Suborder	Great Group	Subgroup		
Histosols				0	Organic soils or bog soils
Entisols	Aquents	Hydraquents		Uf or Um1.41	Alluvial soils (hydromorphic soils)
		Haplaquents	Orthic haplaquents		
			Vertic haplaquents	Ug1 or Uf1.41	
			Thapto albaqualfic haplaquents	Uf1.41	
	Udents	Hapludents	Orthic hapludents Aquic hapludents	Um1.43, Um1.41, Uc1.43 Um1.3, Um1.41–1.42	Alluvial soils (non-hydromorphic soils)
Inceptisols	Aquepts	Umbraquepts		Uf6.61 or Um5.5	Humic gley soils/meadow soils
	Ochrepts	Eutrochrepts	Orthic eutrochrepts	Uc5.12	Brown forest soils
		Dystrochrepts	Orthic dystrochrepts Aquic dystrochrepts	Um5.4	Sols bruns acides/acid brown forest soils
			Oxic dystrochrepts (Plintoxic) Dystrochrepts	Um5.4, locally Um5.3	Latosols/red podzolic soils/ferrallitic soils Gleyed latosols
Mollisols	Rendolls			Uc5.12	Brown forest soils

Alfisols	Aqualfs	Albaqualfs	Orthic albaqualfs Mollic albaqualfs	Gn2.95 Gn2.96	Planosols Meadow podzolic soils
Ultisols	Aquults	Plintaquults	(Ochric) Plintaquults	Gn2.81 and Dg4.81–Dr5.81	Gleyed latosols, ground-water laterites, ferruginous tropical soils
			(Umbric) Plintaquults	Dg4.81, locally Dy–Dr5.51	Gleyed latosols, ferruginous tropical soils
		Umbraquults		Dg4.81, Dr5.81, Gn2.9	Meadow podzolic soils, humic gley soils
	Ochrults	Plintochrults		Gn2.41–2.61, locally Dr and Dy5.11	Gleyed latosols, ground-water laterites
		Typochrults	Orthic typochrults Umbric typochrults	Gn2.21–Gn2.11 Gn2.21	Red earths, latosols, red podzolic soils, ferrallitic soils
	Umbrults	Plintumbrults		Dy–Dr5.51, Dy5.61, locally Gn2.61	Ferruginous tropical soils, gleyed latosols Rubrozems
		Typumbrults		Gn2.21	Red earths, latosols, red podzolic soils, ferrallitic soils
Oxisols	Argox	Petrargox		Gn2.11–2.21	Red earths, latosols, red podzolic soils, ferruginous tropical soils

In addition, 537 sq miles (4·6% of the area) consists of lakes, of which Lake Murray is by far the largest.

(*b*) *Soil Classification*

The 7th Approximation, a comprehensive system of soil classification developed by the United States Soil Conservation Service (1960), has been used in classifying all soils except the oxisols, which have been classified according to Haantjens.*

The soils have been placed into 7 orders, 10 suborders (one undefined), 14 great groups (two undefined), 16 subgroups (9 undefined), and 52 families, as shown in Table 7.

Table 7 also gives the principal profile forms of Northcote (1965) and the corresponding major soil groups of the United States and Africa. Northcote's factual key is widely used in Australia; his principal profile forms are given here mainly to allow comparison between the soils of the Morehead–Kiunga area and similar soils of the previously surveyed Adelaide–Alligator (Story *et al.* 1969) and Mitchell–Normanby (Galloway, Gunn, and Story 1970) areas in Australia.

Each soil family has been given code letters followed by a number. The same code is used in the tabulated land systems to facilitate cross reference. The letters of the code are derived by taking the first, or in a few cases the second, letter of the order, suborder, great group, and subgroup (where these are defined) to which each family belongs.

The soils have been classified on the basis of field data only, and the 7th Approximation names are therefore used tentatively. In many cases the soils could not be fully identified with these names; newly coined names not occurring in the 7th Approximation are given in brackets.

A discussion on the use of the 7th Approximation based on field data has been given by Haantjens (1967).

II. Soil Descriptions

The soil descriptions are based on examinations of profiles by auger borings. Profiles were examined to depths of at least 48 in. Terms used to describe the drainage and soil reaction of the soils are those of Haantjens,† otherwise the descriptive terms used are those of the United States Department of Agriculture (1951).

All colours mentioned refer to moist soil conditions and are those defined in the Munsell colour charts. Dark topsoils are topsoils that have a chroma of 4·0 or less and a value of less than, or equal to, 3·5. Thick dark topsoils refer to soils having an A_1 horizon of $\geqslant 10$ in. thick.

Family descriptions are not complete in themselves and should always be read in conjunction with the descriptions of order, suborder, great group, and subgroup.

* Haantjens, H. A. (1965).—The classification of oxisols (latosols). CSIRO Aust. Div. Land Res. tech. Memo. 65/5 (unpublished).

† Haantjens, H. A. (1965).—Agricultural land classification for New Guinea land resources surveys. CSIRO Aust. Div. Land Res. tech. Memo 65/8 (unpublished).

(*a*) *Order Histosols* (H)

These are organic soils characterized by horizons at or near the surface (< 16 in.) which are more than 12 in. thick and have organic matter contents of at least 30%. They are subdivided into three families based on the degree of decomposition of the organic material. All soils are swampy.

H1 (5 obs.).—Fresh roots and peaty muck overlying wet very soft humic clay to silty clay loam. Soil reaction acid to weakly acid.

H2 (7 obs.).—Peaty muck, generally alternating with layers of loam, clay loam, and clay; peaty muck in places at least 7 ft thick. Soil reaction acid to strongly acid.

H3 (3 obs.).—Muck, commonly with alternate layers of humic silty clay and clay loam. Soil reaction acid to weakly acid.

(*b*) *Order Entisols* (E)

These are undifferentiated soils formed on Recent alluvial deposits. They show little or no profile development except for mottles and some accumulation of organic material.

(i) *Suborder Aquents* (EA).—Generally strongly gleyed entisols.

(1) *Great Group Hydraquents* (EAA).—Swampy soils; permanently wet, sticky; subdivided on soil reaction into four families.

EAA1 (12 obs.).—Silty clay loam, silty clay, and clay, locally covered with a veneer of fresh roots; soil reaction weakly acid to neutral.

EAA2 (6 obs.).—Clay and silty clay loam, commonly with alternate layers of humic clay loam and/or peaty muck; soil reaction acid to weakly acid.

EAA3 (3 obs.).—Clay and sandy clay; soil reaction strongly acid.

EAA4 (1 obs.).—Silty clay loam and silt loam; calcareous; soil reaction alkaline.

(2) *Great Group Haplaquents* (EAH).—Very poorly to poorly drained aquents; commonly wet and plastic; subsoil sticky.

(2*a*) *Subgroup Orthic Haplaquents* (EAHO).—Haplaquents showing little cracking when dry; subdivided on soil reaction into seven families.

EAHO1 (3 obs.).—Silty clay loam and silt loam; soil reaction neutral over weakly alkaline.

EAHO2 (8 obs.).—Silty clay, clay, and heavy clay; soil reaction weakly acid.

EAHO3 (8 obs.).—Silty clay loam, sandy clay, clay, and heavy clay; soil reaction acid.

EAHO4 (9 obs.).—Silty clay loam or clay loam merging into silty clay and clay to heavy clay; soil reaction strongly acid.

EAHO5 (2 obs.).—Clay loam and clay; soil reaction acid over alkaline (at depth >4 ft).

EAHO6 (2 obs.).—Silty clay loam and silty clay; weakly calcareous topsoils; soil reaction neutral to weakly alkaline over weakly acid.

EAHO7 (9 obs.).—Clay and heavy clay; commonly high organic matter contents in the topsoil; soil reaction acid over strongly acid.

(2*b*) *Subgroup (Vertic) Haplaquents* (EAHV).—Haplaquents which show pronounced cracking* when dry and commonly have slickensides; subdivided on soil reaction into four families.

* Maximum cracks encountered during the survey were about 1·5 in. wide and 8 in. deep.

EAHV1 (4 obs.).—Humic clay loam to clay merging into clay and heavy clay subsoil; this in turn merges lower down the profile into beach sand; subsoils saline and calcareous; contain frequently broken shell fragments; soil reaction weakly acid to neutral over alkaline.

EAHV2 (2 obs.).—Clay, often merging very gradually into beach sand at depth; subsoils weakly to strongly saline varying with distance from sea; calcareous throughout; frequently contain shell fragments; soil reaction alkaline to strongly alkaline.

EAHV3 (2 obs.).—Silty clay loam to silty clay merging at depth into clay; microrelief consisting of a polygonal pattern of gullies, approximately 7 in. deep and up to 1 ft wide; soil reaction acid over neutral.

EAHV4 (1 obs.).—Clay; soil reaction acid over weakly acid.

(2*c*) *Subgroup Thapto Albaqualfic Haplaquents* (EAHAt).—Haplaquents with buried profiles.

EAHAt (1 obs.).—Clay and sandy clay overlying silt loam which may be an old A_2 horizon; this in turn merges into a sandy clay subsoil; soil reaction acid over weakly acid.

(ii) *Suborder Udents* (EU).—Generally moist entisols that are not strongly or moderately gleyed.

(1) *Great Group Hapludents* (EUH).—Non-gleyed udents or udents with gleyed and/or mottled subsoils.

(1*a*) *Subgroup Orthic Hapludents* (EUHO).—Non-gleyed well-drained hapludents; subdivided on soil reaction and texture into two families; both friable to slightly plastic in consistence.

EUHO1 (3 obs.).—Sandy loam, loam, and silt loam passing downwards into clay loam and silty clay loam, or with a sandy loam and loamy sand subsoil; soil reaction weakly acid to neutral.

EUHO2 (1 obs.).—Silty clay loam overlying silty clay; soil reaction weakly acid.

(1*b*) *Subgroup Aquic Hapludents* (EUHA).— Hapludents with gleyed and mottled subsoils; imperfectly drained; subdivided on soil reaction into three families.

EUHA1 (4 obs.).—Silt loam and loam merging into a silty clay loam and locally sandy loam subsoil; calcareous throughout or only in the subsoil; consistence varies from friable to slightly plastic; soil reaction weakly alkaline to neutral over alkaline.

EUHA2 (5 obs.).—Clay loam, silty clay loam, silty clay, and clay to heavy clay; consistence either very friable or friable to plastic; soil reaction strongly acid or acid over strongly acid.

EUHA3 (3 obs.).—Silty clay loam and clay loam merging into clay; consistence friable to slightly plastic in topsoil, very sticky in the subsoil; soil reaction weakly acid.

(*c*) *Order Inceptisols* (I)

These are slightly to strongly developed soils with altered B horizons (cambic horizons) and/or acid to strongly acid thick (>10 in.) topsoils (umbric epipedons).

(i) *Suborder Aquepts* (IA).—Slightly developed moderately to strongly gleyed and mottled inceptisols.

(1) *Great Group Umbraquepts* (IAU).—Aquepts with acid to strongly acid thick (>10 in.) dark topsoils (umbric epipedons); subdivided on soil reaction into three families; all occur on Recent alluvial deposits.

IAU1 (14 obs.).—Clay loam or silty clay loam A_1 horizon overlies clay to heavy clay; poorly drained to swampy; consistence plastic to very plastic; soil reaction strongly acid.

IAU2 (3 obs.).—Clay loam or silty clay loam A_1 horizon overlies clay and heavy clay; very poorly drained to swampy; consistence firm to plastic; soil reaction acid.

IAU3 (2 obs.).—Clay loam or clay A_1 horizon merges into clay to heavy clay subsoil; imperfectly to poorly drained; consistence firm to plastic; soil reaction acid over weakly alkaline to alkaline.

(ii) *Suborder Ochrepts* (IO).—Non-gleyed well to imperfectly drained inceptisols; thick dark topsoils absent; altered B horizons (cambic horizons) present.

(1) *Great Group Eutrochrepts* (IOE).—Moderately developed well-drained alkaline ochrepts.

(1*a*) *Subgroup Orthic Eutrochrepts* (IOEO).—Eutrochrepts with calcareous subsoils.

IOEO (1 obs.).—Loamy fine sand merging into a slightly cemented yellowish brown fine to medium sand subsoil with many shell fragments.

(2) *Great Group Dystrochrepts* (IOD).—Moderately to strongly developed acid to strongly acid ochrepts; parent material Pleistocene alluvium.

(2*a*) *Subgroup Orthic Dystrochrepts* (IODO).—Moderately developed uniform-textured well-drained dystrochrepts; subdivided on texture into two families.

IODO1 (2 obs.).—Yellowish brown clay loams or silty clay loams.

IODO2 (2 obs.).—Yellowish brown to greyish brown loams.

(2*b*) *Subgroup Oxic Dystrochrepts* (IODX).—Strongly developed uniform-textured well-drained dystrochrepts; closely resemble oxisols but are less weathered; prominently mottled subsoils absent.

IODX (33 obs.).—Clay loam, clay, silty clay loam, or locally sandy clay loam; moderately developed, generally yellowish brown, topsoil merges into red- or brown-coloured subsoil; generally slightly higher clay content in subsoil; consistence friable to plastic.

(2*c*) *Subgroup* (*Plintoxic*) *Dystrochrepts* (IODP).—Strongly developed uniform-textured well-drained dystrochrepts; closely resemble oxisols but are less weathered; prominently mottled subsoils present.

IODP (3 obs.).—Similar to IODX family but prominently mottled horizon is present below a red and brown subsurface horizon.

(2*d*) *Subgroup Aquic Dystrochrepts* (IODA).—Moderately developed uniform-textured imperfectly drained dystrochrepts; grey mottled subsoils.

IODA1 (4 obs.).—Clay loam or loam.

(*d*) *Order Mollisols* (M)

These are slightly developed soils with weakly alkaline thick (>10 in.) dark topsoils (mollic epipedons).

(i) *Suborder Rendolls* (MR).—Mollisols with large amounts of calcareous material below the dark topsoil.

MR (1 obs.).—Dark brown loose sandy loam merging into a yellowish brown cemented beach sand subsoil which contains shell fragments and carbonate nodules; well drained; soil reaction weakly alkaline over alkaline to strongly alkaline.

(*e*) *Order Alfisols* (A)

These are moderately developed soils with textural B horizons (argillic horizons) having a minimum pH $> 5 \cdot 5$ and a coarser texture (at least one texture class). Surface horizons at least 5 in. thick.

(i) *Suborder Aqualfs* (AA).—Strongly gleyed and mottled alfisols.

(1) *Great Group Albaqualfs* (AAA).—Aqualfs with bleached A_2 horizons (albic horizons).

(1*a*) *Subgroup Orthic Albaqualfs* (AAAO).—Albaqualfs with light-coloured acid topsoils.

AAAO (1 obs.).—Friable silt loam and sandy loam merging into a plastic grey and yellowish brown mottled sandy clay subsoil with carbonate nodules; poorly drained; soil reaction acid over strongly alkaline; parent material Recent alluvium.

(1*b*) *Subgroup Mollic Albaqualfs* (AAAM).—Albaqualfs with dark acid topsoils.

AAAM (4 obs.).—Friable clay loam to locally silt loam, gradually merging into plastic grey, red, and brown mottled clay to sandy clay subsoil; imperfectly to poorly drained; soil reaction acid over neutral; pisolitic iron concretions common in the subsoils, and locally form up to 50% of the subsoil; parent material Recent alluvium(?).

(*f*) *Order Ultisols* (U)

These are moderately to strongly developed acid to strongly acid soils (maximum pH $5 \cdot 5$ in B horizon) with textural B horizons and coarser-textured (by at least one texture class) surface horizons over 5 in. thick.

(i) *Suborder Aquults* (UA).—Ultisols that are gleyed immediately below dark A_1 horizons.

(1) *Great Group Plintaquults* (UAP).—Strongly developed aquults with prominent red, grey, and brown mottles (plinthite) in the subsoil.

(1*a*) *Subgroup* (*Ochric*) *Plintaquults* (UAPO).—Plintaquults with light-coloured topsoils; subdivided on presence or absence of bleached A_2 horizons into two families; parent material Pleistocene alluvium.

UAPO1 (9 obs.).—Friable to very friable loam, clay loam, or sandy clay loam A_1 horizon merging into friable to firm clay to heavy clay B_2 horizon; imperfectly drained.

UAPO2 (20 obs.).—Very fine sandy loam to loamy sand or silt loam A_1 and A_2 horizons; A_2 horizon merges into a clay loam to clay B_2 horizon; B_2 horizon commonly contains pisolitic iron concretions, which locally make up more than 50% of the soil; generally poorly drained; consistence varies, but topsoils are mostly friable and subsoils mostly friable to plastic.

(1*b*) *Subgroup* (*Umbric*) *Plintaquults* (UAPU).—Plintaquults with thick (>10 in.) dark topsoils; subdivided on presence or absence of bleached A_2 horizons into two families; parent material Pleistocene alluvium.

UAPU1 (7 obs.).—Sandy loam A_1 horizon passing clearly into a bleached sandy loam to loam A_2 horizon and a clay loam to clay B_2 horizon; pisolitic iron concretions common in the subsoils and locally make up 50% of the soil; consistence friable; imperfectly to poorly drained.

UAPU2 (1 obs.).—Very friable silt loam passing downwards into a friable to firm clay; imperfectly drained.

(2) *Great Group Umbraquults* (UAU).—Aquults with thick (>10 in.) dark topsoils and lacking the bright mottling specified for the plintaquults.

UAU (5 obs.).—Humic clay loam to clay A_1 horizon passing abruptly into bleached A_2 horizon of sandy loam to sandy clay loam; this horizon overlies a mottled sandy clay to clay B_2 horizon; parent material alluvium; very poorly drained; friable topsoils and plastic to sticky subsoils.

(ii) *Suborder Ochrults* (UO).—Ultisols without thick dark topsoils and with no gleying immediately below the topsoil.

(1) *Great Group Plintochrults* (UOP).—Strongly developed ochrults with prominent red, grey, and brown mottles (plinthite) in the subsoil; subdivided on texture and colour of the topsoil into three families; well to locally imperfectly drained; parent material Pleistocene alluvium; pisolitic iron concretions common in the subsoils.

UOP1 (15 obs.).—Clearly developed generally dark brown to dark yellowish brown loam to clay loam topsoil merges into a brownish to reddish subsoil that becomes prominently mottled at depth; texture of the subsoil increases downwards from clay loam to clay or heavy clay; consistence friable to very friable.

UOP2 (19 obs.).—Similar to UOP1 family but a light-coloured generally yellowish brown topsoil is present.

UOP3 (13 obs.).—Dark to very dark greyish brown or brown very fine sandy loam, silt loam, or loam topsoil merging into a brown to yellowish brown silt loam, loam, or clay loam B_1 horizon, and a clay to clay loam B_2 horizon; pisolitic iron concretion content can be high; consistence very friable to friable.

(2) *Great Group Typochrults* (UOT).—Ochrults without the bright mottling specified for the plintochrults, and gravel contents (pisolitic iron) less than 30%.

(2*a*) *Subgroup Orthic Typochrults* (UOTO).—Typochrults with light-coloured topsoils; subdivided on textural differences into two families; well drained; parent material Pleistocene alluvium.

UOTO1 (21 obs.).—Very friable to friable loam to clay loam or locally silty clay loam topsoil merging into brown and/or red friable to plastic clay subsoil.

UOTO2 (4 obs.).—Very friable to loose fine sandy loam, loamy sand, or loam topsoil merging into brown and/or reddish friable silty clay loam, sandy clay loam, or clay loam subsoil; common pisolitic iron concretions.

(2*b*) *Subgroup Umbric Typochrults* (UOTU).—Typochrults with dark topsoils.

UOTU (4 obs.).—Fine sandy loam to loam topsoil merging into brown and/or reddish clay loam or silty clay loam subsoil; consistence friable to very friable; pisolitic iron concretions common in the subsoil.

(iii) *Suborder Umbrults* (UU).—Ultisols with thick dark topsoils and with no gleying at shallow depth.

