Lands of the Wewak–Lower Sepik Area, Territory of Papua and New Guinea

Comprising papers by H. A. Haantjens, Jennifer M. Arnold, J. R. McAlpine, J. A. Mabbutt, E. Reiner, R. G. Robbins, and J. C. Saunders

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PART I. INTRODUCTION

By H. A. Haantjens*

I. Introduction

(a) *Survey Area, Objective, and Field Work*

The area surveyed covers approximately 4600 sq miles between lat. 3°20′S. and 4°15′S. and long. 143°00′E. and 144°30′E. on the north coast of New Guinea (Fig. 1). Administratively, the survey area comprises the north-eastern part of the Sepik district of the Territory of New Guinea, including Wewak, seat of district headquarters.

The aim of the survey was to describe, classify, and map in a broad but systematic way the lands of the area in terms of rock, land form, soil, vegetation, and climate, relying on a maximum of air-photo interpretation and a minimum of field work.

The field work was carried out between July 26 and October 12, 1959. The general mobile survey team consisted of H. A. Haantjens (pedologist), E. Reiner (geomorphologist), R. G. Robbins (plant ecologist), and J. R. McAlpine (transport officer). A separate and more detailed investigation of the principal forest types at selected sites was made by J. C. Saunders (forest botanist) and R. Pullen (botanical collector). Mr. J. A. Mabbutt (geomorphologist) visited the team in the field for three weeks. The party worked along traverse routes (Fig. 2) selected by pre-survey photo analysis so as to provide typical cross-sections of the country. Although extensive use was made of 4-wheel drive vehicles, approximately 120 miles of traverse were covered on foot, using existing tracks including one across the Prince Alexander Mountains. In the southern regions the launch "Heron" served as base, carrying the party some 300 miles down the Sepik River and to the offshore islands. Two small fibreglass boats with outboard motors made access possible to the many extensive swamps and waterways of this part. A short aerial reconnaissance was made from Marienberg over the swamp lowlands of the Sepik River.

(b) *Aerial Photographs and Base Maps*

The whole area surveyed, with the exception of the northern part of Kairiru Island and three small gaps in map sheets Tring and Korogo, is covered by vertical aerial photography, taken by Adastra Airways Pty. Ltd. in 1958. These photos were taken from a height of 25,000 ft and have a scale of 1 : 50,000 at sea level. The gaps were subsequently closed by photographs taken in 1964.

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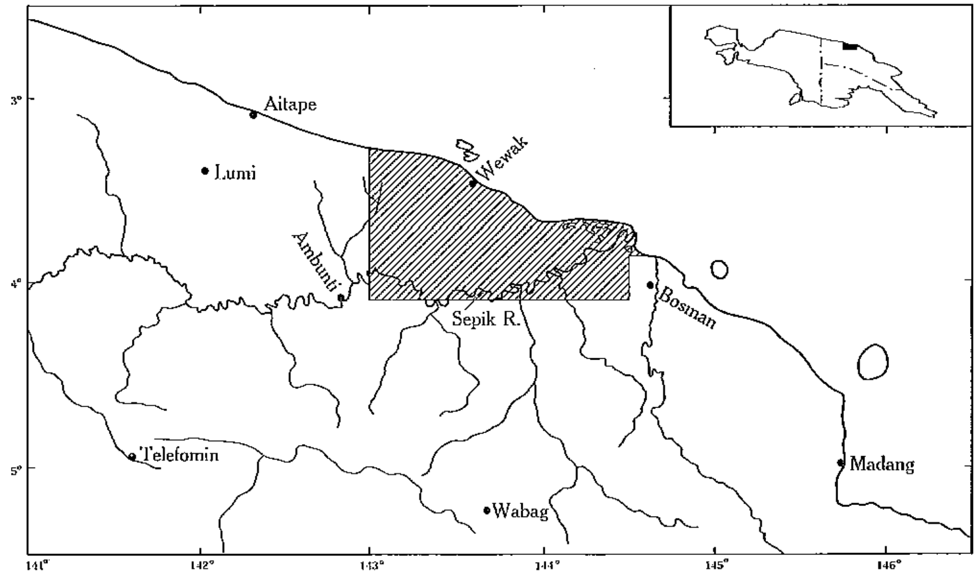

Fig. 1.—Location of the Wewak–Lower Sepik area.

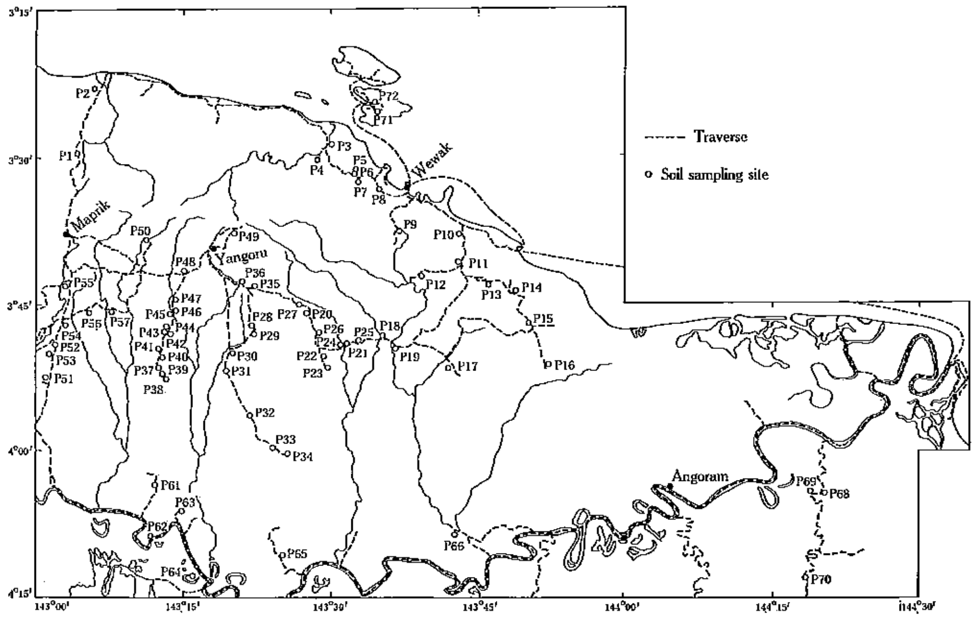

Fig. 2.—Traverses and soil sampling sites. Sites P58, P59, and P60 are just west, P67 just south, of the survey area and are not shown.

The area is fully covered by wartime military sheets at a scale of one mile to the inch. The information contained on these is, however, in many cases inaccurate. A base map at a scale of 1 : 250,000 has been made by the Division of National Mapping, Department of National Development, Canberra. This map has been compiled from the recent aerial photography using the slotted templet method and all available ground control consisting of astrofixes at But, Wewak, Maprik, Angoram, and Timbunke.

II. Summaries

(a) *Land Systems*

Twenty-seven land systems ranging in size from 8 to 600 sq miles have been mapped and described. Mapping at a scale of 1 : 250,000 is based on interpretation of aerial photographs. The descriptions are based on photo interpretation and field observations of land form, soil, and vegetation and include the breakdown of the land systems into units, which are tracts of terrain that cannot be represented individually on the map but have rather small internal variation in land form, soil, vegetation, and land use capability. Data on population and land use are given for each land system, as well as an assessment of its potential for agricultural and forestry development.

On the basis of broad similarities the land systems can be grouped into five categories.

Forested mountains include four land systems and comprise 600 sq miles or 13% of the area. The altitude is 2000–4000 ft and relief 500–1500 ft. Slopes are mostly 20–40° and soils are generally immature, although skeletal soils are very rare. The rain forest consists mainly of lower ranges forest with small areas of lower montane forest.

Forested and grass-covered hills include eight land systems and comprise 1000 sq miles or 22% of the area. Altitude is very variable but up to 1400 ft, whilst relief ranges from 100 to 600 ft. Slopes are mostly steep and soils generally similar to those in the mountains. The lowland hill forest is replaced by regrowth or grassland over many large and small areas. Remnant upland surfaces with gentle slopes occur in three land systems and have various kinds of strongly weathered soils and predominantly grassland vegetation.

Rolling to flat grass plains include three land systems and comprise 1100 sq miles or 23% of the area. Situated mainly between 100 and 400 ft altitude, relief is generally less than 50 ft except near incised through-going rivers. Moderately to strongly weathered soils predominate, mostly with waterlogged slowly permeable subsoils and coarser-textured upper horizons. *Themeda–Ischaemum* grass vegetation gives way to forest near the streams.

Forested alluvial plains include six land systems and comprise 450 sq miles or 10% of the area. Partly liable to flooding, these flood-plain and terrace tracts have undeveloped alluvial soils of varying texture and drainage condition, covered with several types of alluvium rain forest and regrowth, locally grassland.

Sago, grass, forest, and mangrove swamps include six land systems and comprise 1500 sq miles or 32% of the area. Whilst the soils comprise mainly alluvial clay soils and organic soils, the various types of swamp vegetation appear to be closely related to ground-water fluctuations and degree of flooding and inundation. Both tend to be smaller near the coast although ground-water levels tend to be higher there too.