(1) *Great Group Plintumbrults* (UUP).—Umbrults with prominent red, grey, and brown mottles in their subsoils; subdivided on texture into two families; well to locally imperfectly drained; parent material Pleistocene alluvium.

UUP1 (7 obs.).—Friable to very friable very fine sandy loam to loam A_1 horizon, commonly merging into friable clay loam to clay B_2 horizon; locally a brown loam to clay loam transitional horizon occurs between the A_1 and B_2 horizons; pisolitic iron concretions common, locally forming layers up to 6 in. thick with gravel contents of more than 40%.

UUP2 (6 obs.).—Friable to very friable loam or sandy clay loam A_1 horizon, generally overlying friable brown to red clay loam to clay and clay B_2 horizon; locally some of the mottles have hardened to concretions.

(2) *Great Group Typumbrults* (UUT).—Umbrults without the bright mottling specified for the plintumbrults (UUP).

UUT (6 obs.).—Sandy loam, silt loam, or loam A_1 horizon merging into reddish or brownish clay loam, sandy clay loam, or sandy clay B_2 horizon; consistence varies from very friable to plastic when moist to hard when dry; well drained; parent material Pleistocene alluvium.

(*g*) *Order Oxisols* (O)

These are strongly developed acid to strongly acid friable soils with no strong textural contrast or bleached A_2 horizons (albic horizons).

(i) *Suborder Argox* (OA).—Oxisols with finer-textured subsoils (argillic horizons).

(1) *Great Group Petrargox* (OAP).—Argox with a gravelly horizon at least 6 in. thick and containing 50% or more gravel.

(1*a*) *Subgroup* (*Ochric*) *Petrargox* (OAPO).—Petrargox with light-coloured topsoils.

OAPO (9 obs.).—Sandy loam to loam A_1 horizon passing clearly into a reddish or brownish loam B_1 horizon; this merges into red to reddish brown very gravelly loam to gravelly clay loam B_2 horizon; gravel consists mainly of pisolitic iron concretions up to 1 in. diameter, which are red, dusky red, or purple; soils are structureless; consistence very friable to loose; parent material Pleistocene alluvium; well drained.

(1*b*) *Subgroup* (*Mollic*) *Petrargox* (OAPM).—Petrargox with thick dark weakly acid topsoils.

OAPM (1 obs.).—Similar to the OAPO family but with a thick dark reddish brown topsoil.

III. Chemical Soil Fertility

About 150 soil samples from 60 soil profiles were collected during the survey. On these samples, soil reaction, nitrogen, potash, and available phosphate were determined. About 50 samples were also analysed for organic carbon. The analytical data are shown in Table 8.

Generally there is a good correlation between field and laboratory pH, although laboratory pH tends to be lower than the field pH in the pH range 4·0–5·0, and slightly higher in the pH range 7·5–8·5.

In the survey area there is a clear relationship between pH and available phosphate contents, especially in the strongly leached soils (ultisols and oxisols), where low pH values always correlate with very low available phosphate contents (<10 p.p.m.).

Potash contents vary from very low to high. Figures are moderate to high in relatively young soils (entisols, mollisols, and moderately developed inceptisols) but most of these soils are unlikely to be used for agricultural development because of other limiting factors such as drainage, flooding, and inundation. Potash values are mostly low to very low in the strongly leached soils (ultisols and oxisols).

TABLE 8

RANGES OF SOME CHEMICAL PROPERTIES FOR SOIL FAMILIES

Soil	pH H_2O	Organic C (%)	N (%)	Available P (p.p.m.)	Available K (m-equiv. %)
Histosols (H3)					
Organic horizon					
(0–6 in.)	4·9	—	0·73	25	0·15
(36–42 in.)	4·6	—	0·84	<10	0·07
Entisols					
EAA1					
Topsoil	6·0	4·05	0·24–0·39	67–134	0·65–0·79
Subsoil	6·9	0·52	0·12	54	0·82
EAA2					
Topsoil	5·0	—	0·95	51	0·73
Organic horizon	4·7	—	0·72	16	0·13
Subsoil	4·8	—	0·14	—	0·07
EAA3					
Topsoil	4·6	—	0·17	<10	0·23
Subsoil	4·7	0·66	0·10	<10	0·24
EAHO2					
Topsoil	5·3	1·87	0·23	48	0·90
Subsoil	6·1	—	0·11	40	1·03
EAHO4					
Topsoil	4·6	—	0·09–0·37	<10	0·10–0·36
Subsoil	4·3	—	0·03–0·36	<10	0·16–0·18
EAHO5					
Topsoil	5·1	—	0·18	<10	0·35
Subsoil	8·8	—	0·05	<10	0·73
EAHO7					
Topsoil	5·0	2·88	0·31	<10	1·50
Subsoil	4·8	—	0·13	<10	1·15
Deep subsoil	4·4	—	—	—	1·10
EAHV1					
Topsoil	6·7	—	0·24	<10	0·85
Subsoil	7·6	0·71	0·13	24	1·25
Deep subsoil	8·5	—	—	—	1·08
EUHO1					
Topsoil	6·1	0·90	0·11	117	0·67
EUHA1					
Topsoil	8·1	—	0·14	112	1·30

TABLE 8 (*Continued*)

Soil	pH H_2O	Organic C (%)	N (%)	Available P (p.p.m.)	Available K (m-equiv. %)
Inceptisols					
IAU1					
Topsoil	5·4	3·07	0·37	<10	2·11
Subsoil	5·3	—	0·16	<10	2·45
Deep subsoil	4·5	—	—	—	2·51
IODX					
Topsoil	4·4–5·1	1·82–2·96	0·18–0·28	<10	0·14–0·39
Subsoil	4·8–5·4	0·46–0·82	0·03–0·09	<10	0·05–0·24
Deep subsoil	4·9–5·1	—	—	—	—
Mollisols					
MR					
Topsoil	7·8	—	0·45	420	1·21
Subsoil	8·2	—	0·10	<10	0·80
Deep subsoil	8·5	—	—	—	—
Alfisols					
AAAO					
Topsoil (A_1)	4·3	0·81	0·09	<10	0·03
Topsoil (A_2)	6·2	—	0·03	<10	0·03
Subsoil	8·6	—	—	—	0·08
AAAM					
Topsoil (A_1)	4·8	—	0·12	<10	0·05
Topsoil (A_2)	5·5	—	0·04	—	0·06
Subsoil	6·5	—	0·05	<10	0·17
Ultisols					
UAPO1					
Topsoil	4·3–4·8	5·80	0·15–0·38	<10	0·16–0·20
Subsoil	4·6–4·9	—	0·05–0·14	<10	0·08–0·17
UAPO2					
Topsoil (A_1)	5·5	0·36	0·03	<10	0·04
Topsoil (A_2)	5·4	0·07	0·01	<10	0·06
Subsoil	5·0	—	0·01	—	0·16
UAU					
Topsoil (A_1)	4·5–5·2	3·58–4·71	0·40–0·58	<10	0·06–0·25
Topsoil (A_2)	4·8–5·3	0·12–0·18	0·03	<10	0·02–0·05
Subsoil	5·1	0·11	0·03	<10	0·215
UOP1					
Topsoil	4·4–5·0	2·88	0·21–0·34	<10	0·12–0·28
Subsoil	4·7–5·1	0·74	0·05–0·12	<10	0·10–0·18
Deep subsoil	5·0	—	—	—	—

TABLE 8 (*Continued*)

Soil	pH H_2O	Organic C (%)	N (%)	Available P (p.p.m.)	Available K (m-equiv. %)
Ultisols (*Continued*)					
UOP2					
Topsoil	4·3–5·0	1·22–2·06	0·14–0·20	<10	0·11–0·18
Subsoil	4·5–5·1	0·39	0·05–0·09	<10	0·09–0·15
Deep subsoil	4·9–5·0	—	—	—	0·11–0·29
UOTO1					
Topsoil	4·3–5·7	2·23–2·32	0·13–0·64	<10	0·11–0·63
Subsoil	4·6–5·1	0·66–1·33	0·04–0·61	<10	0·05–0·24
Deep subsoil	4·6–5·0	—	—	—	—
UOTO2					
Topsoil	5·3	1·21	0·10	<10	0·11
Subsoil	5·0	—	0·07	<10	0·08
Deep subsoil	5·0	—	—	—	—
UOTU					
Topsoil	5·3	—	0·27	<10	0·24
Subsoil	5·5	0·86	0·07	<10	0·08
Deep subsoil	5·8	—	—	—	—
UUP1					
Topsoil (A_{11})	4·6	2·03	0·18	<10	0·08
Topsoil (A_{12})	5·0	—	0·04	<10	0·02
Subsoil	5·0	—	0·03	—	0·04
UUP2					
Topsoil (A_{11})	4·9–5·3	2·15	0·23–0·45	<10	0·12–0·39
Topsoil (A_{12})	5·5	1·52	0·12	<10	0·06
Subsoil	5·4	—	0·03	—	0·04
UUT1					
Topsoil (A_{11})	5·1	2·20	0·20	<10	0·06
Topsoil (A_{12})	5·1	0·71	0·05	<10	0·03
Subsoil	4·9	—	0·02	—	0·06
Oxisols					
OAPO					
Topsoil	4·9–5·6	3·25–3·47	0·26–0·27	<10	0·11–0·20
Subsoil	5·1–5·5	1·07–1·42	0·09–0·13	<10	0·09–0·11
Deep subsoil	5·2–5·4	—	0·03–0·05	<10	0·05–0·14
OAPU					
Topsoil	6·4	1·58	0·15	<10	0·12
Subsoil	5·4	—	0·05	<10	0·06

Percentage nitrogen varies from very low to high. Generally there is little correlation between the different soil groups, although percentages are higher in soils with dark topsoils.

Organic carbon varies widely but is generally quite high, even in the undifferentiated alluvial soils (entisols).

Soils with low nitrogen, phosphate, and potash content occur in areas which otherwise appear to have the highest land use potential. Fertilizer applications will be necessary if these soils are to be used profitably. Soils with low pH could probably be improved by adding lime, especially for arable crops, and this would possibly increase the effectiveness of other fertilizer applications. Lime could be obtained from limestone outcrops occurring about 20 miles north of Kiunga.

IV. Soil Formation and Distribution

(a) General

The distribution of the great soil groups in the area is shown on the accompanying soil map at scale 1 : 1,000,000. The distribution of the soil families within the land systems of the area is given in Table 9. In the following sections the relationship between soils and environmental factors is discussed for each of the four major geographical regions.

Table 9

ESTIMATED DISTRIBUTION (%) OF SOIL FAMILIES IN THE LAND SYSTEMS

Soil Family	Coastal Plain				Flood-plains				Oriomo Plateau							Fly–Digoel Shelf				
	Wunji	Bula	Wando	Tonda	Fly	Alice	Obo	June	Morehead	Rouku	Mibini	Goe	Indorodoro	Suki	Boset	Avu	Moian	Miwa	Kiunga	Gasuke
H1			40		5		15	5												
H2							15							<5		5	8	<5	5	<5
H3							10								<5					
EAA1					35	35	40													
EAA2														<5?	<5			<5	<5	
EAA3								25												
EAA4	<5				<5															
EAHO1					15	<5														
EAHO2					20	60														
EAHO3																	7	<5	<5	<5
EAHO4			<5					70												
EAHO5					10															
EAHO6					10															
EAHO7			35	40					10											
EAHV1	50	40																		
EAHV2	35																			
EAHV3		15																		
EAHV4		30																		

TABLE 9 (*Continued*)

Soil Family	Coastal Plain				Flood-plains				Oriomo Plateau							Fly–Digoel Shelf				
	Wunji	Bula	Wando	Tonda	Fly	Alice	Obo	June	Morehead	Rouku	Mibini	Goe	Indorodoro	Suki	Boset	Avu	Moian	Miwa	Kiunga	Gasuke
EAHAt			< 5																	
EUHO1					< 5	< 5														
EUHO2																				< 5
EUHA1					< 5	< 5														
EUHA2							< 5										5	< 5	< 5	
EUHA3					< 5		< 5											< 5		
IAU1			10	60					10		10									
IAU2			10				10													
IAU3									< 5		5									
IOEO	5																			
IODO1																	10		< 5	25
IODO2													< 5							
IODX																30?	15	25	55	45
IODP																		5		
IODA													< 5							10
MR	5																			
AAAO											< 5									
AAAM		15									20									
UAPO1														15	35	30?		< 5		5
UAPO2									20		25	35	25	10?						
UAPU1												40	5							
UAPU2																		< 5		
UAU			< 5									5	< 5							
UOP1														60	25	10?	25	10		
UOP2														< 5	5	20?	< 5	15	< 5	
UOP3									60		25		30							
UOTO1																5	25	20	30	10
UOTO2											5		5		5					
UOTU												10	5	< 5						
UUP1											5	10	10		25					
UUP2																		10		
UUT													5					< 5		
OAPO										90			10							
OAPM										10										

(*b*) *The Coastal Plain*

On the coastal plain the soils have developed on Recent alluvial and marine sediments.

Very poorly to poorly drained strongly gleyed clays and silty clays (EAH), which are strongly alkaline near the coast and gradually change from neutral over alkaline to weakly acid over neutral inland, are found on the coastal flats, the swales between beach ridges, and the coastal back plain. During the wet season these soils are subject to inundation. They have impeded drainage and are associated with a vegetation of *Melaleuca* swamp forest and grassland with abundant sedges. These soils crack as they dry out, possibly because of relatively high contents of montmorillonite and swelling illite such as are known to be present in comparable soils in West Irian (van Es and van Schuylenborgh 1967). On the coastal flats and the swales the soils contain shell fragments. On the back plain soil profiles become more developed, and slightly finer-textured subsoils and pronounced red mottling indicate some degree of soil formation. One profile here showed a bleached A_2 horizon and a clearly finer-textured subsoil (AAA).

Alkaline sandy soils with weakly cemented shell accumulations in their subsoils (IOE) and locally with thick dark topsoils (MR) are found on the beach ridges which run roughly parallel to the coast. At increasing distance from the coast the soil profiles become more developed. Beach forest grows on the sandy well-drained ridges which are not subject to inundation.

Very poorly to poorly drained strongly gleyed non-cracking fine-textured soils with an acid to strongly acid reaction (EAH) occur under *Melaleuca* swamp forest on the flood-plains and in semi-permanent swamps. Flood-plains covered by *Imperata* grassland have similar soils but generally have thick dark topsoils (IAU). These soils (IAU) occur also under low swamp grassland in the seasonal swamps, especially along the Bensbach and Tarl Rivers.

Organic soils (H) formed in permanent swamps have mainly a tall sedge vegetation. Here plant residues have accumulated under conditions of permanent waterlogging.

(*c*) *Flood-plains of the Fly River and its Tributaries*

On the flood-plains of the Fly River and its tributaries the soils have developed on Recent alluvium.

Strongly gleyed swampy soils (EAA) and strongly gleyed poorly to very poorly drained soils (EAH) are dominant in this region which is mainly covered with swamp forest and swampy open rain forest. Along the flood-plains of the major rivers the soils are mainly weakly acid to neutral in reaction, except in the south-east where soils have weakly alkaline subsoils (at depths >4 ft). These alkaline subsoils are due to tidal influence up the Fly River, which is reflected in the vegetation by pure stands of *Sonneratia* and occurrence of *Sapium* in the open rain forest. Acid to strongly acid soils occur on the flood-plains of minor rivers. Soil texture on these flood-plains varies mainly from clay loam to clay, and the material is derived from the Fly–Digoel Shelf. Along the major rivers soils become generally finer-textured downstream and away from the river banks. They are locally weakly calcareous, especially in surface layers of recently deposited alluvium. The calcareous nature of some of the topsoils may be due to fragments of freshwater gastropod shells, as recorded in soils along the Digoel River in West Irian (Hekstra and Valette*), or to the presence of limestone detritus derived from outcrops to the north of the survey area.

Imperfectly to well-drained alluvial soils (EUH) occur very locally along the major rivers. These soils are mainly confined to levees, which become more pronounced along the Fly and Alice Rivers upstream from D'Albertis Junction.

Organic soils (H) are found locally on the flood-plains, but dominate together with strongly gleyed swampy soils (EAA) in the back swamps of major rivers. These soils are covered by *Melaleuca* swamp savannah and swamp grassland vegetation. Locally strongly gleyed very poorly drained soils with thick acid dark topsoils (IAU) are also found in the back swamps.

(*d*) *The Oriomo Plateau*

On the Oriomo Plateau most of the soils have developed on Pleistocene alluvium consisting of clay with minor silt and sand. The soils here are mainly acid to strongly acid with loamy topsoils and clayey subsoils. Commonly they contain variable amounts of pisolitic iron concretions in their subsoils.

The formation of these soils is probably influenced by the alternating wet and dry seasons of the monsoonal climate. During the dry season lower levels of soil moisture occur, and clay movement and redeposition take place in three main ways (United States Soil Conservation Service 1967). Firstly, the wetting of a dry soil favours clay dispersion; secondly, when the soil dries cracks form in which percolation of gravitational water, or water held with low tension, can take place; thirdly, the strong tendency for dry soil to take up moisture halts percolating water carrying clay particles by capillary withdrawal. Repetition of this process over long periods could lead to the formation of texture-contrast soils. Topographic influences are probably also important as similar types of soils have developed on the flatter parts of the Fly–Digoel Shelf.

Gleyed soils mainly with bleached A_2 horizons and prominently mottled subsoils (UAP) occur mainly on level ground that is inundated during the wet season. Most of these soils are poorly drained and covered with monsoon scrub or low mixed savannah.

Similar soils, but less gleyed and with a reddish to brownish transitional B_1 horizon (UOP), occur on slightly higher level or slightly sloping ground ($<1°$) not subject to inundation. These soils are mostly well to imperfectly drained, and this is reflected in their tall mixed savannah and monsoon forest vegetation. Locally they have acid to strongly acid thick dark topsoils (UUP), or reddish to brownish subsoils (UOT), or both (UUT).

Strongly developed friable red soils with loamy topsoils and slightly finer-textured subsoils which have very high contents of pisolitic iron concretions (OAP) occur mainly on the Morehead Ridge, the highest part of the Oriomo Plateau. These soils are well drained and deeply weathered with a mostly acid over strongly acid soil

* Hekstra, G., and Valette, J. (1961).—Verslag van een bodemkundige verkenning in het Digoel–Bian gebied. Agric. Res. Stn, Hollandia, West New Guinea (unpublished report).

reaction. They can be considered lateritic soils. Exposures in a well at Morehead Patrol Post showed that these soils are underlain by red and grey mottled clays that extend to a depth of at least 40 ft.

Strongly gleyed soils with finer-textured neutral to alkaline subsoils and bleached A_2 horizons (AAA) occur locally on the plateau. They consist mainly of silt loam and clay loam topsoils overlying clay to sandy clay subsoils. The subsoils commonly contain pisolitic iron concretions, and carbonate nodules occur locally. These soils have probably formed on Recent alluvium.

Other soils formed on Recent alluvium cover relatively small areas, and are found mainly along the rivers traversing the plateau and in narrow swampy valleys. These soils are strongly gleyed and have an acid to strongly acid reaction. They are swampy (EAA) to poorly drained (EAH). Similar soils, but with clearly developed acid thick dark topsoils (IAU), are also found locally.

Termite mounds (Plate 10, Fig. 1) form one of the characteristic features of the Oriomo Plateau. They occur mostly in areas covered with monsoon scrub and low mixed savannah. The mounds are columnar and up to 14 ft in height and are most probably built by the termite *Nasutitermes triodiae* (Froggatt) (F. J. Gay, personal communication). This termite has been recorded in the Northern Territory by M. A. J. Williams (personal communication), who has calculated that in some areas this species redistributes 0·19 ton per acre of soil per year. No data are available about the influence of termites on the soils in the area, but it can be assumed that they transport large amounts of fine material from the subsoil to the topsoil. In other areas covered by monsoon forest and tall mixed savannah are termite mounds which probably belong to a different species. These mounds are conical and up to 3½ ft in height.

(*e*) *The Fly–Digoel Shelf*

On the Fly–Digoel Shelf rainfall increases northwards and is about 125 in. at Pangoa (Lake Murray), which has a less pronounced dry season than the Oriomo Plateau, and about 180 in. evenly distributed throughout the year at Kiunga. Rain forest covers the greater part of the shelf.

The soils on the shelf are mainly red, deeply weathered, and leached, and have developed on Pleistocene sediments in an area characterized by slow rates of erosion compared with most other parts in New Guinea.

Soils that are uniform-textured and soils with finer-textured subsoils are found in this area. Both have acid to strongly acid soil reaction and mostly clay loam to clay textures. These soils occur in catenary sequence. On plateau and ridge crests commonly imperfectly drained soils with red and grey mottled subsoils occur (UOP and IODP). The soils on the slopes are always deep, red, and well drained (UOT and IODX). On the lower foot slopes and in the valleys locally derived alluvial material has been deposited, and here strongly gleyed alluvial soils (EAA and EAH) and/or organic soils (H) have formed under impeded drainage conditions.

The uniform-textured soils occur mostly in the "wetter" northern part of the shelf, where slopes become generally steeper and slope processes, such as slumping and gullying, are more evident than in other parts of the area (see Part V). Soils with yellowish brown B horizons (IODO) are common on the steepest slopes in the north-eastern part of the area.

The soils with finer-textured subsoils are more common in the south and south-west of the shelf, especially in areas with a "drier" season and a monsoon forest vegetation. Around Lake Murray these soils often have thick dark loamy topsoils (UUT). These topsoils are difficult to explain, but could possibly be due to bush fires which occur regularly in this area.

A small area of the shelf consists of a flat plateau surface. Here poorly to very poorly drained conditions exist, and soils with finer-textured strongly gleyed and mottled subsoils (UAPO) occur. This impeded drainage correlates with the presence of *Melaleuca* and some sago in the vegetation.

The soils on the Fly–Digoel Shelf in the survey area are similar to those described by Reynders (1964) near Tanahmerah, West Irian, on the same latitude as Kiunga. Reynders recognized two main types of soils in this area, namely "podzolized gley laterites" and "deeply podzolized latosols". In both types silica and aluminium ratios decrease with depth to the B_2 horizon and then increase in the deep subsoil. Clay minerals are mainly disordered kaolinite. The podzolized gley laterites have formed on undulating low plateau areas under impeded drainage and have distinctly finer-textured subsoils. These soils appear to be very similar to the soils with finer-textured and prominently red and grey mottled subsoils (UOP) occurring on the ridge crests and plateaux in the Morehead–Kiunga area. The deeply podzolized latosols described by Reynders occur on well-drained hilly areas, are uniform-textured, and are comparable to the red uniform-textured soils (IODX) occurring on hill slopes in the survey area.

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PART VII. VEGETATION, FOREST RESOURCES, AND ECOLOGY OF THE MOREHEAD–KIUNGA AREA

By K. PAIJMANS*

I. INTRODUCTION

(a) *General Remarks*

Two vegetation regions, determined by major climatic differences, can be distinguished in south-west Papua. These are the southern and the northern regions. The southern region has a strongly seasonal climate, and here the dominant vegetation types are savannah and monsoon forest which are comparable to those of northern Australia and also some parts of the Port Moresby–Kairuku (Heyligers 1965) and Kerema–Vailala (Paijmans 1969) survey areas of Papua. *Melaleuca*, represented by a number of species and varieties, is the characteristic tree of the southern area. Due to the commonness of *Melaleuca* and its associate *Tristania*, greyish green instead of green colours predominate in the foliage of the savannah vegetation. The northern region has a higher and more evenly distributed rainfall and here the prevailing vegetation is rain forest, mainly of Malayan origin and similar in type to that covering vast areas of New Guinea. The boundary between the rain forest vegetation and the savannah and monsoon forest vegetation roughly follows the Aramia River outside and to the east of the survey area, crosses the survey area in a north-westerly direction to reach the Fly River north of Boset, and from there turns west and south-west to reach the coast in West Irian some 50 miles north-west of Merauke (Fig. 2).

Apart from climate, topography and drainage play a part in determining the character of the vegetation. In contrast to New Guinea generally, where vegetation differences are related to differences in altitude of hundreds of feet, in the southern part of the survey area elevation differences of 1 or 2 ft determine the height and composition of the vegetation. Large areas are subject to prolonged inundation or at least waterlogging in the wet season and to semi-arid conditions during the dry. In consequence, vegetation types are relatively poor in structure and floristics. In the northern region the rain forest of the river flood-plains is poor and open because of frequent flooding, and that of the low hills is intersected by numerous strips of swamp forest and sago woodland situated along creeks and rivers.

Man's impact on the vegetation is most marked in the southern region, most of which suffers frequent burning. Here, fires lit by the local population every year destroy the ground cover in savannah and grass plain and often penetrate well into remnants of monsoon forest. Modifications of the vegetation through shifting cultivation are of minor importance as the population is very sparse throughout most of the area. The northern rain forest forms a virtually unbroken cover. Crocodiles

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and fish are caught and the staple diet sago is collected with negligible damage to the vegetation. However, secondary forest is fairly widespread near Kiunga, where the population is denser and conditions are more favourable for agriculture. Here the recent development of communal rubber plantations has required relatively large-scale clearing of forest.

Influence through grazing and trampling by the numerous deer and wallabies in the south must be considerable, but it is hard to assess as no areas are unaffected.

(b) *Previous Botanical Explorations*

Although remote and difficult of access, south-west Papua is reasonably well known botanically, largely due to the 1936–37 Archbold Expedition. Observations during this expedition were based partly on aerial reconnaissance flights and partly on ground trips made from collecting stations situated along the Fly River upstream from its mouth to the junction of Black and Palmer Rivers just north of the present survey area. Altogether, 2600 botanical numbers were collected and deposited in the Arnold Arboretum at Cambridge, Massachusetts, and duplicates were distributed to other herbaria. Publications resulting from the expedition include an account by Brass (1938), who gave a broad outline sketch of the vegetation of the territory visited and brief descriptions of the principal plant communities, and a more detailed report by Rand and Brass (1940) on the vegetation and environment of localities visited during the expedition. Various specialists have since worked on the identification of the plant material collected.

Van Royen (1963) explored and collected in West Irian in an area of similar climate, topography, and vegetation adjacent to the southern part of the survey area.

In 1960–61 the New Guinea Department of Forests (unpublished reports) carried out a botanical collection and a forest resources survey along the Oriomo River north of Daru, several miles east of the present survey area.

II. Vegetation and Major Environments

(a) *Littoral Environment*

Mangrove borders the coast in a narrow fringe which is unbroken except for a few patches of the usual beach vegetation consisting of herbaceous creepers, grasses, and sedges on small sandy stretches above high-water mark. Nearest the sea and subject to daily tidal flooding is a narrow strip of rather dense low *Rhizophora*. This is bordered further inland by *Avicennia–Ceriops* woodland which is probably inundated only by spring tides. Further inland still is a belt up to 6 miles wide consisting of mixed littoral woodland and forest, man-induced *Imperata* grassland, and tall *Melaleuca* forest. This belt is not subject to tidal flooding but part of it is inundated by fresh water during the wet season. The littoral environment has been mapped as Wunji land system.

(b) *Coastal Back Plain*

Depending on depth and duration of the wet-season inundation the vegetation is as follows: on temporarily dry ground (Bula land system), a low tussock-forming sedge–grassland, treeless or with scattered pandans (Plate 1, Figs. 1 and 2); in semi-permanent swamp (Bula land system), low open *Melaleuca* forest; in permanent swamp (Wando land system), a variety of swamp vegetation types ranging from submerged and floating aquatic vegetation to robust sedges and reed (Plate 3, Fig. 1); where the Morehead and Bensbach Rivers cross the coastal back plain their flood-plains (Tonda land system) are covered with *Melaleuca* forest and *Imperata* grassland (Plate 2, Fig. 2); the river banks are lined with mixed gallery woodland and *Nypa* palm occurs near the water's edge in brackish environments.

(*c*) *Plateau*

A mosaic of sedge–grassland, scrub, savannah, and forest covers the plateau between the coastal back plain to the south and the dissected country to the north. Here local drainage conditions are the main factor that determines the type of vegetation. However, the true relationship between habitat and vegetation type is often obscured by the annual burning which has impoverished the natural vegetation to a varying degree. Generally speaking the following holds true. An area adjacent to the coastal back plain, subject to prolonged inundation (Mibini land system), is covered with *Melaleuca* savannah. To the north, extensive level watershed areas that are subject to wet-season inundation or prolonged waterlogging (Goe land system) support poor low mixed savannah, *Sinoga* scrub, and low to mid-height grassland consisting mainly of perennial, often tussock-forming, sedges and grasses. On gently undulating terrain (Indorodoro land system) the vegetation consists of tall mixed savannah and "monsoon forest", a type of forest that is floristically and structurally poorer than rain forest. The creeks are lined with mixed woodland which has no connection with any particular land system.

(*d*) *Flood-plains*

The flood-plains of the middle and upper Bensbach, Tarl, and Wanggoe Rivers (Wando land system) and their main tributaries are covered with a dense mat of low grass. The habitat is under water for the larger part of the year. Reeds, sedges, and aquatic vegetation fill patches of permanent swamp. *Barringtonia* and *Melaleuca* trees, thinly scattered within the grassland, give the landscape a parkland aspect in the dry season (Plate 2, Fig. 1).

In the central part of the survey area wide stretches of reed, sedges, and grasses occupy the permanent and semi-permanent swamps on the flood-plains of the Fly and Strickland Rivers (Fly land system; Plate 4, Fig. 2). Their continuity is broken only by groups of *Livistona* palms and lines of waterlogged rain forest on old scroll ridges. Rather dense thin-stemmed low *Melaleuca* swamp savannah occurs in back swamps (Obo land system). Further upstream the river banks are higher and flooding is less severe, and here an open swampy type of rain forest becomes dominant (Alice land system; Plate 6, Fig. 2).

(*e*) *Lakes and Lagoons*

The normal sequence in lakes and lagoons is from open water through an inner fringe of floating and submerged water plants to an outer band of swamp grass with patches of *Hanguana*, *Phragmites*, and *Eleocharis*. Small stands of *Melaleuca* are found in shallow embayments which occasionally become dry. River entrances are often blocked by masses of "floating" grass and water-lilies (Plate 12). The grass mat continues a fair way upstream but gradually gives way to swamp forest as the level of the river flood-plain rises (June land system).

(*f*) *Hills*

The forests on the low ridges in the central part of the survey area (southern part of Miwa land system) form a gradation between the southern monsoon forest and the northern rain forest. The rain forest of the northern ridges is rather uniform in structure. A very thin-stemmed and dense type is characteristic of Gasuke land system in the extreme north, and occurs locally throughout Miwa, Moian, and Kiunga land systems. In many places the forests around the shores of Lake Murray are fire-damaged and near the lake's edge open out into a thin band of woodland with savannah trees. Narrow but extensive sago swamps line the numerous creeks within the rain forest.

III. Classification

(*a*) *Methods*

Mapping of vegetation and land systems was initially done from aerial photos, jointly with the geomorphologist, and has been put on a firmer basis by ground observations and helicopter reconnaissance flights.

The classification of the vegetation cover into major groups follows the principles set out in survey reports Nos. 14, 17, 20, and 23 (see list on back cover) and need not be reiterated here. Any subdivision into vegetation types is necessarily arbitrary as many grade into one another. For the purpose of this report 25 vegetation types have been distinguished; their structural and floristic features are described in the section that follows. In a monsoon climate, aspect and species dominance of the ground cover change with the season; descriptions of grassland and savannah refer to conditions met at the time of the survey.

Because of the small scale and poor quality of most of the air photography the rain forests have been classified mostly on topography. The main distinction is therefore between rain forest on flood-plains and rain forest on hills.

Tree volumes have been measured in sample plots, each of which covered one-third of an acre. Basal areas were measured in square metres per hectare using a *spiegelrelaskop* with wide scale (Bitterlich 1962). Some measurements were also made in non-forest vegetation types for purposes of comparison. Metric figures have been converted to square feet per acre. A tree-namer, Cappock, made available by the Department of Forests, Port Moresby, assisted in field identification.

Where plant names are listed in the text, unless stated otherwise the most frequent or commonest comes first. The term "frequent" refers to the proportion of the observations in which a given species was recorded in a given vegetation type; "commonness" refers to the number or density of individuals at an observation site.

A species is indicated by its specific name or by "sp."; when only the generic name is used it refers to the genus as a whole. Herbarium collection numbers are added in brackets where identifications are unavailable or uncertain. The letters P and Pj refer to specimens collected by Pullen and Paijmans respectively.

Herbarium material has been deposited and identified in the Herbarium Australiense, Canberra. The nomenclature of *Melaleuca* spp. follows Blake (1968). Wood samples have been identified by J. C. Saunders, forest botanist, CSIRO, Canberra, and by the Division of Forest Products, CSIRO, Melbourne.

(*b*) *Vegetation–Forest Resources Map*

The vegetation–forest resources map, at a scale of 1:1,000,000, is largely based on photo interpretation, and land system and vegetation boundaries generally coincide. Not all vegetation types described in the text are shown because of the small scale of the map. Only two types of grassland are shown: temporarily inundated low to mid-height sedge–grassland and *Imperata* grassland of Wunji, Bula, Tonda, and Mibini land systems; and low, mid-height, and tall swamp grasslands of Wando and Fly land systems. Both types include aquatic vegetation and other swamp vegetation. Areas of woodland have been combined with the corresponding forest, e.g. mixed woodland is included with littoral forest and monsoon forest, and mixed swamp woodland is included with mixed swamp forest. On the Oriomo Plateau the mosaic pattern of vegetation is shown as a mixture of monsoon forest and mainly tall mixed savannah (Indorodoro land system), as a mixture of monsoon scrub and mainly low mixed savannah (Goe land system), and as a mixture of monsoon forest, *Melaleuca* swamp forest, and *Melaleuca* swamp savannah (Suki land system). On the Fly and Strickland flood-plains swamp grass and open rain forest have been mapped separately only where one or the other is dominant (over 75%), otherwise they are shown as mixture. The boundary between monsoon and rain forest is mainly based on the presence or absence of *Acacia* spp. in ground observations. In the reference to the map, the vegetation types are arranged in order of description in the text, and mixtures of vegetation types and open water come last.

IV. Description of Vegetation Types

(*a*) *Mixed Herbaceous Vegetation*

(i) *Aquatic Vegetation*.—This is a community of floating and partly submerged water plants. *Azolla imbricata*, *Nymphaea* spp., *Nymphoides* spp., *Utricularia* spp., *Pistia stratiotes*, and small floating sedges are frequent and about equally common. The water plants form a mixture or a mosaic in which one or more species may predominate locally. In particular, *Azolla imbricata* and *Pistia stratiotes* each cover large areas that from the air show up as reddish brown patches in the case of *Azolla* and yellowish green patches in the case of *Pistia*. Some members of the community, e.g. *Ipomoea aquatica* and *Polygonum* sp., root in a mat of swamp grass and trail out over open water.

The habitat is the margin between open water and swamp grass in lakes, lagoons, oxbows, blocked channels, and slowly flowing rivers.

(*b*) *Grassland*

(i) *Low Swamp Grassland*.—This vegetation typically consists of a dense mat of almost pure creeping or trailing *Pseudoraphis* sp. (Pj 432) 4 to 8 in. high (Plate 2,

Fig. 1; Plate 3, Fig. 2). Other low grasses such as *Setaria* sp. and *Digitaria* sp. only very rarely form much of the sward. In places low sedges such as *Fimbristylis* spp. and *Rhynchospora rubra* are common. At the time of survey herbs were scarce, probably because of recent prolonged inundation or heavy grazing, or both. Herbs recorded include trailing *Aniseia martinicensis*, *Xyris* sp., *Philydrum lanuginosum*, and *Osbeckia chinensis*. Numerous tiny herb seedlings were visible in areas where the grass was less dense.

Also present are thinly scattered and low trees of *Dillenia alata*, *Barringtonia tetraptera*, *Nauclea orientalis*, *Melaleuca cajaputi*, and *M. viridiflora*, but shrubs are virtually absent. Scattered individuals of *Dillenia alata* occur throughout the community but are most common along the borders of the grass plains where they sometimes form a line marking the edge of slightly higher ground. *Leptospermum abnorme* and *Carallia brachiata* are other trees characteristic for this border environment.

The habitat is subject to prolonged inundation and comprises the flood-plains of the Bensbach, Tarl, and Wanggoe Rivers (Wando land system) and also narrow transition zones between permanent swamp and higher ground covered with *Melaleuca* forest, *Melaleuca* savannah, or monsoon woodland.

(ii) *Low to Mid-height Sedge–Grass Vegetation*.—This type consists of sedges and grasses 1–2½ ft high and is often strongly tussocky. Sedges and grasses occur in about equal proportions although either may dominate. The cover is variable and ranges from 40 to 100%. The most common grass in the coastal area is *Ischaemum barbatum*, most common elsewhere is *Eriachne triseta*. Other grasses present include species of *Eriachne*, *Dimeria*, *Eragrostis*, *Panicum*, and *Aristida*, and *Imperata cylindrica*. Among the sedges, species of *Schoenus* and *Rhynchospora* were recorded, and an unidentified sedge (Pj 428) is common in the coastal area. In places *Selaginella* sp. (P 7160) forms a low cover between the tussocks. At the time of survey a papery film of dried or drying algae covered bare patches.

Widely scattered low thin-stemmed trees, up to 50 ft high but mostly in the 15–30-ft range, occur locally. In some localities of the coastal area the only tree is *Pandanus* sp. (Pj 429), in places in sufficient numbers to lend the vegetation a savannah aspect (Plate 1, Fig. 2). Elsewhere *Melaleuca* spp., *Pandanus* sp., *Tristania suaveolens*, *Acacia leptocarpa*, and *Nauclea orientalis* are found.

Shrubs are low and scattered but occasionally grow in small dense groups up to 10 ft high. The most frequent shrub is *Melaleuca viridiflora*, while other species often present are *Pandanus* sp., *Melastoma polyanthum*, *Dillenia alata*, *Alstonia* sp. (P 7148), and in the coastal area *Melaleuca ?acacioides* (Pj 235) and *Melaleuca quinquenervia*.

Herbs vary in density but are usually moderately common. *Eriocaulon* spp. and *Utricularia ?flava* (P 7136) are always present.

Plains in Bula, Mibini, and Morehead land systems are the habitat for this vegetation type. They are subject to prolonged inundation, frequent burning, and heavy grazing.

(iii) *Mid-height Swamp Grassland.*—In water less than about 10 ft deep (at time of survey) species of the so-called floating grass community are able to secure a foothold. Where the transition to dry ground is rapid they occupy only a narrow zone, e.g. the inner edge of river banks. Where the water shallows very gradually they cover wide marginal areas of lakes and lagoons, filling shallow embayments, surrounding islets, and marking submerged levees (Plate 12, Fig. 1).

In relatively deep water *Echinochloa stagnina* forms a dense mat which rises 2–4 ft above the water level. *Oryza rufipogon*, *Leersia hexandra*, and *Hymenachne acutigluma* are always present and locally dominant. Small groups of *Hanguana malayana* occur within the grass mat and the conspicuous pink lotus *Nelumbo nucifera* is plentiful in places. Various floating and submerged aquatics line narrow channels and patches of open water.

In less deep water where the floor occasionally becomes dry, *Ischaemum polystachyum* is the dominant species, mixed or in mosaic with *Leersia hexandra*, *Oryza rufipogon*, *Phragmites karka*, and *Eleocharis dulcis*.

The habitat is permanently swampy margins of rivers, lakes, and lagoons in Obo land system.