(b) *Climate*

Recorded mean annual rainfall ranges from 69 in. at Bainyik in the plains south of the coastal range to 96 in. at Dagua on the coast north of the range. Amounts well over 100 in. can be expected in the ranges. Monthly averages range from 8 to 14 in. in the wettest month between October and March to 2–5 in. in the driest month between March and October. Rainfall is generally not heavy for a tropical region, with one-half to one-third of the number of wet days recording falls of 0·25 in. or less and daily falls of over 2·00 in. occurring on only 3 to 6 days per year.

Average monthly maximum temperature ranges from about 84 to 87°F along the coast and from 87 to 93°F at low elevation inland. Average minimum temperature ranges from 73 to 74°F at the coast and from 69 to 71°F inland at low elevation. There is a gradual decrease in temperature with increase in elevation.

Relative humidity is high throughout the year, usually between 75 and 85% at 9 a.m. and dropping 5 to 10% at 3 p.m. Inland it may fall to 50% during the day. Winds are generally light; the average velocity of the south-east trade wind from May to October is 10 knots and that of the north-west monsoon from December to March is 6 knots. Squalls during thunderstorms, land and sea breezes up to 15 miles inland, and local mountain and valley winds can have a greater velocity. Average cloud cover is considerable throughout the year, ranging from three- to five-eighths and probably more in the ranges.

On the basis of an assumed monthly evaporation of 5·0 in. and an assumed soil water storage of 4 in., a water deficit for growing crops can be expected during about two months per year on the inland plains. The deficits are not likely to be severe since rainless periods of more than 2 weeks are rare. In large parts of the inland area the effects of any slight droughts are likely to be reduced by the ability of crops to use shallow ground water.

(c) *Geomorphology*

Six physical regions have been recognized in the area: offshore islands; coastal plains; Prince Alexander Mountains; hill zone; upper plains; and Sepik flood-plains.

Apart from a probable crystalline basement and a small area of strongly folded schist in the coastal ranges, the rocks in the area are of Miocene to Recent age. They include a variety of sedimentary rocks and limestone, intrusive igneous and metamorphosed igneous rocks, extrusive rocks ranging from rhyolite to basalt, and Quaternary and Recent alluvia and marine deposits.

The history of the area can be traced back to a period of marine deposition in a trough during the Miocene and Pliocene. Broad up-arching along an east–west axis followed in late Pliocene to early Pleistocene. Strong faulting in the west was associated with batholithic intrusion and volcanism. Erosion led to the formation of a broadly undulating surface across the newly emerged structure and to deposition of fanglomerates and alluvia to the south of the coastal ranges. Renewed uplift caused the dissection of most of the planated upland surfaces of the mountains and hill zone and of the alluvia to the south in the upper plains. This was followed by aggradation of clayey alluvium in between and south of the dissected fanglomerates, probably in response to a relative rise in sea level. These upper-plain sediments were in turn slightly dissected by through-going streams, probably partly as a result of minor tilting and partly by eustatic lowering of the sea level. The Recent period is characterized by the formation of the present flood-plains, particularly that of the Sepik River, which is the second largest river in east New Guinea with a channel depth of at least 30 ft and a width of 200–500 yd.

The land systems are strongly related to lithology and landscape history and the geomorphology of each is briefly discussed.

(*d*) *Soils*

The soils of the area have been grouped into 16 major soil groups, subdivided into 55 soil families. The major soil groups are tentatively equated with great soil groups of the 7th Approximation.

Moderately to little-weathered brown forest soils, locally associated with gleyed forest soils, are the most important soils of the mountains and hills. On local stable sites they give way to strongly weathered uniform red and yellow clays, on limestone and very calcareous sediments to rendzinas and shallow black earths, and on local very steep slopes and narrow crests to lithosols. Remnant upland surfaces with gentle slopes in the hill zone have a complex pattern of strongly weathered meadow podzolic soils, gleyed red and brown earths, uniform red and yellow clays, and podzolic red and yellow earths. The rolling to level grasslands of the upper plains are characterized by meadow podzolic and dull meadow podzolic soils, meadow soils, and rare occurrences of podzolic red and yellow earths, all developed in more or less strongly weathered Pleistocene sediments. Dark colluvial soils occur locally on foot slopes and concave valley heads in low hilly country. Young alluvial soils, dominantly silts and clays, occur on flood-plains and low terraces throughout the area. They are particularly clayey and gleyed in swamps, where they are commonly associated with alluvial black clays and organic soils. Old alluvial soils are formed on some higher terraces, fans, and beach ridges.

Textural differentiation appears to be a more common feature of soil development in this area than is generally the case in New Guinea. It is most pronounced in the two groups of meadow podzolic soils, distinct in the podzolic red and yellow earths and the gleyed red and yellow earths, and noticeable in several gleyed forest and brown forest soils.

There are indications that kind and degree of soil formation are more related to land form and site stability than to parent rock. On the other hand, parent rock appears to have a significant influence on soil fertility, to a large extent independently of the kind of soil.

(*e*) *Vegetation*

Twenty of the vegetation communities recognized have been grouped environmentally into higher mountain, lower mountain and hill, alluvial plain and fan, swamp, and coastal zone vegetation. Nine other communities are grouped as successional and disclimax vegetation.

Higher mountain vegetation includes lower montane rain forest and lower ranges forest, which are restricted to the wettest parts of the area. Lowland hill forest of the lower mountains and hills is the most extensive forest type, a typical tall and very mixed tropical forest. The forests of the alluvial plains and swamps vary in structure and composition with drainage and site stability. They include the tall well-drained alluvium forest, the irregular mixed flood-plain forest, and the much less mixed levee forest, found on small levees in the Sepik flood-plain.

Swamp vegetation includes a whole range of communities from swamp forest to aquatic vegetation. There are three communities in which sago palms are prominent. The best-developed swamp forest is found on organic soils near the mouth of the Sepik River. Various kinds of tall grass communities are extensive throughout the Sepik flood-plain swamps. Sedge–fern swamp, *Scleria* sedge swamp, and herbaceous swamp are of relatively minor importance, occurring commonly in small swampy depressions.

The coastal zone vegetation consists mainly of mangrove woodland near the mouth of the Sepik River and includes a narrow fringe of strand woodland that is almost continuous along the sea-shore.

Six types of grassland are grouped as disclimax vegetation since they are thought to have resulted from forest clearing and burning and to be maintained by regular grass fires. The grasslands of the upper plains, largely consisting of the *Themeda–Ischaemum* complex, are amongst the largest in extent in New Guinea and are of particular ecological interest. The composition of the grasslands appears to be determined both by edaphic factors and by the intensity and history of burning.

River scroll, river terrace, and coastal plain successions occur on unstable parts of the flood-plains and coastal plain.

(*f*) *Forest Resources*

Nine forest types are recognized and mapped. They correspond with the types described in Part VI, but mapping has been selective in order to eliminate poor stands and secondary vegetation. Lower ranges forest with 410 sq miles and an estimated timber volume of 14,000 super ft/ac is the single largest timber resource in the area, tapping of which is extremely difficult, however, because of rugged topography. A large timber volume of 12,000 super ft/ac renders the 80 sq miles of well-drained alluvium forest attractive for exploitation, particularly since there are no serious topographic obstructions. The largest accessible source of timber is 590 sq miles of lowland hill forest with an estimated stocking rate of 5000 super ft/ac. Distributed throughout the northern part of the area, this forest type in addition comprises 210 sq miles on very steep slopes.

Mixed flood-plain forest, although comprising 170 sq miles, is of less significance because of the rather low stocking rate of 3500 super ft/ac. Accessibility is impeded by flooding and poor drainage. *Campnosperma* swamp forest (50 sq miles) is generally of low value, but the timber volume rises locally to 8500 super ft/ac. Accessibility is a major problem. There are 90 sq miles of mangrove in the area. Stocking rates have not been determined but are thought to be generally low.

(g) *Population, Land Use, and Transport*

The indigenous population numbered more than 76,000 in 1959–60, and appears to be increasing at an annual rate of 2% or more. As shown on an accompanying map, the population distribution is very uneven. The overall population density is 17 persons per sq mile but a density of over 400 has been calculated on some tribal lands in the Maprik area. The distribution of the population over the land systems is tabulated.

Subsistence cultivation, predominantly of various types of root crops, is the principal type of agricultural land use. However, sago forms a substantial part of the diet, particularly in the densely populated Maprik–Yangoru area and in the Sepik swamps. Coconuts have always been used for local consumption as well as for commercial copra production. More recently introduced cash crops are upland rice, cocoa, and lowland coffee, which are now established on a very limited scale. The distribution and intensity of subsistence cultivation are shown on an accompanying map. Approximately 375 sq miles or 8% of the area are being used for gardens and bush fallowing. Land use intensity ranges from very high on certain river terraces and levees to very low in parts of the mountains. The distribution of land use in relation to environment and land systems is described. There is very little correlation between land use for subsistence cultivation and land use capability for modern agricultural development, as discussed in Part IX.