(iv) *Mid-height Grassland.*—All mid-height grasslands sampled consist of dense pure *Imperata cylindrica* about 3 ft high. Owing to regular burning, trees, shrubs, and herbs are sparse and poor in species. Frequent trees are *Melaleuca cajaputi*, *Timonius*, *Alstonia actinophylla*, *Livistona* palm, and in the coastal area a low large-leaved *Corypha* palm (P 7025, 7026). Shrubs present include *Glochidion* spp., *Melastoma polyanthum*, *Barringtonia tetraptera*, *Alstonia spectabilis* (coastal), and *Alstonia* sp. (P 7148). Most herbs and also low sedges occur in depressions too soggy for *Imperata* and also in open patches where the grass has been flattened, trampled, and killed by deer. Numerous *Melaleuca* seedlings occur locally in these open patches but they will not survive the next fire. Other herbs such as *Osbeckia chinensis*, *Selaginella* sp., and the ferns *Helminthostachys zeylanica* and climbing *Lygodium* are found scattered throughout the grass.

Imperata grasslands are stable and are maintained by burning. Most of these grasslands are temporarily inundated. They occur on low-lying inland beach ridges in Wunji land system, on higher parts of the flood-plains of the Morehead and Bensbach Rivers (Tonda land system), and border swamps on minor marginal areas of Mibini and Miwa land systems (Plate 2, Fig. 2; Plate 3, Fig. 1; Plate 4, Fig. 2).

(v) *Tall Swamp Grassland.*—The tall grasses *Saccharum robustum*, *Coix lacryma-jobi*, and *Phragmites karka* form a mosaic or mixture, the proportions of which depend on frequency and duration of flooding. In mixtures growing on low levees and levee back slopes *Phragmites* is usually the tallest of the three (up to 15 ft) and *Coix* the lowest (7 ft). In the back swamps behind levees *Phragmites* increases in importance and usually dominates near the edge of open water. On higher levees subject to frequent but brief flooding *Saccharum robustum* commonly forms pure stands.

Widely scattered low trees of *Nauclea orientalis*, *Barringtonia tetraptera*, *Mitragyna speciosa*, and *Glochidion* sp. occur within the community. These are overgrown with climbers and many are dead or dying. Occasional shrubs include

Ficus and *Glochidion*. *Colocasia* sp. (P 7360) is one of the scarce herbs. A yellow-flowering twiner *Merremia* (P 7443) is conspicuous along river banks.

In back swamps a thick mat of coarse dead and live grass stems covers underlying muck. Adventitious roots sprout from the nodes of the ascending stems, they consist of numerous thin and thready rootlets and thicker roots which themselves also develop adventitious rootlets.

Tall swamp grassland characterizes the middle courses of the Fly and Strickland Rivers (Fly and Obo land systems).

(vi) *Tall Sedge–Grass Swamp Vegetation*.—Broad-leaved robust sedges up to 8 ft tall such as *Thoracostachyum sumatranum*, *Scleria poaeformis*, and (lower) *Cyperus platystylis* dominate over large areas. In places grasses and other sedges codominate, e.g. *Phragmites karka*, *Eleocharis* spp., *Lepironia articulata*, and *Leersia hexandra*. Shrubs of *Melaleuca* and *Acacia*, singly or in small climber-covered groups, grow on slight hummocks within the swamp. Low sedges and grasses, and herbs such as *Limnophila* and *Utricularia*, line the border of the sedge community. Floating *Azolla imbricata* and *Nymphaea indica* cover patches of open water.

The boundary with the surrounding vegetation, which is most commonly temporarily dry low sedge–grassland, is quite sharp and in the coastal region produces a peculiar and characteristic fern-leaf-shaped air-photo pattern.

The habitat is permanent, rather shallow, peaty swamp with standing water to a maximum depth of about 2 ft. The main occurrences are in Wando and Obo land systems (Plate 3, Fig. 1).

(*c*) *Scrub and Thicket*

(i) *Mangrove Scrub*.—Scrubby *Batis argillicola* averaging 1 ft in height and mixed with *Fimbristylis* (Pj 430) covers roundish patches several acres in extent within mangrove woodland. Scattered low shrubs of *Avicennia marina* increasing in height and numbers towards the periphery cause the type to grade into the surrounding mangrove woodland.

Mangrove scrub is considered to be an impoverished mangrove woodland, probably due to extreme salinity. It occurs in Wunji land system.

(ii) *Monsoon Scrub*.—In this type of scrub *Sinoga lysicephala* forms an open to moderately dense layer 2–3 ft high over a ground cover of sedges 1–2 ft high. Trees are absent or widely scattered, occasionally in small groups. The few species involved have thin crooked stems. They reach a maximum height of 40 ft and average 10–25 ft. Nearly always present are *Melaleuca cajaputi* and *Banksia dentata*; moderately frequent are *M. symphyocarpa* and *Grevillea glauca*.

Apart from the dominant *Sinoga* and bushy regeneration of the main tree species, the shrub layer commonly includes a hairy and strongly smelling variety of *M. cajaputi* (Pj 315), *Tristania suaveolens*, *Acacia leptocarpa*, *Alstonia* sp. (P 7148), and *Pandanus* sp.

The ground layer has a cover of 50–100%, average 80%, and is characterized by sedges although grasses are always present and occasionally form up to 50% of the cover. *Schoenus* sp. (P 7153) is commonly the dominant sedge, often with *S.*

calostachyus as codominant. Frequent grasses are *Eriachne triseta*, *Eragrostis* sp. (Pj 364, 323), and *Germainia capitata*. Some very low inconspicuous annuals filling in spaces between the sedge tussocks are *Ectrosia* sp. (P 7140), *Dimeria* sp. (P 7100, 7206), and *Isachne confusa*. A thin layer of dried or drying algae covers bare patches.

Generally herbs are moderately common. Many of the component species are ubiquitous. Of these, various species of *Drosera*, *Utricularia*, *Eriocaulon*, and a species of *Nepenthes* (P 7156) occur in fairly large numbers. Commonly present but less conspicuous are *Xyris* spp., *Leschenaultia filiformis*, *Thysanotus chinensis*, the semi-parasite *Cassytha filiformis*, *Haloragis*, and *Selaginella*. *Leptocarpus elatior* is locally dominant on wetter sites. Epiphytic *Dischidia* occurs in many tree crowns.

Monsoon scrub seems to occupy sites of poor to very poor drainage and is thought to be an edaphic climax which has been modified by fire. Towards the perimeter of such sites the scattered trees increase in number to form a low tree savannah which in turn gives way to higher savannah (Plate 10, Fig. 1). After it has been killed back by fire, *Sinoga* springs up afresh. At the few localities visited where the scrub had escaped burning for one or more years, the *Sinoga* had grown to form a dense thicket about 15 ft high, containing a few higher trees but with no ground layer.

Sandy plains with strongly impeded drainage mainly in Goe, but also in Indorodoro land system, are the habitat.

(iii) *Climber Thicket*.—This type consists of a densely tangled mass of climbers, shrubs, and tall herbaceous plants topped by scattered trees. In addition to rattan which is usually plentiful other frequent climbers are *Freycinetia*, *Stenochlaena* and other climbing ferns, *Cayratia* sp. (P 7338), *Mussaenda*, and Convolvulaceae.

The tree layer is very variable. It may consist of only sporadic climber-covered low thin-stemmed individuals of *Nauclea orientalis*, *Mitragyna speciosa*, and *Glochidion*, or may include scattered groups of rain-forest genera such as *Canarium*, *Terminalia*, *Dillenia*, *Alstonia*, *Chisocheton*, *Artocarpus*, *Ficus*, and *Endospermum*, growing to over 100 ft high. Within these groups buttresses, stilt roots, and adventitious roots most probably induced by prolonged inundation are conspicuous, and stems and lower branches of the trees are covered with ferny epiphytes.

The shrub layer is variable in density and its components have an irregular distribution. Apart from the ubiquitous climbers it consists of tall herbaceous plants such as *Phragmites*, gingers, Marantaceae and robust sedges, and shrubs, e.g. *Pandanus*, *Glochidion*, and *Leea*.

Low herbs are sparse or absent. Most frequent are Araceae, e.g. *Cyrtosperma* sp. (P 7324) and *Colocasia* sp. (P 7360), and *Polygonum* and ground ferns.

Near-permanent swamps in flood-plains of Fly land system form the habitat.

(*d*) *Woodland*

(i) *Mangrove Woodland*.—A belt of mangrove woodland up to 1 mile wide lies between a coastal fringe of *Rhizophora* forest and mixed littoral woodland further inland. It consists of fairly dense to scattered *Avicennia marina* up to 45 ft high and a lower storey of *Ceriops decandra* about 25 ft high. There is no ground layer, except for a nail-bed of *Avicennia* pneumatophores about 10 in. high. Inland the *Avicennia* trees become scattered, old, and wide-crowned, and some *Aegiceras* occurs below the *Ceriops*. Strips of dead or dying *Avicennia*, *Ceriops*, and occasionally *Rhizophora* occur in places.

The habitat, in Wunji land system, is probably flooded by spring tides only.

(ii) *Mixed Woodland*.—A number of variations of dry woodland occur in the southern and central parts of the survey area. All conform to a broad pattern that answers the following general description. The highest layer consists of trees up to 90 ft high, and is open to very open. Below this is an irregular but usually moderately dense tree layer between 45 and 70 ft high and a patchy shrub layer of about the same density. The ground layer is also patchy; it is usually very sparse but in places has a cover of up to 60%. It consists of grasses, sedges, seedlings, ferns, and occasional herbs. Tree girths are mainly small, rarely large, and the basal area averages 75 sq ft per acre. Thin woody climbers and epiphytes are common. Some local variations are discussed below.

A rather low type of mixed woodland with trees up to 75 ft high forms a narrow transition zone between mangrove woodland and littoral forest in Wunji land system. The commonest tree is the wide-crowned *Cathormion umbellatum*. Subordinate tree species include *Melaleuca cajaputi*, *Intsia bijuga*, *Heritiera littoralis*, and an unidentified sapotaceous tree which extends to within the adjoining mangrove woodland. Palms, e.g. *Livistona* and *Corypha*, are plentiful both within and below the canopy. Climbers are often thorny. *Glycosmis*, *Syzygium*, and *Randia* were noted in the shrub layer. Where the type occurs in swales it is probably subject to wet-season inundation.

Another type of coastal woodland occurs further inland in habitats which border permanent swamp and are briefly flooded in the wet season (margins of Mibini land system). Common among the high trees are *Linociera*, *Acacia*, *Melaleuca*, and *Cupaniopsis*. *Glochidion*, *Desmodium*, *Antidesma*, *Syzygium*, *Glycosmis*, *Psychotria*, and *Dracaena* are common in the shrub layer and some of these genera are locally abundant. A low grass, *Cyrtococcum*, is usually present in the herb layer.

Along creeks and river banks, gallery woodland, a denser and higher type of mixed woodland with emergents up to 115 ft, occurs. This variant is often referred to in literature as gallery forest, but is dealt with here under woodland because of its structural similarities with other types of woodland. Thin-stemmed bamboo is always present and locally forms a pure substorey about 15 ft high. The tree layers are floristically rich and commonly include a number of species from the surrounding savannah. Frequent are *Acacia aulacocarpa*, *A. mangium*, *Carallia brachiata*, *Syzygium*, *Halfordia*, *Mangifera*, *Calophyllum*, *Vitex ?quinata* (Pj 225), and Lauraceae. In areas of tidal influence *Heritiera littoralis* occurs in the woodland, and *Sonneratia caseolaris* with lanceolate leaves lines the river banks. In addition to bamboo, *Syzygium* and *Randia* are common shrubs and low trees, and *Cathormion umbellatum*, *Glycosmis* sp. (P 7055), *Maniltoa*, and *Barringtonia racemosa* become common towards the coast. The low grasses *Garnotia* and *Cyrtococcum* are common locally. Seen from the air, gallery woodland accentuates the pattern of creeks and drainage lines as it is denser, higher, and greener than the adjacent savannah (Plate 9, Fig. 2).

A type related to gallery woodland but much more open and irregular occurs as a narrow rim around lakes and lagoons, and as patches on low hills west of Boset in Suki land system. The tree layer consists mainly of species adapted to periodic flooding and also includes a few savannah species, e.g. *Acacia* spp., *Tristania suaveolens*, *Xanthostemon brassii*, and *Rhodamnia*. Around the shores of Lake Murray, trees and shrubs in many places are dead or dying because of fire damage; scattered clumps of bamboo occur locally, and the ground layer consists of grasses and sedges, and creepers and twiners such as *Hardenbergia retusa*, *Aniseia martinicensis*, and *Lygodium* fern. West of Boset bamboo locally forms a pure very dense substorey 20 ft high with no ground layer.

(iii) *Sago*-Campnosperma *Swamp Woodland.*—In this type scattered trees up to 145 ft high and with girths of well over 5 ft form an open storey over vigorous sago up to 45 ft high. *Campnosperma* is usually present, *C. brevipetiolata* being rather more frequent than *C. coriacea*. Associated tree genera are *Calophyllum*, *Lagerstroemia*, *Elaeocarpus*, *Vatica*, *Terminalia*, and *Nauclea*. *Melaleuca* does occur but is infrequent. Tree and shrub palms and pandans, fleshy climbers, climbing ferns, and epiphytes are common. Some trees have conspicuous stilt roots or knee roots.

Under dense sago there is virtually no shrub and herb layer. Where there is little or no sago the herb layer is usually quite dense, and so often is a shrub layer in which common plants are coarse sedges, e.g. *Rhynchospora corymbosa*, *Thoracostachyum sumatranum* and *Hypolytrum nemorum*, tall gingers, Marantaceae, and shrub pandans. The lower ground layer consists mainly of ferns and Araceae. The aquatic *Barclaya motleyi* is often found in running water.

Flat swampy valley bottoms in the hill land systems and peaty swamps in Obo land system are the habitat.

(iv) *Mixed Swamp Woodland.*—This type consists of thin-stemmed trees of variable density, up to 75 ft high, commonly 40–60 ft high, with a ground layer of scattered to dense tall sedge up to 8 ft high. There is no low herb layer. Stilt roots are very common and some trees have pneumatophores. The number of tree species is limited, and individuals of some species are plentiful in places. Tree species recorded include *Syzygium* spp. (P 7348, P 7349), *Barringtonia tetraptera*, *Nauclea orientalis*, *Vatica papuana*, *Garcinia* sp. (P 7404), *Carallia brachiata*, and *Dillenia alata*. The basal area probably averages about 100 sq ft per acre.

Mixed swamp woodland is common along small rivers of Moian land system. The habitat is permanently swampy and probably inundated for most of the year.

(*e*) *Savannah*

(i) Melaleuca *Swamp Savannah.*—This type consists of almost pure very thin-stemmed *Melaleuca*, 35–50 ft high, with a ground layer of mid-height to tall swamp grasses and sedges (Plate 8, Fig. 2). The cover of the *Melaleuca* varies between 20 and 60%, and apart from the dense ground layer the aspect is locally that of a low forest. Two species of *Melaleuca* are present, *M. cajaputi*, which is far more common, and *M. leucadendron*. Sparse associated trees include *Barringtonia tetraptera*, *Nauclea orientalis*, *Neonauclea* sp., *Mitragyna speciosa*, and *Erythrina fusca*. Rare sago occurs in the substorey. There is virtually no shrub layer.

In places the ground layer is dominated by *Phragmites karka* up to 13 ft high, and in other places by *Leersia hexandra*. Herbs are generally sparse although *Nelumbo* *nucifera* is common locally. Other herbs recorded are *Polygonum*, *Limnophila*, *Aniseia martinicensis*, and Araceae. Climbing *Stenochlaena* is abundant in places.

Back swamps in Obo land system are the habitat. At the time of survey (dry season) the four sites visited were 6–12 in. under water, but periodic burning is indicated by charred tree trunks.

(ii) Melaleuca *Savannah*.—In this type, thin-stemmed *Melaleuca* trees form a moderately dense to open canopy up to 65 ft high but mostly 25–45 ft high, with a ground layer of low to mid-height grasses and sedges 1–2½ ft high, occasionally up to 4 ft high. *M. viridiflora* is the dominant tree species, although *M. symphyocarpa* is codominant in places. Associated trees include *Tristania suaveolens*, *Acacia leptocarpa*, and *Dillenia alata*. Basal areas measured varied between 45 and 110 sq ft per acre.

Shrubs are usually very scarce, occasionally moderately dense. They consist of shrubby seedlings of the main and associated tree species, *Glochidion*, *Pandanus*, and some scattered *Sinoga lysicephala*.

The ground layer has a cover of 50–90%. Locally common grasses are *Arundinella nepalensis*, *Eriachne triseta*, *Ischaemum barbatum*, and *Germainia capitata*. There is often some thin poorly developed *Imperata cylindrica*, usually on slight rises. *Schoenus* spp. are the dominant sedges. Herbs are usually moderately common; the most frequent species are those listed under monsoon scrub, except for *Leschenaultia filiformis* and *Thysanotus chinensis* which were not found in the savannah, and *Philydrum lanuginosum* and *Nymphoides* sp. which occur on low-lying savannah sites and were not seen in monsoon scrub.

The habitat is subject to wet-season inundation, and the type is mainly found in Mibini and Morehead land systems (Plate 9, Fig. 2).

A peculiar type of *Melaleuca* savannah occurs on areas of flat level ground with strongly impeded drainage within Avu land system. It consists of an emergent storey of tall slender *Melaleuca* trees, lower storeys of mainly savannah species mixed with some rain forest species, *Casuarina papuana*, and sago, and a ground layer of mid-height grasses, sedges, and ferns. Numerous patches of similar photo aspect, i.e. a greyish very fine-grained pattern, show on air photos of Suki land system west of Lake Daviumbu. None of these could be visited on the ground but they are likely to be *Melaleuca* savannah too.

(iii) *Low Mixed Savannah*.—This type consists of irregularly distributed but generally moderately dense trees up to 85 ft high, average 45 ft high, over a mid-height occasionally low ground layer of grasses and sedges 1–4 ft high (Plate 10, Fig. 2). The number of tree species is rather limited. Always present and usually in large numbers are *Tristania suaveolens*, *Melaleuca symphyocarpa*, *Xanthostemon crenulatus*, *Grevillea glauca*, and *Banksia dentata*. Some of the moderately frequent associates are *Deplanchea tetraphylla*, *Melaleuca viridiflora*, *Eucalyptus polycarpa*, *Tristania longivalvis*, *Acacia* spp., *Dillenia alata*, *Parinari nonda*, and *Xanthostemon brassii*. *Eucalyptus polycarpa* and *Planchonia careya* are locally common around Suki Lagoon. Epiphytes are often present but usually inconspicuous. High climbers are absent or rare. Tree girths are mainly small and large girths are rare or absent. The stem form is poor. Basal areas ranged between 35 and 90 sq ft per acre and averaged 50 sq ft per acre.

The shrub layer is 3–10 ft high and is usually open. It is often patchy because of fire damage. Always present and normally plentiful are shrubs and low trees of *Acacia leptocarpa* and *Choriceras tricorne*. In addition to young individuals of the main tree species, the shrub layer in many places includes *Melastoma polyanthum*, *Rhodamnia*, *Acacia simsii* (locally dense), *Helicteres* sp. (P 7166), *Timonius*, *Glochidion*, *Sinoga lysicephala*, *Alstonia* sp. (P 7148), low *Pandanus*, and shrub palms.

The ground layer has a cover of 80–100%. Sedges are always common and both sedges and grasses are represented by many species. Always present are the grasses *Imperata cylindrica* (usually rather poorly developed) and *Pseudopogonatherum irritans*. Moderately frequent are *Germainia capitata* and *Eriachne squarrosa*. Many other grass species occur, some of which are locally dominant such as *Eragrostis* sp. (P 7152), *Ischaemum barbatum*, and *Eriachne pallescens*. The sedges are mainly represented by *Schoenus* spp., *Scleria* (in large, tall bunches), and *Rhynchospora rubra*.

Herbs and ferns are sparse. Always present are *Nepenthes* and *Dianella*. Other frequent species are *Borreria* sp. (P 7105), *Osbeckia chinensis*, *Phyllanthus simplex*, *Mitrasacme* spp., the low climber *Hardenbergia retusa*, and the semi-parasite *Cassytha filiformis*. *Selaginella* is moderately frequent. *Utricularia*, *Drosera*, and *Eriocaulon* are found in areas of very poor drainage. Low mixed savannah occurs mainly in Indorodoro land system but also in Goe and Mibini land systems. The habitat is inundated or waterlogged in the wet season and burnt in the dry.

(iv) *Tall Mixed Savannah*.—In this type the trees are up to 110 ft high and average 70 ft. They are scattered to moderately dense and have an irregular distribution. The ground layer consists mainly of mid-height grasses 3–4 ft high (Plate 11, Fig. 1). Sedges are rare to moderately common, occasionally common. The trees are mostly of small to moderate girth but unlike in the low mixed savannah some large-girthed trees are usually also present. The basal area ranges between 35 and 115 sq ft per acre and averages 80 sq ft per acre. As in low mixed savannah, epiphytes are often present and high climbers are rare. The most frequent and common trees are *Tristania suaveolens* and *Melaleuca cajaputi*. Frequent and moderately common associates are *Xanthostemon crenulatus*, *Acacia mangium*, *Melaleuca symphyocarpa*, and *M. leucadendron*. Some individuals of *Dillenia alata* are usually present.

The shrub layer is taller than in the low mixed savannah, being between 5 and 12 ft high, and is usually open. The composition is generally similar to that of low mixed savannah, although *Sinoga lysicephala* was not found, shrub palms and pandans are rare, and *Leea* and *Cordyline* are rather frequent.

The usually dense ground layer consists largely of *Imperata cylindrica*, often mixed with *Pseudopogonatherum irritans* or *Arundinella nepalensis*. *Setaria surgens* is common in places.

Herbs and ferns are sparse to moderately common. The herbs are more varied in composition than in low mixed savannah but the most frequent species are the same, except for *Nepenthes* which is uncommon in the tall mixed savannah. *Schizaea dichotoma* is a rather frequent ground fern.

Tall mixed savannah occurs on well to imperfectly drained sites which are not inundated in the wet season, mainly in Indorodoro, but also in Goe and Rouku land systems.

(*f*) *Forest*

(i) Melaleuca *Swamp Forest*.—This forest consists of almost pure stands of tall *Melaleuca* trees, up to 100 ft high, average 80 ft high (Plate 2, Fig. 2; Plate 3, Fig. 2). The canopy may vary from open to fairly dense but normally has a closure of 40–50 %. Regeneration is in groups in open patches. Trees of small girth are common and of medium girth moderately common. They rarely reach a girth of 5 ft and the forest is considered unproductive from the timber point of view. The basal area is very variable; in dense stands it may be as high as 200 sq ft per acre, well above the maximum basal area for monsoon and rain forest.

The main species is *Melaleuca cajaputi*. Other species or varieties of *Melaleuca* do occur and in one instance a stand of pure *M. leucadendron* was found. Some of the fairly frequent subordinate trees are *Dillenia alata*, *Barringtonia tetraptera*, *Acacia* spp., *Mangifera* sp. (P 7053), *Vitex ?quinata* (Pj 225), and *Nauclea orientalis*. *Dillenia alata* and *Vitex ?quinata* are markedly more common along the edges where the habitat borders higher ground. *Barringtonia tetraptera* is more common in depressions. *Acacia* spp. appear to prefer the less poorly drained sites. Tree palms (*Livistona*) are infrequent generally, but may be locally common. Climbers are rare generally, but in places the climbing fern *Stenochlaena* decks the tree trunks. Epiphytic orchids (*Dendrobium* spp.), *Dischidia*, and *Myrmecodia* are plentiful.

The shrub layer is very open or absent. *Canthium* sp. (Pj 311), a shrub or low tree, is locally common and so are patches of tall sedge on very poorly drained sites.

The ground layer is sparse or altogether absent. Density and type vary greatly with drainage conditions. Sedges are usually present. The most frequent grass is *Pseudoraphis*, varying in density from rare to very common. Other locally common grasses are *Sacciolepis indica*, *Ischaemum barbatum*, and *Arundinella nepalensis*. *Imperata cylindrica* occurs on slight rises. *Philydrum lanuginosum*, *Eriocaulon*, and *Hygrophila phlomoides* are herbs characteristic of very poorly drained sites, whilst *Azolla imbricata*, *Nymphoides*, *Blyxa*, and *Utricularia* are found in permanently swampy depressions.

Trees of *Melaleuca* may have masses of adventitious rootlets up to flood level (Plate 4, Fig. 1). Charred trees are common and most areas appear to be burnt regularly. The habitat is flooded in the wet season and ranges from almost permanently swampy to poorly drained. *Melaleuca* swamp forest is found along the middle and lower courses of the Morehead, Bensbach, and Wanggoe Rivers and their tributaries, mainly in Wando, but also in Mibini, Morehead, and Tonda land systems. The occurrence of this forest, much taller than *Melaleuca* savannah of the same land systems, is probably due to a more favourable nutrient status rather than the absence of moisture stress in the dry season.

(ii) *Mixed Swamp Forest*.—This is a mid-height to low thin-stemmed and usually dense type of forest. Emergents reach a height of 115 ft and the canopy averages 70 ft. Most tree crowns are in the canopy and lower strata are not normally discernible. As a rule stem forms are straight. The basal area averages 115 sq ft per acre.

Mangifera sp., *Carallia brachiata*, and *Vatica papuana* are nearly always present. In addition, the following species are frequent: *Calophyllum* sp., *Elaeocarpus* spp., *Nauclea orientalis, Barringtonia tetraptera, Mitragyna speciosa, Dillenia alata, Garcinia* sp. (P 7404), *Lagerstroemia ?speciosa* (P 7376, 7431), and *Syzygium* spp.

The shrub layer is very open and the herb layer virtually absent, probably because of prolonged flooding. In many places lianes and ferny climbers encase the individual tree trunks. The forest is very easy to walk through when not flooded because of the scarcity of low trees and shrubs, the absence of a ground layer, and the growing habit of the climbers.

Palms are usually absent from the canopy but can be moderately common below, and in the shrub layer. Rattan is absent or rare in dense forest, but common in patches where the canopy is open. Epiphytes are often rather plentiful in tree crowns and on trunks. Buttresses are not conspicuous but many trees are stilt rooted and some, for instance *Calophyllum* sp., have numerous pneumatophores. Adventitious roots often sprout from the base of trees, palms, and thick lianes.

Towards grass swamp the forest becomes lower and thinner stemmed and tall broad-leaved sedge is prominent in the undergrowth (Plate 8, Fig. 1). On drier ground hill forest species begin to occur but the general aspect of the forest does not change until the habitat is no longer subject to periodic flooding.

The habitat is probably flooded for most of the year. Mixed swamp forest occurs mainly on the flood-plains of minor rivers in the central part of the survey area (June land system) and also on old scroll ridges and low hill spurs within the grass swamps of Fly and Obo land systems.

(iii) *Littoral Forest*.—Both canopy and lower tree storeys of this forest type are rather dense. Emergents reach 120 ft and the canopy averages about 90 ft. The stem form is poor. The basal area is around 115 sq ft per acre.

The species composition is very mixed. *Melaleuca cajaputi* and *Acacia auriculiformis* are common emergent trees, the first particularly near the Bensbach River. In addition, the following trees were noted in the canopy: *Aleurites moluccana* and *Alstonia spectabilis* (both locally common), *Intsia, Dysoxylum, Ficus, Canarium*, and *Sterculia*. *Syzygium* spp. and Myristicaceae are conspicuous in the lower storeys.

The shrub layer is open and the herb layer very sparse. Climbers are moderately common to common and epiphytes are rare. Some of the large trees have very high buttresses. Palms, e.g. *Corypha* sp. (P 7025, 7026), are common in the shrub layer and lower tree storeys and some grow up into the canopy.

Littoral forest occurs on the old beach complex of Wunji land system. The pattern of low ridges and flats shows clearly from the air through differences in height, composition, and colour of the vegetation, although the terrain has a very low relief. At the time of survey some quite boggy areas were found on the inland side of the beach ridge complex, and the recurring photo pattern of emergent *Melaleuca* suggests that considerable portions are subject to periodic inundation. The occurrence of patches of grassland within the forest is attributed to human interference.

(iv) *Seral Forest*.—*Timonius* along the Fly River and *Althoffia* along the Strickland River form almost pure even-aged moderately to well-closed stands of seral forest on scrolls. The height is variable and is dependent on the age of the trees.

The ground layer consists of tall herbs and shrubs to 8 ft high, such as gingers, Marantaceae, pandans, *Leea*, and stinging *Laportea*. Low herbs are practically absent. Climbers, mostly fleshy, are common and rattan is abundant in open patches.

A dense young stand of *Nauclea orientalis* and *Mitragyna speciosa* was found pioneering in the mud of a recently cut-off meander of the Fly River near Kiunga (Plate 7, Fig. 1).

Older stands become mixed with an assortment of rain forest species of river flood-plains such as *Terminalia, Bischofia, Dysoxylum, Nauclea, Euodia, Canarium, Octomeles,* and *Artocarpus* which will eventually take over to form open rain forest.

(v) *Open Rain Forest*.—This type of forest occurs on low levees and flood-plains of the major rivers (Plate 4, Fig. 2; Plate 6, Fig. 2). It is irregular in structure throughout all layers. The very open canopy only occasionally reaches a cover of 50%. Emergents are up to 145 ft high and the canopy averages about 90 ft high. The stem form is poor. The basal area averages 85 sq ft per acre. The most frequent trees are *Terminalia complanata, Octomeles sumatrana,* and *Ficus* spp., the first two being especially frequent on levees. In addition, the rain forest genera that have been listed under seral forest are also commonly found in the open rain forest.

The shrub layer is variable in density but is usually open. The number of poles and saplings is small in comparison with the closed rain forest of the hills. Gingers and Marantaceae are locally plentiful and the tall sedge *Thoracostachyum sumatranum* is common on swampy sites.

The herb layer is absent or nearly so. When present it consists mainly of seedlings. In a few places grasses form a moderately dense cover.

Lianes, fleshy climbers, and rattan are very common and in many places where trees are scarce the vegetation approaches the type described as climber thicket. Epiphytes are often common in the tree crowns and are usually found along the trunks also. Palms were not seen to grow into the canopy but are fairly frequent in the substoreys and are very common in places in the shrub layer. Many trees are buttressed, some are stilt rooted and some have abundant adventitious roots up to the level of flooding. Not surprisingly, a number of tree genera of the open rain forest commonly occur in mixed swamp forest also, e.g. *Lagerstroemia, Mangifera,* and *Calophyllum* with pneumatophores.

A dense regrowth of ferns, gingers, Marantaceae, and fleshy climbers, with scattered trees of *Macaranga* and *Artocarpus*, mark the rare places where levees have been gardened in the past.

The habitat is very poorly to imperfectly drained and is subject to frequent and sudden flooding, on most sites probably of only short duration. The type occurs in Fly and Alice land systems.

(vi) *Closed Rain Forest*.—This is a forest of the hills. It has a moderately dense canopy of 50–60% cover and a height of 90–100 ft. Emergents reach 155 ft and have an average height of 125 ft. The lower tree strata are generally dense. As a rule boles are straight. The basal area varies from 75 to 150 sq ft per acre and averages 115 sq ft per acre. The most frequent tree genera are *Vatica, Lithocarpus, Canarium, Anisoptera, Hopea,* and *Syzygium*. A large number of other genera are moderately frequent, e.g. *Gironniera, Cryptocarya, Mastixiodendron, Calophyllum, Parinari, Schizomeria,* and the understorey trees *Baccaurea* and *Gnetum*.

The shrub layer is generally moderately dense. Its cover is 40% generally but varies between 20 and 60%. The very scanty ground cover is made up mostly of seedlings, ferns, mosses, and locally gregarious *Selaginella*.

Climbers, including rattan, are uncommon to moderately common. High palms growing up into the canopy are very frequent but usually occur in small numbers only. Palms are rare to moderately common in the lower tree storeys and are generally common in the shrub layer. Tree ferns are rare. *Cycas* is infrequent but locally moderately common.

Closed rain forest covers virtually all of the northern part of the survey area, i.e. Avu, Moian, Kiunga, and Gasuke land systems and the greater part of Miwa land system (Plate 11, Fig. 2). Minor structural variations are caused mainly by topographic differences. The high proportion of wide valleys in the lower parts of Moian and Kiunga land systems creates a generally damper environment, and here buttresses and stilt roots, tree ferns, and epiphytic mosses on lower tree trunks and surface roots are more common than in the higher parts under similar macroclimatic conditions. The forest in valleys generally has a more open canopy, more rattan, and a denser herb layer in which Araceae are conspicuous. *Pometia* is a frequent canopy tree.

The steep slopes of Gasuke land system support a dense thin-stemmed variety of rain forest with lower emergents (to 135 ft), a slightly lower canopy (80 ft), and a more open shrub layer. Trees rarely reach a girth of 5 ft, although the average basal area is similar to that of the closed rain forest elsewhere. *Vatica papuana* is the most common tree in all layers and in places almost dominates the forest. Dense thin-stemmed forest also occurs locally in the other hilly land systems where it could not be correlated with topography (Plate 13, Fig. 2).

(vii) *Monsoon Forest*.—This forest type has an open to moderately dense canopy with an average height of 75 ft. Emergents reach 130 ft and average 100 ft. The lower tree strata are dense. Boles are rather frequently branched and crooked. The basal area reaches a maximum of 130 sq ft per acre and averages 105 sq ft per acre. The most frequent trees are *Acacia* spp., *Tristania*, *Syzygium* spp., *Parinari*, *Mangifera*, and *Halfordia*. In addition, the following trees are moderately frequent: *Alstonia*, Lauraceae, *Xanthostemon*, *Rhodamnia*, *Choriceras*, *Melaleuca* spp., *Calophyllum*, *Flindersia*, and *Schizomeria*.

The shrub layer is moderately dense to open and the herb layer is very sparse, so that the forest is easy to walk through. Shrubs and trees are locally heavily damaged by fire, and in many of the open places a dense growth of tall gingers and secondary species has sprung up. Climbers are common to moderately common, but rattan is infrequent and uncommon. Epiphytes are not conspicuous and palms are absent or rare in the canopy. Leaves are predominantly small.

Monsoon forest is floristically related to savannah but is much richer in species. It contains all the tree species of the tall mixed savannah but has only few of the rain forest. Structural differences with rain forest are only minor, for instance, generally smaller leaf size, lower and rather more open canopy, more woody climbers but less fleshy climbers, rattan, epiphytes, palms, and pandans. Although the forest is of a dry type, deciduous trees, e.g. *Xanthostemon, Terminalia, Aleurites,* and *Sterculia* form only a small proportion of the total number.

Monsoon forest on the relatively high Morehead Ridge (Rouku land system) locally approaches rain forest in type. This is possibly because the ridge catches more rain, but a more likely cause is that the forest has not been burnt for a considerable time.

In a broad transition zone in Boset and the southern part of Miwa land system the monsoon forest grades into rain forest. This is shown floristically by the disappearance of characteristic savannah and monsoon forest genera such as *Acacia, Melaleuca, Tristania* (*T. suaveolens* and *T. longivalvis*; not *T. ferruginea* which is a rain forest species), *Halfordia, Xanthostemon, Rhodamnia,* and *Choriceras,* and the appearance or increasing commonness of Dipterocarpaceae, *Castanopsis, Lithocarpus,* and *Podocarpus.*

A striking feature of the forest west of Lake Daviumbu, and to a lesser extent also of that west of Boset, is a dense understorey of tall clump bamboo. In many places the bamboo is so dense that it excludes all other undergrowth, and locally the forest opens up to form bamboo woodland. Van Royen visited the area on the west side of the border and in his notes (1963) distinguishes a "bamboo belt" which he regards as a transitional stage between rain forest and savannah.

Monsoon forest occurs on well-drained, occasionally imperfectly drained, terrain in Indorodoro, Rouku, Boset, and Suki land systems and also forms local patches in Goe and Mibini land systems. Most of the villages in the southern part of the area are situated in monsoon forest and patches of secondary vegetation often rich in bamboo occur here.

V. Forest Resources

(*a*) *General*

Forest covers roughly 60% of the survey area. Scattered pockets and bands of monsoon forest in the south become denser northwards and grade into rain forest which forms a virtually unbroken cover over the northern part of the area.

No large-scale logging operations have been or are being carried out in the area. The Lake Murray Co-operative and some of the mission stations own small sawmills using trees such as *Calophyllum* and *Podocarpus* which are brought in by the population. The timber is used locally. A sawmill on the Oriomo River north of Daru, outside the survey area, has recently closed down.

During the survey 179 one-third-acre sample plots were measured in monsoon forest, in open rain forest, and in two varieties of closed rain forest. Closed rain forest type 1 comprises the forests of the lower hills where flat swampy valleys are common, and the thin-stemmed forest of Gasuke land system in the north. Closed rain forest type 2 occurs on higher terrain where there are few swampy valleys, and also differs from type 1 in having a greater number of large-crowned emergents. A list of trees occurring on the plots appears in Table 10 and estimated timber volumes

TABLE 10

TREES RECORDED ON SAMPLE PLOTS AND THEIR COMMONNESS OF OCCURRENCE

Occurrence of trees is listed as D (dominant, 50–80%); SD (subdominant, 20–50%); VC (very common, 15–20%); C (common, 10–15%); O (occasional, 5–10%); R (rare, <5%); ( ) (locally)

Botanical Name	Timber Quality Group*	Forest Type: Monsoon Forest	Open Rain Forest	Closed Rain Forest
Acacia aulacocarpa	4B	C		
Aglaia	3		R	R
Alstonia brassii	5			R
A. scholaris	5		R	R
Amoora	3			R
Anisoptera kostermansiana	4B	R		O(C)
Annesijoa novoguineensis	5			R
Anthocephalus	5		R	
Antiaris toxicaria	5			R
Bischofia javanica	4B		R(O)	
Blumeodendron	5			R
Buchanania	5	R	R	R
Calophyllum	4A	R(O)	R	O
Cananga odorata	5		R	
Canarium	4B	R	O	O
Castanopsis acuminatissima	5	R		R(C)
Ceratopetalum succirubrum	5			R
Chisocheton	5		R	R
Cordia	4B		R	R
Cryptocarya	5	R	R	O
Ctenolophon	5			R
Dillenia	4B	R	R	
Dracontomelum	1		R	R
Dysoxylum	4B		R(O)	R
Elaeocarpus	5	R	R(O)	R
Emmenosperma alphitonioides	5			R
Endospermum	5	R	R	R
Eucalyptopsis papuana	4A			R(O)
Euodia	5	R	R(O)	R
Ficus	5	R	O	R
Flindersia	3	O		R
Ganophyllum falcatum	5	R		R
Ganua orientalis	5			R
Garcinia	4B	R		R
Gironniera	5	R		R(O)
Gluta	5			R
Gmelina	3	R		
Gonystylus	5			R
Hibiscus	5			R
Homalium foetidum	4A			R
Hopea 1	4A	R(SD)		R(O)
Hopea 2	4A	R		R(C)
Horsfieldia	5			R
Ilex	5			R
Intsia bijuga	4A		R	

TABLE 10 (*Continued*)

Botanical Name	Timber Quality Group*	Forest Type: Monsoon Forest	Open Rain Forest	Closed Rain Forest
Ixonanthes	5			R
Kingiodendron	5		R	
Lagerstroemia	5		R	
Lithocarpus	4B	R		O(C)
Litsea	5	R		R
Lophopetalum	5			R
Mangifera	4B	O	R	
Maniltoa	5		R	
Mastixiodendron pachyclados	5			R(O)
M. cf. *stoddardii*	5			R(O)
Nauclea orientalis	4B		O	
Neonauclea	4A			R
?Neoscortechinia	5			R
Octomeles sumatrana	4B		O	
Opocunonia nymanii	5			R
Oreocallis brachycarpa	5	R		
Palaquium	3			R
Parastemon	5			R
Parinari corymbosa	5			O
P. nonda	5	O		
Pithecellobium	5			R
Planchonella	5			R
Podocarpus blumei	2B			R
P. neriifolia	2B			R
Polyalthia	5			R
Pometia tomentosa	4A			R
Pterocarpus indicus	3			R(O)
Schizomeria	5	O		O
Sloanea	4B	R		R
?Sloanea	4B	R		
?Stenocarpus	5	R		
Syzygium	4A	O		O
Terminalia	4B	R	O	R
Ternstroemia	5			R
Teysmanniodendron bogoriense	5			R
Trichadenia philippinensis	4B			R
Tristania ferruginea	4A			R(O)
Vatica papuana	4A	R	R	C(D)
Vavaea chalmersii	5		R	
Xanthophyllum papuanum	5			R
Unidentified				
(1) Leguminosae wood samples 57, 66, 84	5			R
(2) Sapotaceae herb P 7499	5			R
(3) Wood sample 90	5			R

*Timber quality groups are listed as 1 (high-quality veneer); 2 (conifers: A, *Araucaria*; B, other conifers); 3 (high-quality cabinet timber); 4 (construction timber: A can be used as cabinet timber; B, construction only); 5 (construction timber, not well known generally, requires treatment).

are compiled in Table 11. No figures are given for littoral forest, *Melaleuca* forest, and mixed swamp forest as these types are considered unproductive (stocking rate less than 3000 super ft per acre).