For New Guinea conditions the area is well supplied with roads and airstrips (mostly of low standard), and with navigable waterways. There is a dearth of good anchorages, and even Wewak, the main port, does not allow large ships to berth at wharves.

(h) *Land Use Capability*

Land use capability has been assessed for all units of land systems according to a method adopted from the system used by the United States Soil Conservation Service, United States Department of Agriculture.

Areas totalling 90 sq miles (2%) comprise land without or with only very slight limitations to land use, and very suitable for arable crops and tree crops as well as improved pastures.

Land with slight limitations totalling nearly 400 sq miles (9%) is also suitable for many types of agricultural production, but will require some erosion control, drainage improvement, or heavy applications of fertilizer.

Approximately 1100 sq miles (24%) of land with moderate limitations to land use are generally primarily suitable for improved pastures, but marginal for permanent cultivation. The limitations to development include flood hazards or waterlogged, slowly permeable soils that cannot easily be improved. In addition, soil fertility is very low on half this land. The wettest land in this group appears rather suitable for irrigated rice.

Nearly 1000 sq miles (21%) of land have serious limitations, either because of serious erosion hazards or very poor drainage, commonly associated with flood hazards. Such land is unsuitable for cultivation but could generally be used for improved pastures and, on 600 sq miles of steep land with fairly good soils, for tree crops, although access would present problems. Irrigated rice appears to offer possibilities on very poorly drained land, which in some areas has low to moderate sago resources.

More than 1100 sq miles (24%) of land with very serious limitations is either swampy or very steep and rugged. The steep land is best left under protection forest, but forest exploitation may be locally possible. There are no other uses of this land in the foreseeable future, although locally it is much used for shifting cultivation.

Nearly 1000 sq miles (20%) in the area are so rugged, severely flooded, and/or swampy that they can be classed as land without any agricultural potential.

Large-scale reclamation of poorly drained and/or flooded land appears to offer good prospects for raising the potential of some land now classed as having moderate limitations. It will be more difficult to reclaim much of the land with serious waterlogging and flooding problems, and it will be very difficult indeed to reclaim the land with very serious limitations in the Sepik flood-plain swamps, even though the swamp soils represent a large store of soil fertility.

PART II. LAND SYSTEMS OF THE WEWAK–LOWER SEPIK AREA

By H. A. HAANTJENS,* E. REINER,† and R. G. ROBBINS ‡

I. INTRODUCTION

The land systems, as described in this Part and shown on the accompanying land system map, are natural landscapes with a characteristic pattern of rocks, land forms, soils, and vegetation that can be mapped from aerial photographs at the map scale used.

Although the land systems are primarily natural, i.e. genetic entities, much consideration is also given to factors of land use potential in their establishment. Land system names are derived from local geographical features such as villages, rivers, and mountains.

Each land system consists of one or more units. These are areas of land with a particular combination of land forms, soils, and vegetation, and are not mappable either from aerial photographs or at the map scale used. A distinction is made between simple units, with only one particular type of land form, soil, and vegetation (e.g. flat terrace surface), and compound units, which have a particular sequence of land forms, soils, and vegetation (e.g. steep ridges and narrow valleys). The great majority of units in this report are compound units. They differ from land systems only in that they are not mappable because of their very intricate pattern, indistinct boundaries, or small size. Consequently, in land systems with only one unit, land system and unit are identical.

In the land system descriptions, the extent and geographical position of the units are indicated under the heading Area and Distribution. It will be clear from the previous discussion that this information cannot possibly be exact and must remain tentative.

II. GROUPING OF LAND SYSTEMS FOR GENERAL DESCRIPTION OF THE AREA

The 27 land systems have been grouped into the following broad environmental types of land (Fig. 3).

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Forested mountains comprising 600 sq miles (13% of the area).

Forested and grass-covered hills comprising 1000 sq miles (22% of the area).

Rolling to flat grass plains comprising 1100 sq miles (23% of the area).

Forested alluvial plains comprising 450 sq miles (10% of the area).

Sago, grass, forest, and mangrove swamps comprising 1500 sq miles (32% of the area).

In the following discussion the land systems which constitute each group are listed in brackets after each heading to enable the reader to follow the distribution of these land types on the land system map, and to refer to the illustrations and detailed information in the land system tables at the end of this Part.

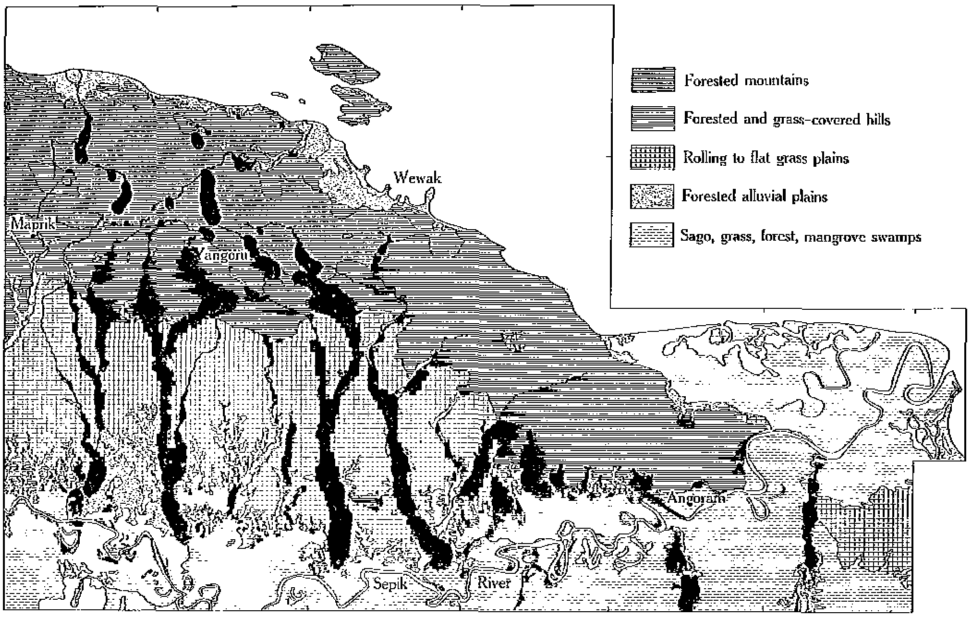

Fig. 3.—Distribution of groups of land systems.

Each group is illustrated by one or two vertical air photos, published with the permission of the Director, Division of National Mapping, Department of National Development, Canberra.

(*a*) *Land Systems of the Forested Mountains*

(Turu, Nagapam, Imbia, Numoiken. Plate 1, Fig. 1)

Comprising the Prince Alexander Mountains, an almost west–east-oriented coastal range of broad anticlinal structure, this zone is widest and highest (generally 2000–3000 ft) in the west, and narrows and descends to 1500 ft in the east (Numoiken land system; Plate 5, Fig. 1). It includes the high mountain mass of Kairiru Island.

It is very rugged country with many deep V-shaped river valleys, very steep and strongly dissected slopes, and narrow ridge crests. Turu land system consists of volcanic and basic igneous rocks and includes the highest peaks in the area, such as Mt. Turu (3900 ft). The other land systems comprise Tertiary sedimentary rocks, ranging from mudstone to conglomerate, with local occurrences of limestone. Warping, faulting, and jointing of these sediments exert strong control over the drainage pattern and land forms, especially in Nagapam and Imbia land systems (Plate 5, Fig. 2; Plate 6, Fig. 2). The water divide between the coastal and inland drainage lies remarkably close to the southern margin of the mountains. There are indications that the water divide occupied a far more northerly position in an earlier stage of landscape development. The northern and southern boundaries of the mountain range are largely controlled by faults.

The soils are predominantly rather shallow and mostly fine-textured brown forest soils, which are only moderately leached. Strongly weathered fine-textured and generally deep red clays occur very locally, mostly on broader crests, whilst very friable acid yellow-brown clays are common above 1500 ft altitude.

The vegetation of the higher western part of the mountains consists of lower ranges forest, a mixed three-layered rain forest with a dense uniform canopy at 100 ft. The lower eastern part, which appears to be slightly drier, is covered with lowland hill forest, a three-layered very mixed rain forest with a more irregular canopy at 100–120 ft, with few emergent trees and a somewhat different species composition. Lower montane rain forest occupies the highest mountain peaks above 3500 ft altitude. It has only two tree layers, with a canopy at 80–90 ft, and contains fewer species than the lower ranges forest. The forest is very locally replaced by garden regrowth, mainly on the lower ridges of Imbia land system.

Nearly all this land is unsuitable for permanent cultivation of arable crops and only marginal for tree crops and grazing. As it is also very poorly accessible and forms the catchment area of many large rivers, it is best kept under forest cover, but forest exploitation is generally very difficult, except perhaps along the edges.