TABLE 11

ESTIMATED NUMBER OF STEMS AND VOLUME (SUPER FT/AC) BY TIMBER QUALITY GROUP AND GIRTH CLASS FOR EACH FOREST TYPE

Timber Quality Group	Girth Class (ft)	Forest Type: Monsoon Forest No.	Monsoon Forest Vol.	Open Rain Forest No.	Open Rain Forest Vol.	Closed Rain Forest, Type 1 No.	Closed Rain Forest, Type 1 Vol.	Closed Rain Forest, Type 2 No.	Closed Rain Forest, Type 2 Vol.
1	5–6	—	—	—	—	<1	22	<1	106
	7+	—	—	—	—	—	—	—	—
	5+	—	—	—	—	<1	22	<1	106
2B	5–6	—	—	—	—	<1	55	<1	120
	7+	—	—	—	—	—	—	—	—
	5+	—	—	—	—	<1	55	<1	120
3	5–6	<1	81	1	430	<1	314	<1	236
	7+	—	—	—	—	<1	226	<1	283
	5+	<1	81	1	430	<1	540	<1	519
4A	5–6	3	2259	<1	529	2	2152	3	3268
	7+	<1	451	—	—	<1	81	<1	848
	5+	3	2710	<1	529	3	2233	3	4116
4B	5–6	2	1607	3	2480	1	883	2	1475
	7+	<1	534	<1	1425	<1	372	1	1577
	5+	2	2141	3	3905	1	1255	3	3052
5	5–6	1	654	2	1500	2	1601	3	2374
	7+	<1	396	1	2521	<1	631	<1	651
	5+	1	1050	3	4021	2	2232	3	3025
1–5	5–6	6	4601	6	4939	6	5027	8	7579
	7+	1	1381	2	3947	<1	1310	1	3359
	5+	7	5982	8	8886	6	6337	9	10,938

A striking feature of the rain forest is the commonness of the dipterocarps *Vatica papuana*, *Anisoptera kostermansiana*, and two species of *Hopea*. They occur throughout the rain forest and also occur, though they are generally less common, in the monsoon forest. The forests around Boset are particularly rich in all three dipterocarps, and *Vatica* all but dominates the forests north and east of Kiunga. In addition to the dipterocarps, *Syzygium* spp. and *Parinari corymbosa* are common throughout. *Pterocarpus indicus* is locally common in the Kwina River area, along the Strickland River, and around Lake Murray. The most frequent trees in each forest type are given in the descriptions of vegetation types in the foregoing section.

Large-scale timber exploitation is an unattractive proposition because of the low overall timber volume, the long distance to the coast, and additional transport problems in the wet season.

(*b*) *Timber Volumes*

Timber volumes of all trees over 5 ft in girth at breast height have been calculated in super ft per acre using a tree volume table for mixed species in Papua–New Guinea. This table is in use with the Department of Forests. Figures apply to volume outside bark. No allowance has been made for internal defect.

Table 11 shows that volume figures are low, particularly in the better-quality timber classes, and that trees over 7 ft in girth are very scarce.

(i) *Monsoon Forest.*—The overall timber volume estimate, which is based on 19 sample plots, is 6000 super ft per acre from 7 trees per acre. In Indorodoro and Boset land systems the average volume is somewhat higher, and in Suki land system and the monsoonal part of Miwa land system somewhat lower than the average for monsoon forest. The total area of monsoon forest is approximately 1600 sq miles, made up of 500 sq miles in Boset and Miwa land systems, and about 500 and 600 sq miles in Suki and Indorodoro land systems respectively, where it occurs in mosaic with *Melaleuca* swamp forest and tall mixed savannah.

(ii) *Open Rain Forest.*—The overall timber volume estimate is based on 15 sample plots and is 8900 super ft per acre from 8 trees per acre. Four of the plots are in the rather denser forests of the Upper Fly, Alice, and Elevala River flood-plains, where the estimate is 12,500 super ft per acre from 10 trees per acre. Open rain forest, not including scattered patches within swamp grassland, covers an area of 293 sq miles.

(iii) *Closed Rain Forest Type 1.*—The timber volume estimate from 122 sample plots is 6300 super ft per acre from 6 trees per acre. On average less than 1 tree per acre has a girth of 7 ft or more. Type 1 is much more extensive than type 2 and covers 2810 sq miles, of which roughly 20% consists of unmappable lines of swamp forest and sago swamp.

(iv) *Closed Rain Forest Type 2.*—The timber volume estimate from 27 sample plots is 10,900 super ft per acre from 9 trees per acre. On average 1 tree per acre has a girth of 7 ft or over. This type generally occurs on the higher parts of the hills, well away from rivers and lakes; it covers 1148 sq miles.

VI. Ecology

It is convenient to deal separately with the ecology of the monsoonal environment, the rain-forest environment, and the river flood-plain, lake, and lagoon environment.

(*a*) *Monsoonal Environment*

(i) *Environmental Factors.*—The monsoonal climate with its marked wet and dry seasons is the main influence determining the type of vegetation in the south, although two other factors, drainage and burning, are also very important. On well-drained sites that have not been burnt, monsoon forest is considered to be the climatic climax. As has already been described it differs floristically and structurally from rain forest but approaches it on favourable sites.

If, as often happens, a fire from the surrounding savannah enters the forest, many shrubs and some fire-sensitive trees are killed. In the open spaces formed by burning, gingers, other tall herbs, and forest seedlings spring up, and without further burning the vegetation will return to forest. With frequent burning, grasses become established, increasing the fire hazard. Only species able to endure repeated burning will survive and they will eventually become predominant. In addition, species from the surrounding savannah will invade the forest, and tall mixed savannah, a fire-disclimax of monsoon forest, comes into being, equal in height to monsoon forest but much poorer in species (Plate 11, Fig. 1).

Where drainage is impeded because of impermeable subsoils, and run-off is insufficient through lack of relief, the terrain becomes waterlogged or inundated during the wet season. Such conditions are reflected in the vegetation by lower tree heights and smaller girths which are features of the low mixed savannah (Plate 10, Fig. 2). With longer inundation the vegetation becomes still lower and poorer in species and changes to a savannah with low thin-stemmed trees almost entirely of *Melaleuca viridiflora*, *M. symphyocarpa*, *Banksia dentata*, and *Grevillea glauca*. The extreme case is low sedge–grassland with only a scattering of these four tree species and with or without *Sinoga lysicephala* scrub (Plate 10, Fig. 1). Herbs of the genera *Drosera*, *Eriocaulon*, *Utricularia*, and *Leptocarpus* are indicative of prolonged waterlogging. Although water stress in the dry season will also adversely affect the vegetation, it seems likely that the decisive factors are the duration and depth of inundation in the wet season.

The severity and frequency of burning add to the impoverishment caused by impeded drainage and prevent recovery towards the true edaphic climax, thus obscuring the true relationships between the vegetation and the environment.

Imperata grassland occurs on sites that are either subject to short inundation or are well drained. It is stable, and is maintained by annual burning. The area of *Imperata* grassland will increase through burning but it is thought that in most cases it first develops on abandoned garden sites.

(ii) *Origin of the Vegetation*.—The monsoonal vegetation is like that of northern Australia, especially in physiognomy but also floristically. For instance, the same low thin-stemmed *Melaleuca viridiflora* savannah dominates large areas of seasonally inundated country in the Mitchell–Normanby area (Story 1970), the paperbark forest described in the Adelaide–Alligator area (Story 1969) is similar to *Melaleuca* swamp forest, and the *Tristania–Grevillea–Banksia* community occurring in the Katherine–Darwin area and described and depicted by Christian and Stewart (1953) is almost identical to the poorest form of low mixed savannah of the present survey area.

Rand and Brass's opinion (1940, p. 375) that most of the grasses, herbs, and shrubs may be regarded as Australian elements cannot be confirmed from the present survey's records. The majority of the monsoon species recorded occur in Malaysia or Asia as well, and they may be regarded as elements of Malaysian origin that have migrated to Australia during periods of land continuity. On the other hand, only a limited number of species are exclusively common to south Papua and northern Australia and have not been recorded elsewhere; examples are various species of *Melaleuca*, *Eucalyptus*, and *Acacia*, *Tristania suaveolens*, *T. longivalvis*, *Banksia dentata*, *Grevillea glauca*, *Choricerus tricorne*, *Dillenia alata*, *Alstonia actinophylla*, *Leschenaultia filiformis*, *Planchonia careya*, *Oreocallis brachycarpa*, *Leptospermum abnorme*, *Hardenbergia retusa*, and *Deplanchea tetraphylla*. Many of these species are very common or aspect-dominating in the savannahs of the southern part of the survey area, and they are probably Australian elements that have migrated northward. According to Burbidge (1960), northward migration of Australian elements has been less successful than southward migration of Malaysian elements, probably because of an ecological barrier consisting of dense tropical vegetation which may have existed in north and north-east Australia during the Pleistocene when the climate may have been wetter than at present. This barrier of tropical vegetation would have been a source of Malaysian species moving southward and would have inhibited penetration and northward movement of light-requiring Australian elements.

Only a few of the species occurring in both the southern part of the survey area and Malaysia have not been recorded in Australia. Examples are *Alstonia spectabilis*, *Mitragyna speciosa*, *Batis argillicola*, *Schoenus calostachyus*, *Ceriops decandra*, *Xanthostemon crenulatus*, *X. brassii*, *Hygrophila phlomoides*, and *Oryza officinalis*. It is self-evident that no record does not mean non-occurrence.

The poor representation of eucalypts in the survey area is rather surprising. The four species which have been recorded, *E. confertiflora*, *E. papuana*, *E. polycarpa*, and *E. tereticornis*, are only occasionally present and never abundant.

(*b*) *Rain-forest Environment*

In the north, a higher and more evenly distributed rainfall creates an environment suitable for rain forest. For instance, in the Kiunga–Atkamba area the "dry season" rainfall from May to October is only slightly less than half the annual total of 177 in. (5 years of records).

Frequent recordings of tree genera such as *Castanopsis*, *Lithocarpus*, and *Opocunonia*, and, in the far north, ericaceous epiphytes confirm Brass's finding (1938, p. 187) on the rain forest near Oroville Camp (now Kiunga), that "Excepting those of the flood-plains and lower ridges the forests are not truly lowland in character. At 100 m elevation or less many species occur that seem out of place on lowlands and in parts the general facies is that of mountain rain forest of at least the 1000 m contour". Brass (1938, p. 188) ascribes this to the fact that "Mountain forest climatic conditions, characterized by constant moisture, short daily periods of sunshine, and regular reduction of light by permeating mists and fogs are closely approximated in this lowland region". These conditions apply in the Kiunga–Atkamba region. *Castanopsis* and *Lithocarpus*, however, are widespread throughout the hill forest and were recorded as far south as Boset and the Herbert and Strickland Rivers, in monsoonal or near-monsoonal environment. Therefore, the conclusion of van Steenis (quoted by Brass 1938, p. 188) that "the establishment of mountain plants in the lowlands of Malaysia is mainly dependent upon an open vegetation and infertile, mostly acid-reacting soil" seems to be more generally applicable.

Sago–*Campnosperma* swamp woodland of the flat-bottomed creek valleys and mixed swamp forest along rivers and larger creeks are considered to be a more or less stable edaphic climax, rather than a succession to rain forest.

(*c*) *River Flood-plain, Lake, and Lagoon Environment*

The climate of the central region is semi-monsoonal. Pockets of *Melaleuca* swamp savannah are common in the Lake Murray area and reach northward along the Fly, June, Boi, and Kaim Rivers to about 6°40′S. Swamp savannah and swamp grassland are burned in the dry season, and monsoon species such as *Oreocallis brachycarpa* and *Xanthostemon brassii* were recorded as far north as the Binge River area.

The vegetation of the lakes and lagoons is clearly correlated with depth of water. Ten feet (at time of survey) was found to be the maximum depth at which rooting aquatics had established themselves. Lake Murray, sounded at a consistent depth of about 22 ft, has much open water, and aquatics and swamp grass occur only along the margins and in shallow embayments (Plate 12). Boset Lagoon and Lake Daviumbu are shallower and consequently have a lower percentage of open water without vegetation. Their narrow connections with the Fly River, lined on both sides with swamp grass, tend to close up and the Boset channel has to be kept open by the Mission. Suki Lagoon, shallower still, has very little open water and is all but choked by water weeds and swamp grass.

As the lagoon becomes shallower towards dry land various seral stages can be observed: from open water to floating and rooting aquatics and then to swamp grassland of *Echinochloa stagnina*, *Leersia hexandra*, and *Ischaemum polystachyum*, roughly in this order. *Melaleuca* swamp savannah occurs on temporarily dry ground, as either narrow strips along the edge of lagoons or small stands in shallow embayments (Plate 12, Fig. 2). Where a creek enters an embayment, *Melaleuca* swamp savannah gives way to low mixed swamp forest. *Melaleuca* and its associates *Nauclea orientalis*, *Barringtonia tetraptera*, and *Livistona* palm can endure near-permanent inundation by stagnant water. Species such as *Carallia brachiata*, *Garcinia* sp. (P 7404), *Mangifera* sp., *Syzygium* sp. (P 7463), and *Vitex ?quinata* (Pj 225) are somewhat less tolerant and seem to favour a habitat that is dry for at least part of the dry season. At higher levels a rim of woodland occurs which is characterized by tree species that are both fire-resistant and able to endure short inundation, such as *Acacia* spp., *Tristania suaveolens*, and *Xanthostemon brassii*. Clumps of bamboo which is also present at this level may have been planted by the local population.

As lakes and lagoons silt up, eventually becoming filled in by river sediments and organic matter, *Melaleuca* swamp savannah will probably gain ground, and mixed swamp forest or sago woodland may develop near running water. Tall swamp grassland is characteristic of the flood-plains of the middle Fly where these are subject to frequent severe and deep flooding, whereas *Melaleuca* swamp savannah occupies the back plains. These are as swampy as the flood-plains but are subject to a more gradual inundation by run-off water from the hills. This water becomes stagnant as it is impounded by the slow-draining grass swamps which have few outlets. Rand and Brass (1940, p. 374) regard this type, referred to as *Melaleuca* swamp forest, as successional to both savannah and rain forest. Here it is thought best to consider it as a virtually stable edaphic climax.

On slight rises and very low ridges, bands of open swamp woodland and swamp forest are found. When the flood-water recedes the terrain temporarily becomes dry. The vegetation is then often burnt and may degrade to *Ischaemum polystachyum–Leersia hexandra* swamp grassland.

Wherever the level of the flood-plain is slightly higher, a vegetation type referred to in this Part as climber thicket is often found. The type is considered to be a seral stage in the development, through woodland, towards open rain forest.

Tidal influence up the Fly River is evident from the vegetation as far north as Kwina River by the presence of *Sapium* in open rain forest and *Dolichandrone spathacea* and *Hibiscus tiliaceus* lining the banks of the Fly and Kwina Rivers. Downstream from Ellangowan Island all scrolls are pioneered by *Sonneratia caseolaris* with lanceolate leaves. Van Royen (1963, p. 218) found that in the Merauke area *Erythrina fusca* does not occur beyond the limit of tidal influence. Two recordings of the species in swamp forest along the Fly and Strickland Rivers, 14 and 6 miles north and north-east of Everill Junction respectively, indicate that it is not restricted to a brackish environment.

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PART VIII. POPULATION AND PRESENT AND POTENTIAL LAND USE OF THE MOREHEAD–KIUNGA AREA

By P. Bleeker*

I. Population and Present Land Use

(a) General

The area surveyed is one of the most lightly populated in Papua–New Guinea. The total population is 7200† and the population density averages just over 1 person per 2 sq miles. The population distribution by villages is indicated on the land use potential map accompanying this report.

The population is mainly centred in three areas which differ markedly in their physical environments, and hence in their land use; these are the area in the vicinity of Morehead and Weam, the area around Lake Murray and the middle Fly, and the environs of Kiunga. These areas are dealt with separately below.

(b) *Area in the Vicinity of Morehead and Weam*

The population in this area amounts to 2500 and is concentrated slightly to the south of the centre of the Oriomo Plateau. Outside the main area are two minor centres, one to the north-east where three large villages with a total population of 790 are situated around Suki Lagoon, and another smaller one along the coast on the higher parts of the coastal plain, where there are three villages with a total population of 210.

The population subsists mainly on the products of their gardens supplemented by the yields from fishing and hunting. The staple diet is yam (*Dioscorea* sp.). Other food items grown are taro (*Colocasia esculenta*), cassava (*Manihot esculentus*), sweet potato (*Ipomoea batatas*), sugar-cane (*Saccharum officinarum*), banana (*Musa sapientum*), and papaw (*Carica papaya*) (Williams 1936), and introduced fruits such as pineapples, tomatoes, and water-melons. Each village has its own coconut palms. Most of the gardens are found on well-drained land of Rouku and Indorodoro land systems, although in places, as near Weam, they also occur on alluvial flats.

(c) *Area around Lake Murray and the Middle Fly*

About half of the total population of 2600 in this area lives around Lake Murray and the other half lives along the middle Fly. Both populations subsist mainly on sago (*Metroxylon sagu*) growing in the numerous swampy valleys of Miwa,

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† Source: Annual village census data (1966–67) supplied by Department of District Administration, Daru.

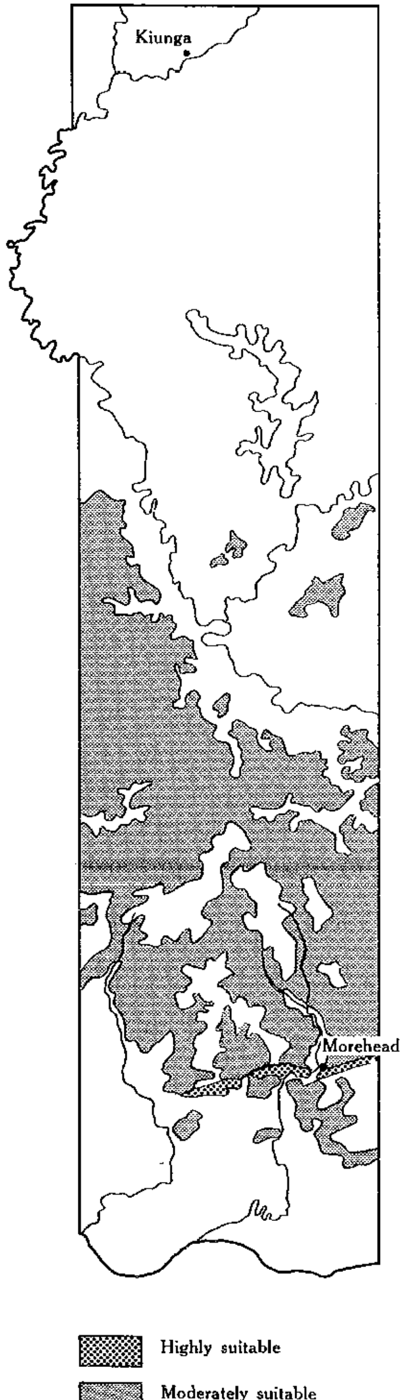

Fig. 10.—Distribution of areas highly and moderately suitable for arable crops.

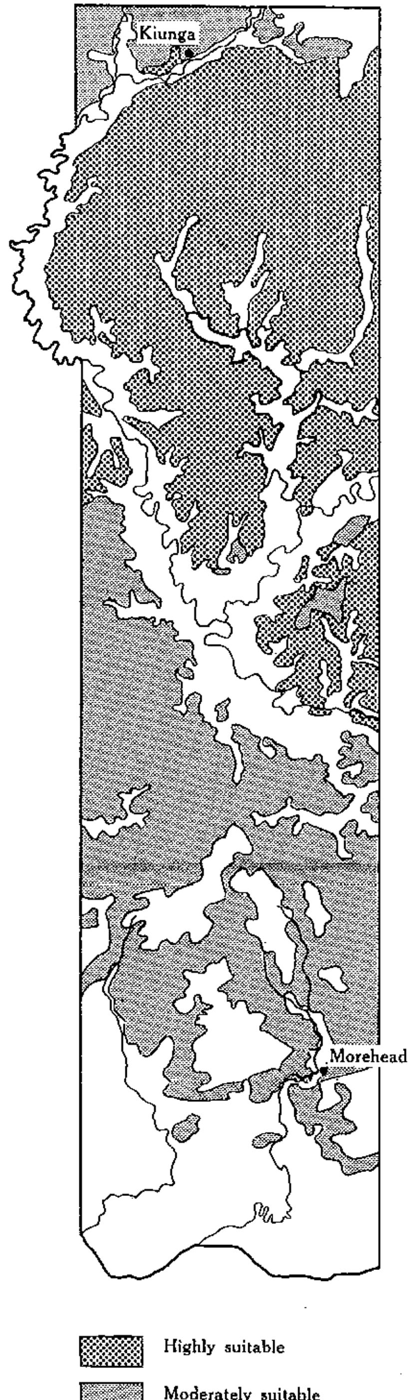

Fig. 11.—Distribution of areas highly and moderately suitable for tree crops.

Moian, and Boset land systems. The diet is supplemented by fish, crocodile meat, and some garden produce. Cash income is derived from the sale of crocodile skins.

(*d*) *Environs of Kiunga*

The population in this region totals 2100 and lives in villages situated on low ridges near the main rivers. People subsist chiefly on sago and garden produce. The most important food crops grown are taro, sweet potato, and banana. Cultivation takes place mainly on the low ridges of Miwa and Kiunga land systems but is also carried out on the alluvial plains of Alice land system.

Currently, a programme of rubber planting is being undertaken by villages on the Fly–Digoel Shelf under the direction of the Department of Agriculture. The programme has involved some village resettlement.

II. Agricultural Land Use Capability

(*a*) *General*

The land use capability of the area is discussed here in relation to arable crops, tree crops, improved pastures, and irrigated rice. The capability for each of these four types of land use has been rated in classes: 1, very high; 2, high; 3, moderate; 4, low; 5,very low; and 6, nil.

The classification used follows Haantjens (unpublished data, 1965*). Twelve characteristics that may limit agricultural land use (see Appendix I) were recorded at each field observation site. From these data and an assessment of possible climatic limitations, the capability class for each land system was obtained for the four types of land use considered. The distribution of the capability classes is shown on the land use capability map and in Figures 10–13, which give the distribution of the high and moderate classes for arable crops, tree crops, improved pastures, and irrigated rice respectively. The approximate areas of land in each class are presented in Table 12.

The nutrient status of the soils is expressed in terms of nitrogen, available phosphate, and potassium contents, each of which has been grouped into classes (see Appendix II). These classes are based on analytical data obtained from New Guinea surveys during the last 15 years.

(*b*) *Potential for Arable Crops*

A total of 55 sq miles is considered highly suitable for arable crops and a further 2900 sq miles is considered moderately suitable.

The area with a high suitability is Rouku land system which forms the highest part of the Oriomo Plateau and has slopes of mostly less than 2°. Soils are red, deeply weathered, well drained, and gravelly. Limiting factors are acid to strongly acid soils which generally have a low nutrient status especially in available phosphate and potash, slight erosion hazards on slopes greater than 2°, and probably drought stress. The low nutrient status of the soils could be improved by fertilizers. Drought

* CSIRO Aust. Div. Land Res. tech. Memo. No. 65/8 (unpublished).

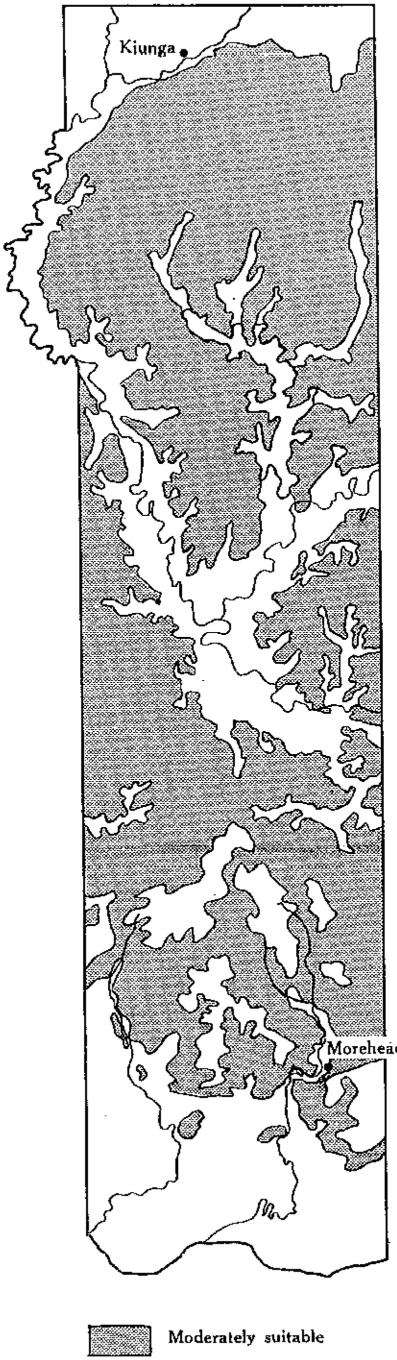

Fig. 12.—Distribution of areas moderately suitable for improved pastures.

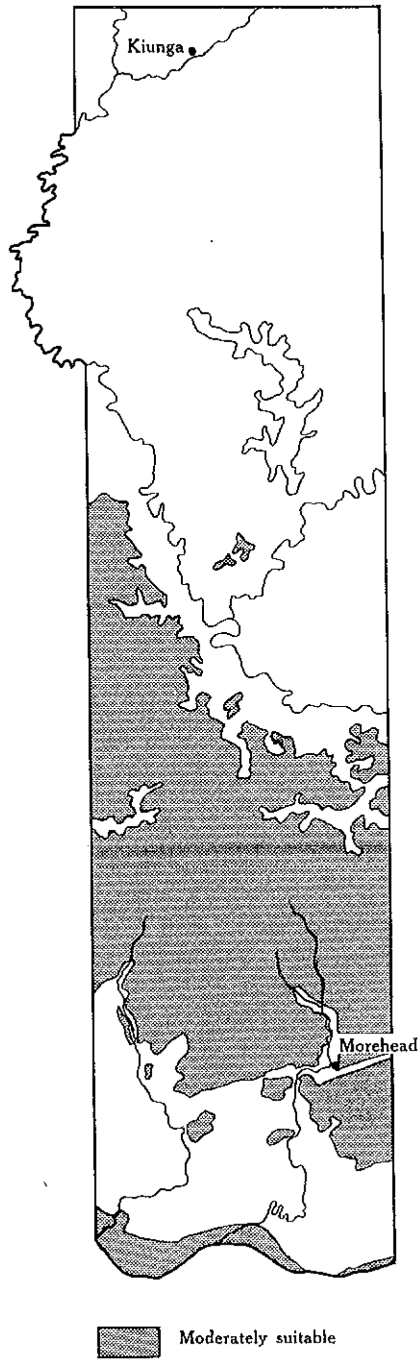

Fig. 13.—Distribution of areas moderately suitable for irrigated rice.

stress is likely to occur in the period of low rainfall between June and November, and will influence the choice of crops.

TABLE 12

AREAS OF LAND SUITABILITY CLASSES (SQ MILES) FOR FOUR TYPES OF AGRICULTURAL USE

Suitability Class	Arable Crops	Tree Crops	Improved Pastures	Irrigated Rice
2 (High)*	55	3610	—	—
3 (Moderate)	2900	3270	6560	3610
4 (Low)	4540	885	1880	1130
5 (Very low)	935	615	480	1235
6 (Nil)	2790	2840	2300	5245
Total†	11,220	11,220	11,220	11,220

* No land systems are rated in suitability class 1 (very high).

† Lakes cover an area of approximately 540 sq miles.

Of the 2900 sq miles with a moderate capability for arable crops, 2850 sq miles occur on the northern part of the Oriomo Plateau in Boset, Suki, and Indorodoro land systems, and the remaining 50 sq miles occur east of the Strickland River in Avu land system. Both areas consist mainly of slightly undulating terrain with slopes less than 3°. Limitations are acidity and low nutrient status of the soils, imperfect to poor drainage on plains and valley bottoms, and slight erosion hazards on slopes greater than 3°. Because of higher rainfall, drought risk will be less than in Rouku land system.

(c) Potential for Tree Crops

Approximately 3610 sq miles of the area have a high capability for tree crops and a further 3270 sq miles have a moderate capability.

Areas with a high capability occur on the intricately dissected plateau of the Fly–Digoel Shelf in Moian and Miwa land systems. Characteristic slopes here are 5–8°. The main limitation is strongly leached acid to strongly acid soils with a low to very low nutrient status. Erosion hazards affect tree crops to a lesser extent than arable crops, and slopes of up to 8° are not limiting. Climate may also be a limitation for tree crops, as records taken over a period of three years at Pangoa (Lake Murray) showed that rainfall in the dry season (June–November) ranged from 3·74 in. in 1965 to 54·91 in. in 1966. However, it appears that these years were very dry and very wet respectively. Soil moisture storage capacities in this area, as calculated from soil textures, appear to be moderate to high but drought risks are likely to occur during a dry season such as occurred in 1965.

North of Lake Murray rainfall becomes more evenly distributed, and it is this part of the area that is particularly suitable for the establishment of tree crops. A beginning has already been made with the establishment of rubber plantations, and by October 1967 310 acres of high-yielding rubber, mainly from seeds imported from Malaya, had been planted, mostly near Kiunga.

Oil palm might also be considered for planting. In Malaya the highest yields from oil palm are obtained in areas with an evenly distributed rainfall of 80–120 in. (Mendham 1967). However, on most soils oil palm can also withstand three months with a minimum monthly rainfall of 2–3 in. Oil palm also requires more than 2000 hours of sunshine per year (Mendham 1967) and this could be a limitation in the northern part of the Fly–Digoel Shelf. Tanahmerah, on the same latitude as Kiunga, has a mean annual total of 1639 hours of sunshine and has very low mean monthly totals from June to September (Table 5). However, in the vicinity of Lake Murray cloudiness can be expected to be less, and sunshine hours higher, than at Tanahmerah. Oil palm does not seem to be as exacting in respect of physical properties of the soil, chemical fertility, and topography. It does, however, require ample rooting depth, but this would not be a limiting factor in most of the soils of the Fly–Digoel Shelf.

Areas moderately suitable for tree crops occur in the most northern part of the area in Kiunga land system, further south in Avu land system, and on the Oriomo Plateau. In Kiunga land system limitations are similar to those of Miwa and Moian land systems, but slopes are generally steeper and erosion hazards consequently greater. In Avu land system soils are mostly similar to those of Miwa land system, but the larger percentage of imperfectly and poorly drained soils lowers the suitability for tree crops by one class.

On the Oriomo Plateau, Rouku, Suki, Boset, and Indorodoro land systems all have a moderate capability for tree crops. Limitations here are as for arable crops, discussed earlier. Drought risks make this area less suitable for tree crops such as rubber and oil palm, but conditions here might favour the growing of teak. According to Troup (1921), teak thrives best in areas with annual rainfalls ranging from 50 to 120 in. Also it requires well-drained sites and will not endure soils that are liable to inundation and waterlogging. This agrees with experience obtained in the Brown River area some 25 miles north-east of Port Moresby, where teak planted on alluvial soils with impeded drainage was subject to root rot (Levingston 1967). The best results have been obtained on well-drained alluvial soils, while lateritic soils such as occur in Rouku land system are generally considered unsuitable (Puri 1960). Soils of Suki, Boset, and Indorodoro land systems are mainly well to imperfectly drained with slowly permeable red and grey mottled subsoils at depths over 20 in. and hence are probably only moderately suitable for teak.

(*d*) *Potential for Improved Pastures*

A total of 6560 sq miles has been rated moderately suitable for improved pastures. Areas with this potential occur in Miwa, Moian, Avu, Suki, Boset, Indorodoro, and Rouku land systems which also have a high to moderate capability for tree crops. The main limitations are the low nutrient status and acid to strongly acid reaction of the soils. In addition, erosion hazards limit pastures on slopes over 6°. On the Oriomo Plateau the monsoonal climate with its dry season would also have some effect on pastures.

(*e*) *Potential for Irrigated Rice*

A total of 3610 sq miles is considered to have a moderate capability for irrigated rice. The whole of this area occurs on the coastal plain and on the Oriomo Plateau.

The main limitation for rice appears to be the lack of good-quality irrigation water, especially during the dry season. The rivers here are relatively small; during the dry season they have low stream discharge rates and some are subject to tidal inflow of brackish water.

It seems likely that one rice crop could be grown fairly easily during the wet season, as has been done near Merauke in West Irian since 1908 (Wttewaall 1955). Irrigation, even during the wet season, is considered necessary near Merauke for the successful growing of rice, otherwise crop failures could occur in some years due to the unreliability of the rainfall (Anon. 1955). Conditions near Merauke are probably similar to those in that part of the survey area rated moderately suitable for irrigated rice.

Areas with a moderate suitability for rice occur on the coastal plain in Wunji land system, and on the Oriomo Plateau in Mibini, Indorodoro, Goe, Boset, and Suki land systems. In Wunji land system, in addition to availability of irrigation water, limitations are short periods of fresh and salt water flooding and alkaline soils which are locally saline.

From the few data on soil nutrients available, nitrogen, phosphate, and potash contents appear to be moderate, low, and high respectively, although figures probably vary considerably, as in similar soils in West Irian.* Bula land system has a low capability for irrigated rice as it suffers from prolonged inundation. However, an advantage here would be low clearing costs because of the scarcity of trees.

Large areas of the Oriomo Plateau have a moderate capability for irrigated rice. Here irrigation water is available from the Morehead and Bensbach Rivers. Other limitations are low nutrient contents, acid to strongly acid soils, and, particularly in Goe land system, wet-season inundation. In parts of Boset and Suki land systems an abundant supply of irrigation water would be available from the Fly River. Because of the extensive swamps surrounding this river, places to establish pumping stations are rather limited.

(f) Possibilities for Land Reclamation, Flood Control, and Drainage

Large parts of the survey area are at present unsuitable for most agricultural purposes because of inundation, very poor drainage, and flooding. Such areas occur on the coastal plain, the Oriomo Plateau, and flood-plains of rivers.

The coastal plain is mostly less than 10 ft above sea level, and here inundation and drainage could possibly be controlled by drainage ditches with sluices to make use of the tidal range.

On the Oriomo Plateau, inundation control would be very difficult because of the flat terrain, and closely spaced drainage ditches would be necessary with outlet channels and pumping stations.

Large-scale flooding is prevalent in Fly, Obo, and Alice land systems. Control of flooding and consequent inundation of the back plains would be virtually impossible because of the size and the strongly fluctuating flow of the Fly, Strickland, and Alice Rivers. Drainage improvement would also be extremely difficult.

* SCHROO, H. (1957).—Bodemvruchtbaarheids-rapport gronden Marau en Koembe. Agric. Res. Stn, Hollandia, West New Guinea (unpublished).

III. Capability for Animal Industries

In 1913 and 1920 deer were introduced into West Irian (van Bemmel 1949; van Eechoud 1951). The deer have increased greatly and many have migrated into the survey area where they are mainly found on the coastal plain. According to a deer shooter (B. Johnson, personal communication), about 38,000 deer occur between the Morehead and Bensbach Rivers. Downes (1969) gives an estimate of 57 deer per sq mile based on transect count flown over 150 sq miles of the coastal plain in October 1968.

The deer are now being exploited for meat in a limited way and the Department of Agriculture, Stock, and Fisheries is examining the potential for expansion of the industry (J. L. Anderson, personal communication).

The swampy conditions of the coastal plains would probably suit water buffaloes, as these animals can maintain a good condition on a variety of feed, including water plants, whereas cattle have a more restricted diet (Story 1969).

Beef-cattle raising appears to have a real potential in the savannahs in the southern part of the area. These savannahs, which have ground storeys mainly dominated by kunai (*Imperata cylindrica*) and *Pseudopogonatherum irritans*, are ungrazed at present except for some deer on the southern margins. In order to develop types of cattle adapted to New Guinea conditions, the Department of Agriculture, Stock, and Fisheries (Anon. 1968) is cross-breeding Zebu type and British breeds at several locations. An example of what may be possible is given by an experiment undertaken at Moitaka, near Port Moresby. On natural savannah dominated by kangaroo grass (*Themeda australis*), spear grass (*Heteropogon contortus*), and kunai, half and three-quarter Brahman–Angus cross-bred cattle grew to approximately 900 lb liveweight in $2\frac{1}{4}$ years (Anderson 1968). The savannahs in the Morehead–Kiunga area have a more favourable rainfall than Moitaka, but large parts are subject to inundation during the wet season. Also, the soil fertility and the nutrition value of the natural pasture in the Morehead–Kiunga area are not known, and local testing will be necessary before any development takes place.

The establishment of a local meat industry based on deer, water buffalo, and cattle would save the Territory of Papua and New Guinea from having to continue importing large quantities of meat. However, the isolation of this area from the main centres of population may give this industry a low priority.

IV. Crocodile Skin Industry

The crocodile skin trade for many years has been a major source of income for the indigenous population, but recently it has become endangered because of indiscriminate shooting. The industry could probably be expanded provided certain protective measures were taken. One such measure would be to restrict shooting to crocodiles within an upper and a lower size limit, as the best-quality skins come mainly from medium-sized specimens. An upper limit would enhance production as large crocodiles lay more eggs, and a lower size limit would ensure that crocodiles are left to grow to an economic size. Land ownership also would need to be established, as now anyone can shoot crocodiles anywhere. In addition, restocking is urgently required and could possibly be undertaken by means of egg hatcheries. These are the suggestions of Dr. H. R. Bustard (personal communication), of the Australian National University, who visited the Fly and Sepik areas in 1967.

V. General Conclusions

For many years the Western District of Papua has generally been considered to be a vast swampy area with few or no possibilities for development. However, the survey, although carried out only at reconnaissance level, indicates that the area does have some potential.

Results of the survey indicate that there is considerable potential for tree crops on the dissected plateau of the Fly–Digoel Shelf and on well-drained areas of the Oriomo Plateau. Investigations will be needed to decide which are the most suitable tree crops. Other possible prospects for development are crocodile farming in the central part of the survey area and a meat industry based on deer and introduced water buffaloes on the coastal plain and on Zebu-cross cattle on the savannah areas.

Climatic data available are insufficient for a reliable assessment of the potential for various crops, and the early establishment of stations recording rainfall, evaporation, temperature, sunshine, etc. is strongly recommended.