(*b*) *Land Systems of the Forested and Grass-covered Hills*

(Kaboibis, Yangoru, Wonginara, Kumbusaki, Winge, Senambila, Passoram, Muschu. Plate 1, Fig. 2; Plate 2, Fig. 1)

The hills form a continuous belt along the southern margin of the mountains, merging into a broad zone along the south-eastern extension of the anticlinal structure of the Prince Alexander Mountains and reaching the Sepik River from Angoram to Marienberg. Scattered hilly areas are found along the northern boundary of the mountains and on Kairiru Island, and comprise much of Muschu Island, whilst Kumbusaki land system forms an isolated enclave in the Prince Alexander Mountains.

The height above sea level ranges from 200 to 1400 ft. The hills consist predominantly of Tertiary sedimentary rocks (mainly mudstone), but are of basic volcanic and igneous rocks in Senambila land system, metamorphic rocks in Yangoru land system, and limestone in Muschu land system and parts of Kaboibis and Passoram land systems. In the last two the limestone forms a thin capping on sedimentary rocks and has been eroded into a very dense pattern of low hills and ridges with local sink-holes, and forming escarpments along major rivers. The greater part of the hill zone has a very broken and densely dissected topography (Plate 6, Fig. 1) in which the land forms are influenced by landsliding as a major agent of erosion, with a widespread development of colluvial valley heads, aprons, and benches. Individual differences in land forms of the various land systems are due to differences in rock type, altitude, and severity of stream dissection, and locally, to structural control. The highest relief is found in Kaboibis and Senambila land systems, the lowest in Winge land system. Extensive parts of Senambila and Passoram land systems have a rolling to undulating topography (Plate 7, Fig. 2), representing an older land surface which has escaped the most recent cycle of erosion. Similarly, in Muschu land system large parts of the original reef topography have been preserved.

The soil pattern in the steep hilly areas is strongly dominated by brown forest soils, which are commonly very shallow and locally skeletal. Slightly mottled red clays occur locally. Shallow black earths and dark colluvial soils are common in the lower parts of Kaboibis and Winge land systems. Gleyed forest soils with poor topsoils and mottled plastic subsoils have developed locally on sites with slowly permeable rock. Limestone areas are mostly covered with shallow unleached black rendzinas. More complex soil patterns are found on the flatter remnant surfaces. In Senambila land system the soils are mainly uniform red clays and gleyed red and yellow earths (mainly fine-textured soils with iron concretions and dark, sandier top-soils, overlying red or brown plastic subsoils, which become strongly mottled with depth); in Passoram land system there are mainly meadow podzolic and meadow soils. Uniform red clays are common on more level limestone country in Muschu land system.

The vegetation of the hills consists largely of lowland hill forest (Plate 7, Fig. 1), but of lower ranges forest in Kumbusaki land system. In Kaboibis, Yangoru, Winge, and the western part of Passoram land system the forest has been replaced with garden regrowth and grassland, ranging from tall cane grass to the *Themeda–Arundinella* short grass association, and commonly very mixed, with much *Imperata* and *Ophiuros*. The flatter remnant surfaces in Senambila and Passoram land systems are almost completely covered with short grassland of the *Themeda–Arundinella* or *Themeda–Ischaemum* associations, the latter on the more poorly drained sites. It should be mentioned that this correlation between the vegetation and the land forms and soils is not natural, but man-induced: on small areas of flatter land forest is still found, whilst grassland occurs on many sites typical for the forest-covered steep hill slopes.

The valleys of the major rivers in the hilly zone are wider than those in the mountains and contain narrow flood-plains and terraces, with alluvial soils and commonly forest vegetation.

Large areas of the hill zone appear to be suitable for tree crops or grazing, although commonly the shallowness of the soils restricts the potential for the former use. Moderately large areas with steep long slopes should remain in forest or be reafforested as they would thus contribute significantly to the forestry potential of the area. Topography and soils of the rolling grassland areas are most suitable for grazing but, with erosion control measures, arable crops may be successful in a mixed farming system. Rather serious soil fertility problems require attention on this land. Arable farming, mostly with soil conservation practices, appears possible on most of the small colluvial slopes scattered through many parts of the hill zone, whilst cultivation or grazing is possible on the narrow valley floors depending on the degree of flooding.

(c) *Land Systems of the Rolling to Flat Grass Plains*

(Kworo, Yambi, Bosman. Plate 2, Fig. 2)

This land forms a broad belt of country between the hills and the Sepik River and to the east of this river.

The altitude ranges from 40 to 400 ft and the plains have a general gradient from north to south. They represent different stages and phases of mainly Pleistocene sediments, which have been slightly uplifted. Kworo land system (Plate 8, Fig. 1) comprises the older, higher, more dissected, and hilly to rolling stage of generally coarser-textured fluviatile sediments, but includes finer-textured marine deposits in the east. Yambi and Bosman land systems represent the younger, lower, little-dissected, and undulating to flat stage of fine-textured material, which is of fluviatile origin in Yambi land system (Plate 8, Fig. 2) and of estuarine origin in Bosman land system. Major rivers traversing the area have formed distinct valleys, 20–60 ft below the general land surface, but the drainage on the plains is poorly developed and consists of swampy depressions and gullies (Plate 9, Fig. 2). On very gentle slopes in Kworo and Yambi land systems the land surface is commonly pitted, the unconnected holes being 6–36 in. deep, 1–4 ft across, and steep-walled.* In Kworo land system stone stripes* parallel with the slopes have developed locally on slopes of 5–10° (Plate 9, Fig. 1), whilst some of the higher crests are covered with 1–3 ft of quartz and iron concretion gravel.

The soils are predominantly meadow podzolic and meadow soils with strongly mottled, slowly permeable, fine-textured subsoils and dark topsoils. The meadow podzolic soils have coarse-textured topsoils, commonly many concretions, and are mostly very strongly leached. Brown forest soils and gleyed forest soils are found on the steeper slopes towards the major streams.

The vegetation is very largely grassland, consisting of the tall *Ophiuros–Imperata* association in Bosman land system and of the short *Themeda–Ischaemum* association in Kworo and Yambi land systems, where it merges into poor stands of pure *Themeda* on gravelly rises and into *Ischaemum*–sedge communities in swampy depressions. The steeper slopes towards the rivers are commonly covered with lowland hill forest, which thus contributes to the characteristic vegetation pattern of large expanses of grassland, separated by narrow north–south-oriented strips of forest. The evidence indicates that the grasslands are of a secondary nature (Reiner and Robbins 1964) and have replaced an original but probably poorly developed forest vegetation (Haantjens, Mabbutt, and Pullen 1965).

Although most of this land is topographically very suitable for permanent cultivation, many soils are so deficient in plant nutrients that no development is possible until the fertility problems are solved. These include not only deficiencies

* A more detailed discussion of these features is given by Haantjens (1965).

of phosphate and potash but also of several trace elements, whilst commonly the nitrogen levels are also low. The problem is complicated by the strong phosphate-fixing capacity of the very acid soils. The poor physical condition of the soils, with their slowly permeable subsoils and commonly droughty sandy topsoils, makes this land essentially best suited for grazing, whilst tree crops probably cannot be grown at all. Drainage improvement, raising of the water-holding capacity of the topsoil by means of compost, green manuring, or ley pastures, and crop selection may result in increasing possibilities for arable crops. Such development would be of great importance in view of the large size of the area, its suitable topography, good accessibility, and low clearing costs. However, land development will be more costly where pitted land surfaces make land grading necessary. Wet rice-growing may offer prospects in the swampy depressions, whilst the forested slopes are more easily developed for mixed farming, with tree crops on the steepest slopes.

(*d*) *Land Systems of the Forested Alluvial Plains*

(Madang, Nubia, But, Nagam, Misinki, Palimbai. Plate 3, Figs. 1 and 2; Plate 10, Figs. 1 and 2)

Land of this category occurs throughout the non-mountainous part of the survey area. The largest areas (Nagam land system) are associated with the grass plains north of the Sepik River and occur along the coast west of Wewak.

This land consists mainly of almost level flood-plains, 5–12 ft above normal river level (Nagam and Misinki land systems), with higher terraces in Nagam land system (Plate 3, Fig. 2). It also includes the scattered levee and scroll land (Plate 10, Fig. 2) of Palimbai land system, 10–20 ft above low-water level along the Sepik River, the 8–20 ft high beach ridges and swales of Nubia land system, the slightly raised (10–50 ft above sea level) plains and coral reefs of Madang land system, and the alluvial screes and fans of But land system, all of which have a slightly stronger relief than the flood-plains. Flooding is severe on the levee-type country in the Sepik flood-plain (Misinki and Palimbai land systems), but generally of much less importance on the flood-plains of Nagam land system.

The soils are mainly recent alluvial soils of medium to fine texture and the latter in particular are mostly poorly drained. Older brown alluvial soils with well-developed topsoils are locally found on higher terraces and are common in But and Nubia land systems. They are coarse-textured on the beach ridges. Shallow black rendzinas cover the coral reefs of Madang land system.

The vegetation consists predominantly of forest, which ranges from a tall three-layered mixed rain forest on well-drained land, with a canopy at 100 ft or over and occasional emergent trees up to 140 ft high, to a lower two-layered forest, poor in species but locally rich in tall palms or sago palms, on poorly drained or seasonally inundated land. Levee forest (Plate 10, Figs. 1 and 2), which ranges from low stands of pioneering trees to a forest approaching that of the well-drained plains and which is commonly very rich in *Ficus* sp., is found on the severely flooded levees and scrolls of Misinki and Palimbai land systems. Where land systems of this group border the sea (But, Madang, and Nubia land systems), a narrow strip of strand woodland is found, characterized by such trees as *Barringtonia*, *Calophyllum*, and *Hibiscus*. In these coastal areas the natural vegetation has been largely destroyed and replaced by garden regrowth, tall grassland, and coconut groves. The most poorly drained areas in this group of land systems have a vegetation of sago palm communities and locally mangroves along the coast.

The high soil fertility and level topography make this potentially the most productive land for permanent cultivation in the area. Large areas require drainage improvement, whilst present land use potential is restricted to grazing in some parts because of periodic flooding. In Nagam land system especially, but also in Misinki land system, flood control appears to be possible and would greatly increase the range of crops that can be grown. But this range may remain limited on poorly drained very heavy clay soils, where wet rice-growing and grazing offer the greatest possibilities.

(*e*) *Land Systems of the Sago, Grass, Forest, and Mangrove Swamps*

(Pandago, Kabuk, Sanai, Pora, Kobar, Murik. Plate 3, Fig. 2; Plate 4, Figs. 1 and 2)

Apart from small occurrences associated with the grass plains (Section II(*c*)) and along the north coast, this land occupies the wide flood-plain and deltaic region of the Sepik River and its tributaries.

The subdivision into land systems in this area is based primarily on vegetation differences, corresponding with differences in swampiness and duration and depth of flooding. The order of increasing swampiness is roughly: Pandago–Sanai–Kabuk–Pora–Kobar. The order of increasing flooding is: Kobar–Pora–Pandago–Kabuk–Sanai. Whilst much of Pandago land system has water-tables well below the ground surface in the dry season, the water level remains largely well above the surface throughout the year in Kobar land system. But seasonal variations in water level are very small in Kobar land system, whereas Sanai land system is flooded to a depth of about 10 ft during the whole wet season.

Degree of flooding appears to have the most decisive influence on the vegetation, which consists largely of different types of tall swamp forest, low swamp woodland, and herbaceous fern–sedge swamp in Kobar and Pora land systems, sago palm communities in Pandago land system, sago palm–*Phragmites* swamp in Kabuk land system, and *Phragmites* and mixed grass swamp (Plate 11, Figs. 1 and 2) in Sanai land system, which also has much aquatic vegetation (Plate 12, Fig. 2) in its numerous shallow lakes. Narrow strips of very tall *Saccharum* cane grass line the slightly higher or better-drained banks of all rivers (Plate 10, Fig. 2) and natural drainage channels.

The soils are swampy plastic alluvial heavy clays, black alluvial clays, and various types of organic soils, the last being particularly common in Pora and Kobar land systems.

Murik land system has a special position in this category as an area of tidal mangrove swamps with mangrove peat soils.

Present land use potential is confined to the exploitation of the rather meagre sago resources of Pandago land system. In view of the high soil fertility, particularly of the black peat soils, swamp reclamation could yield large areas of valuable land in Pandago and Pora land systems. Land use possibilities might be restricted on puggy heavy clay soils to wet rice-growing, grazing, and a limited number of arable crops, but on medium-textured alluvial soils and black peat soils a large range of crops might be grown. Reclamation, which is at present a purely academic problem, would involve flood control by levee banks and artificial drainage. Some technical problems to be overcome would be the foundation of levee banks in areas with soft deposits, and the effect of empoldering on raising flood levels more upstream. Reclamation appears to be impossible or not worth considering in Kabuk, Sanai, Kobar, and Murik land systems, partly because of the great depth of flooding, partly because of the very poor physical condition of the soils. It might be possible to establish freshwater fish ponds in Kobar land system and exploit the mangrove bark for tannin in Murik land system.

III. Notes on Tabular Descriptions

(a) General

The tabular descriptions are necessarily compact and short. Therefore, the reader has to refer to other relevant parts of the report when more detailed information is required on geomorphology, soils, vegetation, and forest resources. The index in the back of the report will facilitate this. Names in the Soils column refer to soil families.

The terms used and figures given for population and land use are defined in Part VIII. As a generalization, it can be said that the population living on a land system use land for cultivation only on that land system. Where this assumption is grossly misleading, a comment is made.

Areas of land systems have been determined with a dot grid of 100 dots per square inch, and have been rounded off to the nearest square mile for land systems less than 20 sq miles in size, to the nearest 5 sq miles for those between 20 and 100 sq miles, and to the nearest 10 sq miles for those over 100 sq miles in size. Areas of land units are estimates based on photo interpretation and field observation.

(b) Block Diagrams and Plans

Where possible the land system descriptions are illustrated by block diagrams or plans, the latter for land systems with very little relief. Some care should be exercised in the interpretation of these illustrations.

(1) It is impossible to draw all diagrams to the same scale. However, the approximate scale in miles is indicated and approximate height figures give an idea of the relief. Each diagram should be viewed in relation to these scale indications, otherwise a wrong impression may be gained.

(2) It is normally impossible to assign to the land units the same relative area in the block diagram as they occupy in the whole of the land system. In general, large units are shown too small, small units too large. In some cases very small units even have to be shown at a slightly larger scale than that of the diagram as a whole.

(3) Although every illustration is actually drawn from aerial photographs, the block diagrams are commonly abstract compositions of all the units, each or some having been derived from different photographs.

(c) Drainage Classes

The drainage status of the land units is indicated in terms of the following six land drainage classes, which are similar to those described in the Soil Survey Manual of the United States Department of Agriculture (1951), except that class 5 of the manual has been omitted.

(i) *Swamp (permanent or seasonal).*—Water is removed so slowly that the water-table remains over or near the surface permanently or for a large part of the year. The soils are strongly gleyed throughout the profile, in many cases prominently rusty mottled and/or containing half-decomposed plant remains. These gley phenomena are commonly less pronounced in seasonal swamps.

(ii) *Very Poorly Drained.*—Water is removed so slowly that the soil remains saturated for a long part of the year. The water-table is commonly at or near the surface for considerable periods. The soils have distinct mottles and grey colours, starting above 9 in. depth.

(iii) *Poorly Drained.*—Water is removed from the land slowly enough to keep the soil saturated for significant periods, especially in the subsoil. Shallow water-tables may occur for considerable periods. The soils have distinct mottling and grey colours, starting between 9 and 20 in. depth.

(iv) *Imperfectly Drained.*—Water is removed from the land somewhat slowly, so that the soil is wet for short but significant periods, especially in the subsoil. Shallow water-tables may occur, but only for short periods. The soils have distinct mottling and grey colours, starting between 20 and 44 in. depth.

(v) *Well Drained.*—Water is removed from the land readily but not rapidly. The soil is rarely too wet and rarely too dry. The water-table remains well below the ground surface. There are no indications of gleying in the soils above 44 in. depth.

(vi) *Excessively Drained.*—Water is removed from the land very rapidly. The soil is too dry for significant periods.

IV. References

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Haantjens, H. A., Mabbutt, J. A., and Pullen, R. (1965).—Environmental influences in anthropogenic grasslands in the Sepik plains, New Guinea. *Pacif. Viewpt* 6, 215.

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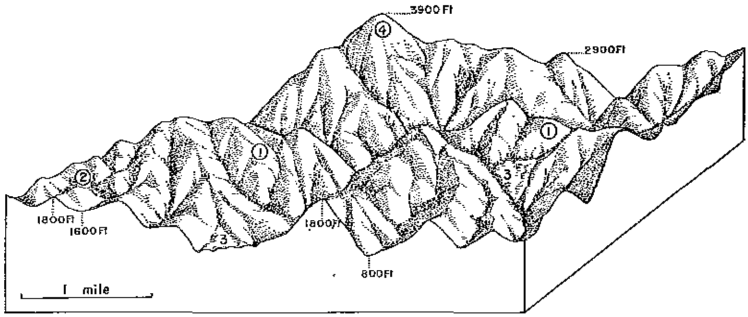
United States Department of Agriculture (1951).—Soil survey manual. Agric. Handb. No. 18.

(1) Turu Land System (170 sq miles)

Rugged mountains of igneous rock in the Prince Alexander Mountains and Kairiru Island.

Geology.—Probably Pliocene: intrusive rocks (amphibolite, pyroxenite, gabbro), widespread and typical of highest parts; extrusive rocks (basalt mainly on Kairiru Island, andesite, trachyte, submarine tuff). Strongly uplifted and faulted on mainland.