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APPENDIX I

RATINGS OF FACTORS LIMITING AGRICULTURAL LAND CAPABILITY*

Symbol and Rating	Explanation
e1	Very slight erosion hazards
e2	Slight erosion hazards
e3	Moderate erosion hazards
e4	Serious erosion hazards
e5	Very serious erosion hazards
e6	Extreme erosion hazards
f1	Rare (once in 6–12 years) flood hazards
f2	Common (once in 1–5 years) flood hazards
f3	Frequent (at least twice a year) flood hazards
f4	Rare flood hazards, causing major damage
f5	Common flood hazards, causing major damage
f6	Frequent flood hazards, causing major damage
i1	Inundated for 15–30 days a year
i2	Inundated for 30–90 days a year
i3	Inundated for 90–150 days a year
i4	Inundated for 150–240 days a year
i5	Inundated for over 240 days a year
w1	Imperfectly drained
w2	Poorly drained
w3	Very poorly drained
w4	Swampy
p1	Rapidly permeable (2·5–8 in. per hr)
p2	Moderately permeable (0·5–2·5 in. per hr)
p3	Very rapidly permeable (> 8 in. per hr)
p4	Slowly permeable (0·1–0·5 in. per hr)
p5	Very slowly permeable (< 0·1 in. per hr)
d1	Deep soil
d2	Moderately deep soil
d3	Moderately shallow soil
d4	Shallow soil
d5	Very shallow soil

*Detailed explanation of these ratings is available in Division of Land Research tech. Memo. 65/8 (unpublished).

Symbol and Rating	Explanation
m1	High water-holding capacity (8–10 in. in 6 ft)
m2	Moderately high water-holding capacity (6–8 in.)
m3	Moderate water-holding capacity (4–6 in.)
m4	Low water-holding capacity (2–4 in.)
m5	Very low water-holding capacity (<2 in.)
t1	Moderate tillage difficulties
t2	Serious tillage difficulties
a1	Neutral soil reaction* (pH 6·6–7·5)
a2	Acid soil reaction (pH 5·0–5·9)
a3	Weakly alkaline soil reaction (pH 7·6–8·0)
a4	Alkaline soil reaction (pH 8·1–8·5)
a5	Strongly acid soil reaction (pH <5·0)
a6	Strongly alkaline soil reaction (pH >8·5)
c1	Weakly saline soil
c2	Moderately saline soil
c3	Strongly saline soil
w1	Slight surface unevenness (depth of depressions 6–12 in.)
w2	Moderate surface unevenness (depth of depressions 12–30 in.)
w3	High surface unevenness (depth of depressions 30–48 in.)
g1	Minor irrigation difficulties†
g2	Moderate irrigation difficulties
g3	Great irrigation difficulties
g4	Very great irrigation difficulties

*A weakly acid soil (pH 6·0–6·5) is considered not to be a limiting factor.

†Ratings are based on slopes. In the tabulated land systems no g rating is given for land units with slopes > 6°, as such units are considered unsuitable for irrigated rice.

APPENDIX II

Ratings of Soil Nutrients

Rating	Nitrogen (%)	Available Phosphate (p.p.m.)	Potassium (m-equiv./ 100 g soil)
Very high	>1·0	>100	>1·50
High	0·5–1·0	50–100	0·75–1·50
Moderate	0·2–0·5	20–50	0·40–0·75
Low	0·1–0·2	10–20	0·20–0·40
Very low	<0·1	<10	<0·20

INDEX TO LAND SYSTEMS

Fig. 1.—Coastal plain. The wide and generally featureless expanse of the coastal back plain mapped as Bula land system is shown by this aerial view. The plain is inundated during the wet season but was largely dry when the picture was taken (August 1967). Deer have made tracks through the low sedge–grassland and have trampled the ground around isolated trees and scattered patches of shrubbery growing on slightly higher ground.

Fig. 2.—Coastal plain. Pandan trees, wind-swept and crooked, are typical of large parts of the coastal back plain (Bula land system).

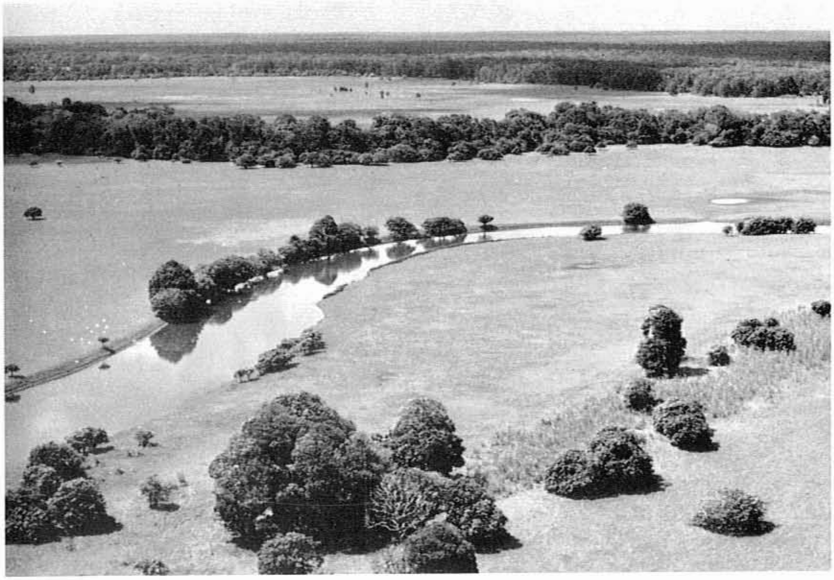

Fig. 1.—Coastal plain. The swampy flood-plains along the lower reaches of the Bensbach River form part of Wando land system. The low swamp grassland and scattered low deep-crowned *Barringtonia* trees give the landscape a parkland aspect during the dry season.

Fig. 2.—Coastal plain. The slightly higher flood-plains of the Morehead and Bensbach Rivers, flooded for a shorter period than Wando land system, have been distinguished as Tonda land system. The kunai grassland is probably flooded only for short periods in the wet season, but parts of the associated *Melaleuca* swamp forest remain swampy throughout the year. Felling of one tree in the grassland allowed the helicopter easy access, through a break in the gallery woodland along the Morehead River, to the pad in the grassland.

Fig. 1.—Coastal plain and Oriomo Plateau. The aerial view shows the sharp indented contact between permanent reed and tall sedge swamp of Wando land system, top and bottom left, and the slightly higher, seasonally dry plain of Mibini land system, to the right, with *Melaleuca* savannah and peripheral *Imperata* grassland. The dark-toned margin of Wando land system is formed by a zone of low swamp grassland (*Pseudoraphis* sp.).

Fig. 2.—Coastal plain and Oriomo Plateau. The swampy flood-plains of the Tarl and Bensbach Rivers (Wando land system) extend northward as deep indentations of the coastal plain within the Oriomo Plateau. The picture shows the Bensbach River flood-plain south of Weam, with a vegetation of low swamp grassland and *Melaleuca* swamp forest. The terrain, largely dry underfoot in the dry season, is probably flooded for at least 6 months a year. The dark band at the base of the tree trunks indicates the level of wet-season flooding.

Fig. 1.—Coastal plain and Oriomo Plateau. *Melaleuca* often forms a mass of adventitious rootlets up to about 4 ft high around its base, probably induced by prolonged inundation. The picture is a close-up of one of the trees on the right of Plate 3, Figure 2.

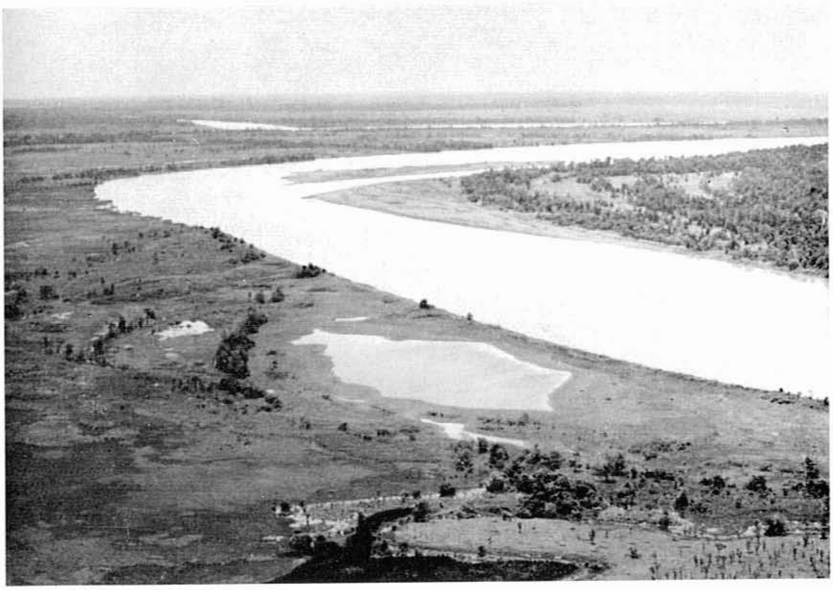

Fig. 2.—Flood-plains of the Fly River and its tributaries. The aerial view is of the Strickland River near Everill Junction (Fly land system). Gently curving lines of open rain forest reveal the pattern of developing and former scrolls. A low ridge spur of Miwa land system covered with *Imperata* grassland is seen in the bottom right corner.

Photograph courtesy Director of National Mapping, Department of National Development, Canberra.

Fig. 1.—Flood-plains of the Fly River and its tributaries. The middle reaches of the Fly River and the lower course of the Strickland River are characterized by fan-shaped scroll complexes made up of interlocking groups of meander scrolls, and are interspersed with numerous abandoned meanders (Fly land system). Long and narrow scroll ridges covered with waterlogged open rain forest alternate with depressions that have a vegetation of tall swamp grass. Depending on their age, some of the abandoned meanders have open water without or with aquatic vegetation, some have swamp grass, and some have climber thicket with scattered trees. Extensive back swamps (Obo land system), partly shown in top right and bottom left corners, flank the scroll complexes; they are covered with swamp grass and *Melaleuca* swamp savannah. Frequent and deep flooding makes the land unsuitable for agriculture. The picture is part of an aerial photograph showing the Strickland River just south-west of Massey Baker's Junction.

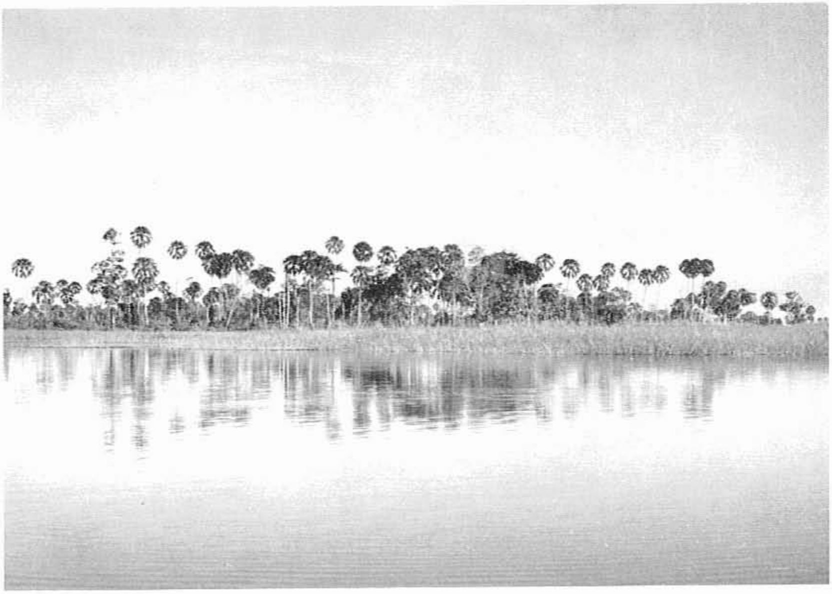

Fig. 1.—Flood-plains of the Fly River and its tributaries. Another typical feature of Fly land system is groups of slender *Livistona* palms breaking the monotony of the vast stretches of swamp grassland.

Fig. 2.—Flood-plains of the Fly River and its tributaries. Alice land system comprises the flood-plains of the Alice and upper Fly Rivers, which are more stable and less severely flooded than those of Fly land system downstream. Open rain forest is the predominant vegetation. The open stand of *Campnosperma* with an undergrowth of sago, centre, indicates a swampy depression.

Fig. 1.—Flood-plains of the Fly River and its tributaries. A dense stand of *Nauclea orientalis* and *Mitragyna speciosa* colonizes the broad mud scroll of a recently cut-off meander of the Fly River west of Kiunga (Alice land system). The grass in front of the trees is *Brachiaria* sp. Open rain forest in background covers the alluvial plain flanking the meander.

Fig. 2.—Flood-plains of the Fly River and its tributaries. Low levees of the Agu River in Obo land system show the first stages in the development of swamp forest. Many trees die prematurely, probably as a result of occasional exceptionally prolonged flooding and being smothered by climbers.

Fig. 1.—Flood-plains of the Fly River and its tributaries. Swamp forest and swamp woodland are a characteristic feature of the flood-plains of tributary valleys which comprise June land system. The view is of a flooded tributary valley of the June River. The open canopy transmits sufficient light for an undergrowth of tall sedge to become established, and epiphytes abound. There is almost no shrub and low herb layer.

Fig. 2.—Flood-plains of the Fly River and its tributaries. Tall swamp grassland bordering open water of the Kaim River is flanked by *Melaleuca* swamp savannah in the back swamp (June land system), behind which is rain forest on low hills of Miwa land system. This example illustrates on a small scale the environmental changes that occur on a larger scale along the middle courses of the Fly and Strickland Rivers, where swamp grassland characterizes Fly land system and most of the *Melaleuca* swamp savannah is included in Obo land system.

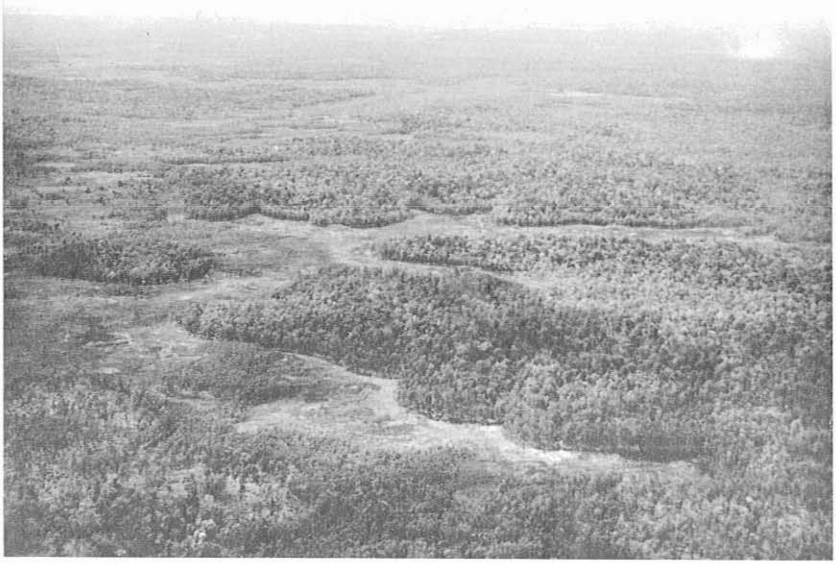

Fig. 1.—Oriomo Plateau and flood-plains of the Fly River and its tributaries. Swamps of Obo land system in tributary valleys of the Fly River are sharply bounded by slightly undulating plains of Suki land system which are mainly covered with poor monsoon forest. Flat, temporarily inundated parts have *Melaleuca* swamp forest.

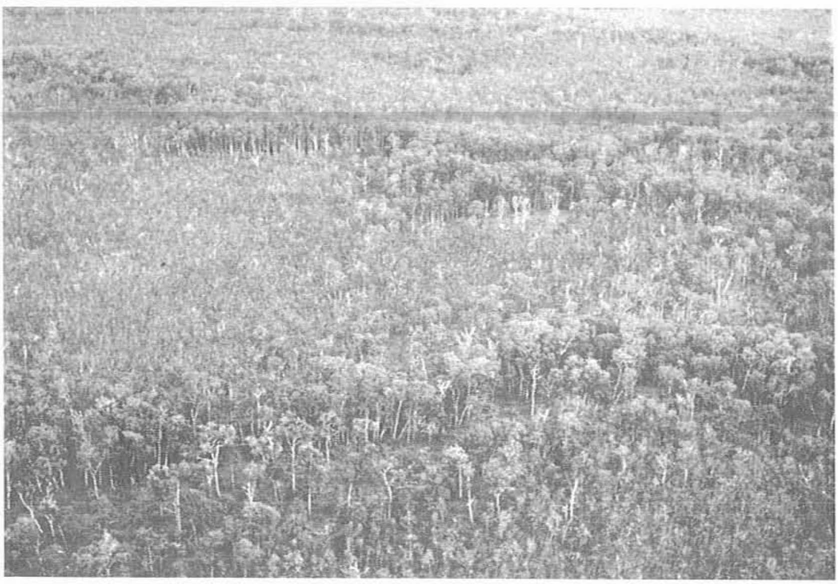

Fig. 2.—Oriomo Plateau. *Melaleuca* savannah is typical of Mibini land system, a smooth plain of very low gradient on the south side of the Oriomo Plateau. Drainage lines are revealed by gallery woodland, which is taller, denser, and darker-toned than the surrounding savannah.

Fig. 1.—Oriomo Plateau. Termitaria are a characteristic feature on poorly drained flats in Goe and Indorodoro land systems. A rim of low, thin-stemmed, and gnarled *Melaleuca–Banksia–Grevillea* savannah commonly occurs between sedge–grassland on the flats and tall mixed savannah on the surrounding slightly undulating terrain.

Fig. 2.—Oriomo Plateau. Low mixed savannah and sedge–grassland commonly with scrubby *Sinoga* predominate on the flat plains of Goe land system. Because of lack of relief, and impermeable subsoils, the plains are waterlogged or inundated in the wet season and roads are then impassable. The picture shows part of the road southwards from Morehead; the trees are mainly *Acacia leptocarpa*.

Fig. 1.—Oriomo Plateau. The slightly undulating terrain of Indorodoro land system is characterized by tall mixed savannah dominated by *Melaleuca*, with smooth, light-coloured trunks, and *Tristania*, with fissured, darker-coloured bark. Both trees survive periodic burning of the ground layer of kunai grass.

Fig. 2.—Dissected plateau of the Fly–Digoel Shelf. Lake Murray in the background is surrounded by closely spaced and densely forested low ridges of Miwa land system.

Fig. 1.—Dissected plateau of the Fly–Digoel Shelf. Lake Murray, formed in the drowned valley of the Herbert River, mainly consists of open water with a uniform depth of about 22 ft (October 1967). Swamp grass forming a dense matted cover finds a foothold in shallow water along the shores of the lake and around many islets, in numerous embayments, and on submerged silt jetties of rivers flowing into the lake.

Fig. 2.—Dissected plateau of the Fly–Digoel Shelf. Swamp grass in embayments of Lake Murray prevents passage and landing of speed-boats and obstructs navigation by canoe. A rim of *Melaleuca* trees marks the transition to the surrounding rain forest on the high ground of Miwa land system.

Fig. 1.—Dissected plateau of the Fly–Digoel Shelf. Aerial view of a village on a low ridge crest of Miwa land system. The small size of the planted bread-fruit, papaw, coconut, and banana indicates fairly recent establishment.

Fig. 2.—Dissected plateau of the Fly–Digoel Shelf. In recent years suitable areas around villages have been cleared and planted with rubber by the local population in communal labour, under the guidance of the Department of Agriculture. The picture shows a fresh clearing in thin-stemmed closed rain forest on gently undulating terrain of Moian land system.

Fig 1.—Dissected plateau of the Fly–Digoel Shelf. The aerial view shows the intricate pattern of low ridges with dense rain forest and swampy valleys with vigorous sago in Kiunga land system.

Fig. 2.—Dissected plateau of the Fly–Digoel Shelf. Kiunga, situated on the Fly River, and centre of administration in the northern part of the survey area, can be reached by vessels with up to 8 ft draught throughout the year. The aerial view shows the pattern of low ridges typical of Kiunga land system. On the river cliffs dark-toned clay, sand, and gravel of the Lake Murray beds unconformably overlie pale sands and clays of the Kiunga and Elevala beds. All are of Pleistocene age.