Physical Features.—Mountains between sea level and 4000 ft: rugged, deeply dissected areas with steep slopes, mainly up to 3000 ft above sea level, with minor peaks up to 3980 ft; landslide scars and colluvial aprons; headwater areas of close, narrowly incised drainage with short, joint-controlled tributary valleys; minor areas of smaller dissection and accordant lower ridges; relief up to 1500 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	150 sq miles. Throughout land system	Mountain ridges and slopes below 3000 ft: undulating narrow ridge crests and secondary spurs with dissected slopes, 25–40°, small benches and shoulders; minor precipitous escarpments and landslide scars; relief 400–1500 ft	Mainly brown forest soils (Yaugiba) with commonly friable yellow clays (Turu) above 1500 ft. Locally uniform red clays (Aricone) commonly on small spurs. On precipitous slopes presumably shallow stony brown soils and lithosols. Well drained	Lower ranges forest
2	9 sq miles. Mainly between Dagua village and Hawain River and in eastern part of Kairiru Island	Hill ridges: accordant rounded ridge crests, irregular strongly dissected slopes (25–35°), relief 200–300 ft	Presumably brown forest soils (Yaugiba) with locally uniform red clays (Aricone). Well drained	Garden regrowth and some lowland hill forest
3	7 sq miles. Scattered in major valleys at foot of steepest mountain ridges. Mainly in western part of land system	Colluvial aprons: irregular dissected slopes, 10–20°, up to 1 sq mile in extent	Presumably stony brown colluvial soils. Well drained	Lower ranges forest
4	4 sq miles. Summit areas of Mt. Turu, Mt. Wesagunimi, and Kairiru Island	Mountain peaks above 3000 ft: straight, little-dissected slopes, 30–40°, attaining 4000 ft above sea level; minor benches and shoulders and narrow rounded crests	Friable yellow clays (Turu). Well drained	Lower montane rain forest merging into lower ranges forest on lower slopes

Population and Land Use.—300 people using 8 sq miles of the periphery and lower occurrences of unit 2 at moderate intensity.

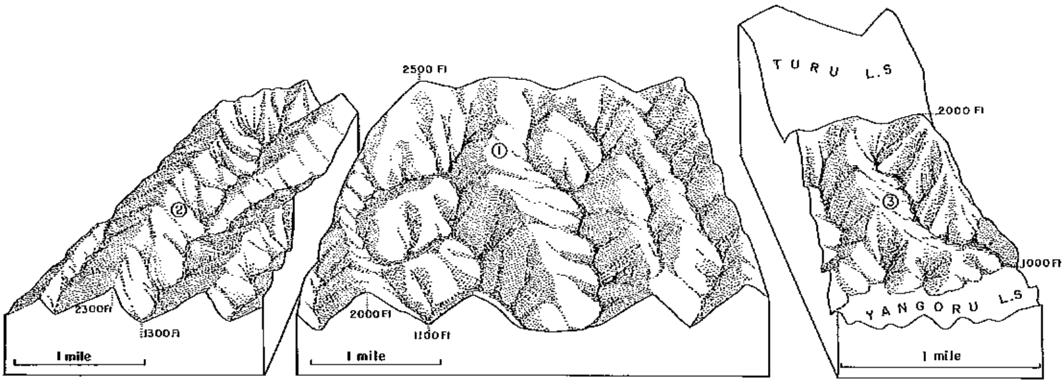
Assessment.—Because of its ruggedness this land is unsuitable for agriculture or is very marginal for tree crops and grazing. Small pockets of land, suitable for tree crops or grazing, occur in units 2 and 3, but are generally inaccessible. The importance as a catchment area makes it desirable to maintain the forest cover, but inaccessibility will make exploitation of the forest resources, which are of moderate commercial value, very difficult, except along the northern edges.

(2) Nagapam Land System (250 sq miles)

Very rugged mountains of sedimentary rocks in the Prince Alexander Mountains.

Geology.—A basement rock of gneiss (more to the west) and amphibolite is covered by upper Miocene and Pliocene rocks: massive interbedded marine siltstone and mudstone, with minor areas of cavernous coral reef limestone; warped in a broad anticline, and strongly block-faulted; narrow zone of schist south of Mt. Turu.

Physical Features.—Mountains below 3000 ft; rugged, deeply dissected areas, mainly of short ridges, locally of NW.–SE. strike ranges; close, deeply incised, fault-controlled drainage, with larger valleys trending WNW. and tributary valleys commonly following NNE. cross-faults; transverse gorges through strike ranges; relief up to 2000 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	200 sq miles. Central and eastern part of land system	Short mountain ridges: narrow to rounded crests; slopes 20–35°, with minor benches and shoulders, dissected into sharp spurs; relief 1000–1500 ft	Brown forest soils (Nagapam) and locally uniform yellow clays (Turu) above 1500 ft. Well drained	Lower ranges forest and some garden regrowth
2	44 sq miles. Western part and southern fringe of land system	Strike ridges: long narrow crests; dip slopes, 15–30°; outcrop slopes, 25–40°, with narrow benches; relief 1000–1500 ft	Largely similar to unit 1. Also observed were gravelly brown forest soils (Kamesal). On steepest slopes presumably shallow stony brown soils and lithosols. Well drained	Lower ranges forest
3	6 sq miles. Narrow belt south of Mt. Turu	Short schist ridges: short narrow-crested ridges with long dissected slopes, 25–40°; relief 500–1200 ft	Shallow stony brown forest soils (Ambakanya). Well to excessively drained	Mainly garden regrowth with some remnants of lower ranges forest

Population and Land Use.—1300 people using 22 sq miles of unit 3 and broader ridge crests and gentler upper hill slopes of unit 1 at low intensity.

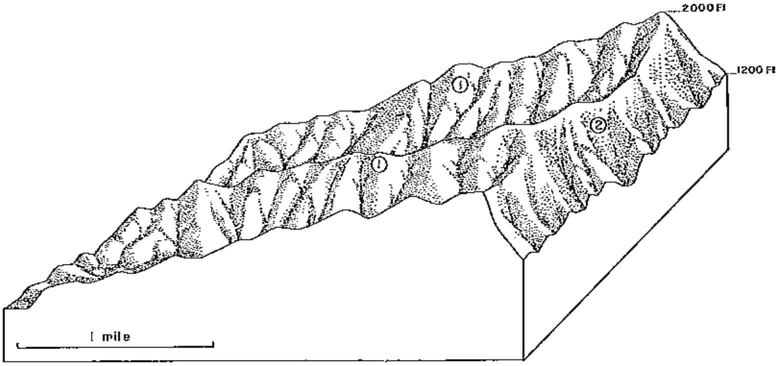
Assessment.—This land is so rugged that it is only marginally suitable for tree crops, except parts of unit 2, with less steep slopes, which are quite suitable for tree crops or grazing, but are poorly accessible. In view of its importance as a catchment area, this land is best kept under forest. Although it comprises large areas of forest of moderate commercial value, their exploitation appears to be most difficult.

(3) Imbia Land System (25 sq miles)

Very rugged serrated mountain ridges of sedimentary rock with shallow soils in the south-west of the Prince Alexander Mountains.

Geology.—Pliocene: massive marine mudstone and siltstone with thinner beds of sandstone and pebble conglomerate, and coral limestone locally; forming faulted southern limb of broad coastal anticline.

Physical Features.—Mountains between 600 and 2000 ft; a broad strike ridge with a steep, north-facing escarpment, and dip slopes up to 3 miles long broken by parallel valleys into ridges up to 1 mile wide; the dip slope ridges have a chevron pattern of secondary strike spurs; relief up to 1000 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	22 sq miles. Major part of land system	Dip slope ridges: ridge crests broken into numerous chevron strike spurs; slopes 20–40°; relief up to 1000 ft	Presumably brown forest soils (Nagapam, Kamesal) with shallow stony soils on precipitous slopes. Well drained	Lower ranges forest. Garden regrowth and secondary forest on lower slopes
2	3 sq miles. Along northern edge curving southward along major streams traversing land system	Escarpments: 500–1000 ft high, slopes 35–45°, with close, shallow dissection; less steep colluvial aprons at foot	Presumably shallow stony soils and lithosols. Excessively drained	Lower ranges forest

Population and Land Use.—700 people using 8 sq miles of the ridge crests and upper hill slopes of unit 1 at moderate intensity.

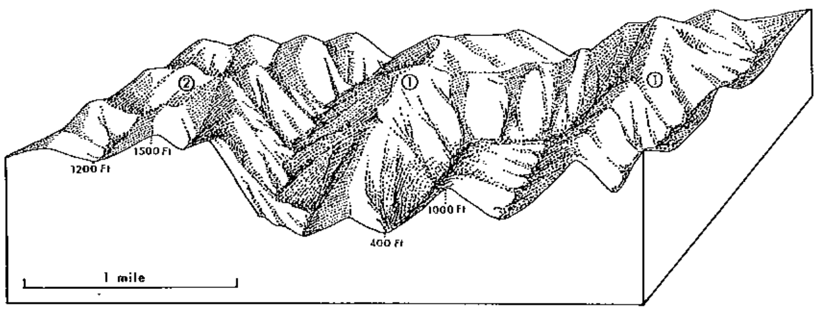
Assessment.—This land is either unsuitable or marginally suitable for tree crops and grazing. Where the forest vegetation is destroyed by shifting cultivation, reafforestation would be the most appropriate form of land use. Although difficult, commercial exploitation of reafforested areas appears to be possible.

(4) Numoiken Land System (140 sq miles)

Low mountains of sedimentary rocks in the eastern parts of the Prince Alexander Mountains.

Geology.—Pliocene: massive marine mudstone and siltstone with minor thin pebble conglomerate: mixed volcanic rocks, mainly metamorphosed dolerite, near northern margin; gently up-arched, and forming part of coastal fault zone.

Physical Features.—Mountains between 100 and 1500 ft; an irregular pattern of steep narrow ridges, higher near the more dissected northern margin and lower in the central watershed area; close fault-controlled pattern of narrow valleys; relief up to 800 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	110 sq miles. Throughout land system	Higher ridges: narrow crests; slopes 20–30°, dissected into sharp spurs; relief 400–800 ft	Brown forest soils (Nagapam), locally shallow (Abauge). Also local black earths (Pagoma). Pockets of gleyed forest soils (Witibi). Well drained	Lowland hill forest, garden regrowth, and secondary forest
2	30 sq miles. In central part of land system close to the main water divide	Accordant lower ridges: narrowly rounded crests and strongly dissected slopes, 20–30°; relief 200–400 ft	Brown forest soils (Nagapam). Locally shallow (Abauge), and with pockets of gleyed forest soils (Witibi). Well drained	Lowland hill forest, locally garden regrowth

Population and Land Use.—3100 people using 20 sq miles on crests and less steep upper hill slopes of units 1 and 2 at moderate intensity.

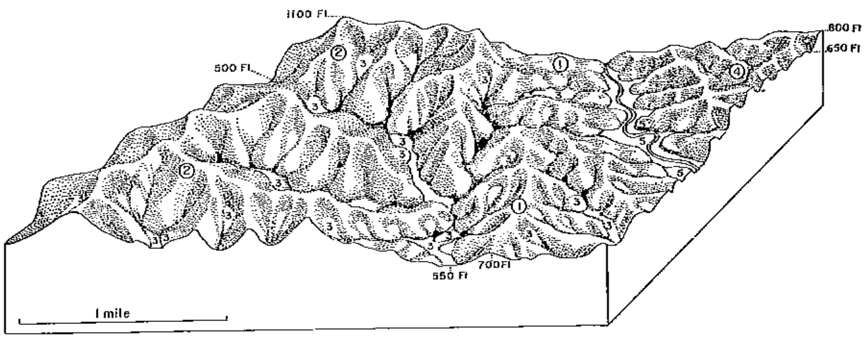
Assessment.—By far the greater part of this land system comprises land very marginal for tree crops and grazing. Small areas with less steep and shorter slopes, especially in unit 2, are more suitable, particularly for grazing. Much of the land is covered with forest of moderate commercial value, and as the land system forms part of the main catchment area in this region, protection of forest cover is desirable, with only local inclusions of grazing and tree-crop land. However, access is difficult, even for forestry purposes.

(5) Kaboibis Land System (160 sq miles)

Extremely dissected steep hill ridges of sedimentary rock with shallow soils south of the Prince Alexander Mountains.

Geology.—Mainly Pliocene, with minor exposures of Upper Miocene rocks: massive marine mudstone and siltstone with minor marl and coral limestone in the east, and pebble conglomerate locally in the central part; part of faulted south limb of coastal anticline.

Physical Features.—Hills between 600 and 1200 ft: strongly dissected, high hilly areas with an intricate pattern of branching ridges with narrow crests and steep to moderate slopes; flat-crested limestone ridges in the east; narrow, through-going valleys with discontinuous low terraces, and close, branching tributary valleys with rounded valley heads and poorly drained floors with much colluvial fill; higher ridges in the north and west with up to 600 ft relief; relief decreases southwards to 200 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	70 sq miles. Southern part of land system, interfingering with unit 2 or bounded by minor faults	Lower ridges: short, narrow crests; irregular locally benched slopes 15–30°; bevelled lower spurs; relief 150–300 ft	Brown forest soils (Nagapam) and shallow black earths (Pagoma). Locally lithosols. Well to excessively drained	Extensive areas of *Ophiuros–Imperata* grassland. Much garden regrowth with remnants of lowland hill forest. Some *Polytoca–Sorghum* grassland, mixed association grassland, and local patches of *Themeda–Arundinella* grassland
2	50 sq miles. Northern part of land system, interfingering with unit 1 or bounded by minor faults	Higher ridges: undulating narrow rounded crests; little-dissected, slightly concave slopes, 20–35°, with prominent short spurs; relief 300–600 ft	Brown forest soils (Nagapam), commonly very shallow (Abauge, Kaboibis). Locally lithosols, especially on crests. Well to excessively drained	Remnants of lowland hill forest with much secondary phase and garden regrowth. Small local patches of *Polytoca–Sorghum* grassland and *Ophiuros–Imperata* grassland
3	25 sq miles. Scattered in association with units 1 and 2	Colluvial toes, valley heads, and valley fill: concave slopes 10–20° in valley heads, 5–10° on toes, 2–5° on surfaces of valley fill	Dark colluvial soils, mostly fine-textured (Winge), locally sandy (Kwaliangu). Poorly to imperfectly drained	Garden regrowth and secondary phases of lowland hill forest with *Ophiuros–Imperata* grassland
4	10 sq miles. Eastern part of land system	Low limestone ridges: winding, flattish crests; convex slopes, 20–35°, with numerous short spurs; relief up to 200 ft	Rendzinas (Passam) and black earths (Tonembi). Well to excessively drained	Garden regrowth with patches of *Ophiuros–Imperata* grassland, *Polytoca–Sorghum* grassland, mixed association grassland, and lowland hill forest
5	5 sq miles. Along major through-going streams	Alluvial terraces and flood-plains: flattish terraces up to 300 yd wide, 5–15 ft above flood-plains; flood-plains up to 100 yd wide, with gravel and sand, regularly flooded	Mainly medium-textured young alluvial soils. Poorly to well drained	Garden regrowth and river terrace succession

Population and Land Use.—15,800 people using 123 sq miles of all units at high intensity.

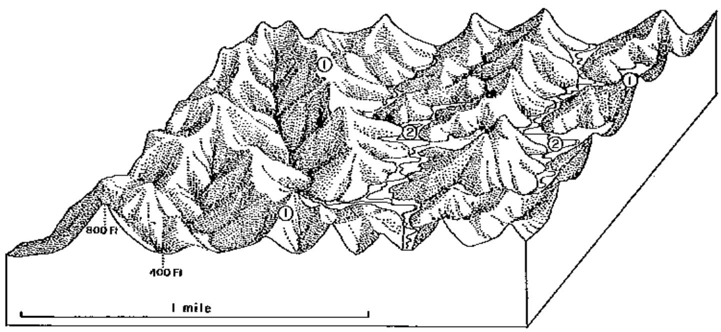
Assessment.—A large part of this land system, mainly in units 1, 3, and 4, offers possibilities for tree crops and grazing, whilst a somewhat smaller proportion appears to be suitable only for forestry, because of very steep slopes and/or very shallow soils. As very little natural forest exists, there is a case for reafforestation on a large scale. Small areas of units 3 and 5 are suitable for permanent cultivation, although erosion control measures are generally necessary.

(6) Yangoru Land System (9 sq miles)

Steep hills of schist with shallow stony soils between Mt. Turu and Yangoru.

Geology.—Probably pre-Tertiary: schist, strongly folded and contorted.

Physical Features.—Hills between 700 and 1000 ft: strongly dissected, high hilly areas with a very close pattern of branching ridges and isolated hills with steep slopes; very close drainage pattern of narrow, through-going valleys with discontinuous terraces, and short tributary channels; relief up to 400 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	7 sq miles. Throughout land system	Hills and ridges: ridges with narrow, very uneven crests with pronounced hill summits; isolated, conical hills; slopes, 25–40°; relief 200–400 ft	Shallow stony brown forest soils (Ambakanya) and locally lithosols. Well to excessively drained	*Polytoca–Sorghum*, *Ophiuros–Imperata*, and mixed association grassland. Some *Themeda–Arundinella* grassland on dry sites. Much garden regrowth and remnant lowland hill forest
2	2 sq miles. Along major streams traversing land system	Alluvial terraces and flood-plains: flattish terraces up to 100 yd wide, 5–15 ft above flood-plains; flood-plains up to 50 yd wide, with sand and boulders, regularly flooded	Medium-textured young alluvial soils. Well to poorly drained	Garden regrowth and river terrace succession

Population and Land Use.—1200 people using 9 sq miles of all units at high intensity. Land use is generally restricted to crests, upper hill slopes, and flood-plains.

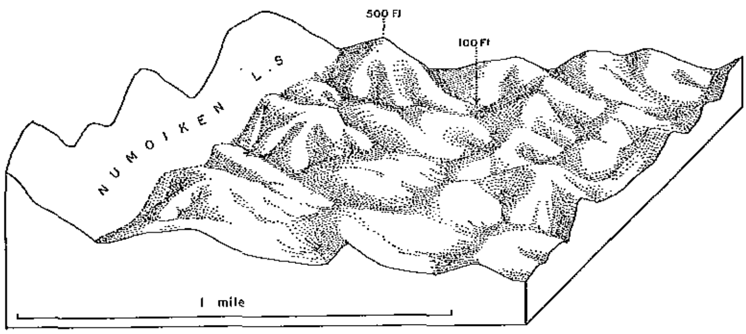
Assessment.—Because of very steep slopes and very shallow soils, this land is suitable only for forestry, or as marginal grazing land. Reafforestation is desirable, as there is virtually no natural forest left. Very little arable land is found in unit 2.

(7) WONGINARA LAND SYSTEM (35 SQ MILES)

Foothills and hilly mountain basins in the northern part of the Prince Alexander Mountains.

Geology.—Pliocene: marine mudstone and siltstone, with minor areas of tuffaceous greywacke; part of down-faulted north limb of coastal anticline, with variable dips.

Physical Features.—Hills between 100 and 800 ft; closely dissected foothills and basins, with short ridges and hills; short valleys tributary to adjacent plains.



Land Form.—Ridges and hills: short, rounded ridge crests, and rounded hill summits; moderately dissected slopes, 15–30°; relief 200–400 ft.

Soil and Drainage Status.—Brown forest soils (Nagapam) and locally gleyed forest soils (Witibi). Commonly well and locally poorly drained.

Vegetation.—Lowland hill forest and garden regrowth.

Population and Land Use.—*1000 people using 4 sq miles of unit 1 at moderate intensity only near Wonginara and Boiken villages.*

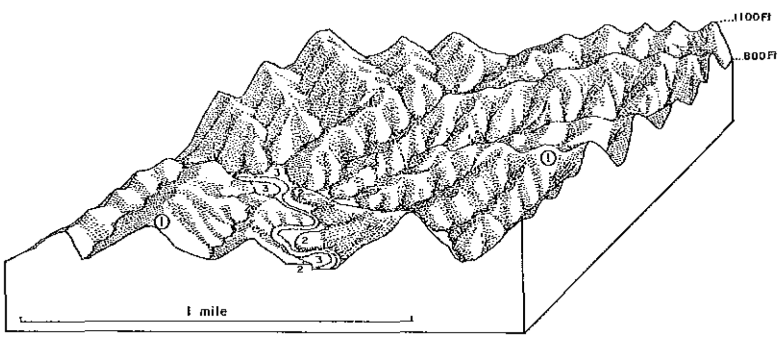
Assessment.—This land system is partly moderately suitable and partly marginal for tree crops and grazing. Locally there are easily accessible forest resources of moderate commercial value.

(8) Kumbusaki Land System (13 sq miles)

Hilly, extremely dissected mudstone uplands in the western part of the Prince Alexander Mountains.

Geology.—Pliocene: massive marine mudstone, with thinner interbedded siltstone, pebble conglomerate, and, locally, coral limestone; amphibolite is exposed locally in lowest parts; gold-bearing alluvium in Screw River; a fault-basin within the coastal anticline.

Physical Features.—Hills between 800 and 1300 ft; a mountain basin in which mudstones have been very closely dissected into an intricate pattern of short, narrow-crested ridges; closely drained by the branching headwaters of the Screw River; relief up to 400 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	11 sq miles. Major part of land system	Ridges: short, narrow crests; closely and deeply dissected slopes, 20–35°, irregular and liable to mud creep; relief 200–400 ft	Brown forest soils (Nagapam, Kamesal). Well drained	Lower ranges forest
2	1 sq mile. Mainly along Screw River	Higher terraces: slightly undulating surfaces up to 200 yd wide, 30–40 ft above flood-plains	Medium-textured young alluvial soils. Well drained	Garden regrowth and well-drained alluvium forest
3	1 sq mile. Mainly along Screw River	Lower terraces and flood-plains: slightly undulating terrace surfaces up to 100 yd wide, and 5–10 ft above flood-plain; flood-plains up to 50 yd wide, with boulders and sand, regularly flooded	Medium- and coarse-textured young alluvial soils. Well drained	Garden regrowth and river terrace succession

Population and Land Use.—Nil.

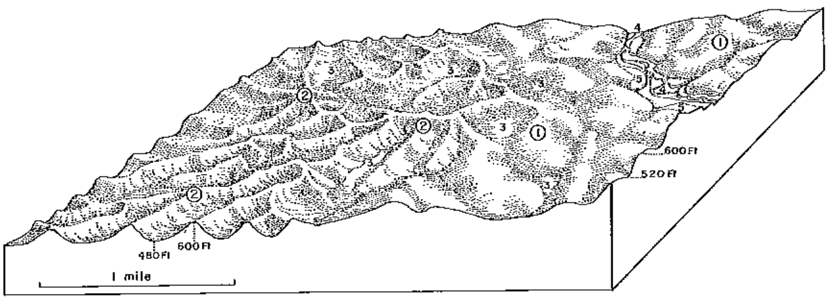
Assessment.—This land is marginal for tree crops and grazing and is covered with forest of moderate commercial value, exploitation of which, though difficult, appears to be possible. There are very small areas suitable for cropping in units 2 and 3.

(9) Winge Land System (65 sq miles)

Low, mainly grass-covered hills with shallow soils south-east of Maprik.

Geology.—Pliocene: massive marine mudstone, siltstone, and interbedded thin sandstone and pebble conglomerate; gentle southward dips on south limb of coastal anticline.

Physical Features.—Hills between 400 and 700 ft: a complex of higher, steep-sided ridges and rounded lower ridges with gentler slopes; through-going drainage, with alluvial flood-plains and terraces, and short tributary valleys with steep, amphitheatral heads with colluvial aprons and valley fills; relief 50–150 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	25 sq miles. Scattered areas	Lower, rounded ridges: short, undulating, rounded crests; slightly convex slopes, 10–20°, locally with pitted surface; relief 50–100 ft	Mainly black earths (Pagoma, very little Tonembi) with locally uniform yellow clays (Boen). Well to excessively drained	Garden regrowth and some lowland hill forest; mixed association, *Ophiuros–Imperata*, and *Polytoca–Sorghum* grassland
2	23 sq miles. Scattered areas	Higher, steeper ridges: straighter, sharp crests; slightly concave slopes, 15–30°; relief 100–150 ft	Brown forest soils, commonly shallow (Nagapam, Abauge, little Kamesal). Very locally shallow black earths (Pagoma) and dark colluvial soils (Winge). Well to excessively drained	*Ophiuros–Imperata* and *Themeda–Ischaemum* grassland complex
3	13 sq miles. Closely associated with units 1 and 2	Colluvial toes, valley heads, and valley fills: concave slopes, 2–10° up to 200 yd long	Mainly dark colluvial soils (Winge, less Sima) with some alluvial black clays (Kasamp, Mungin) in wider valley bottoms, very locally gleyed red earths (Wawat). Commonly medium-textured old alluvial soils (Dumpu) in small valleys associated with land unit 2. Imperfectly to poorly drained. Old alluvial soils well drained	*Themeda–Ischaemum* grassland complex, *Ischaemum–Apluda* grassland. Some garden regrowth
4	3 sq miles. Along through-going streams	Lower terraces and flood-plains; discontinuous terraces, 5–10 ft above flood-plains; flood-plains up to 50 yd wide, regularly flooded	Medium-textured young alluvial soils. Well drained	Remnants of well-drained alluvium forest and garden regrowth with some river terrace succession on flood-plain
5	1 sq mile. Along major streams	Higher terraces: discontinuous surfaces up to 200 yd wide and 10–20 ft above flood-plains	Variable: meadow soils (Yari, Roma), alluvial black clays (Mungin), dull meadow podzolic soils (Soandagum), meadow podzolic soils (Paru), and uniform yellow clays (Boen). Poorly drained	Mostly mixed association grassland

Population and Land Use.—3700 people using 24 sq miles mostly of unit 1 at moderate to high intensity in the western occurrences of the land system.

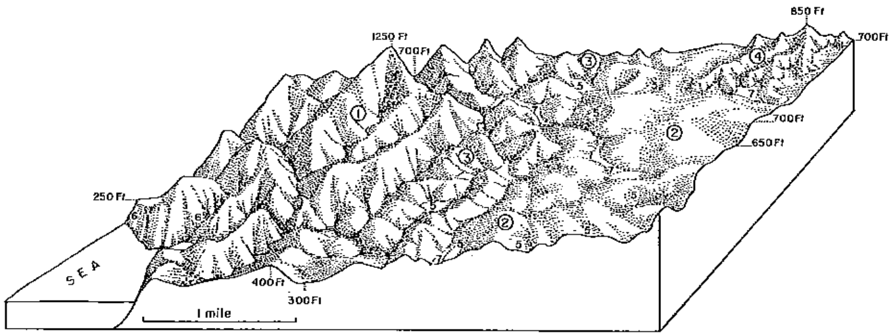
Assessment.—A moderate percentage of rather poor arable land is found in units 1, 3, 4, and 5, but may have erosion hazards or impermeable soils. The largest part of the land system is moderately good or marginal grazing land on steep slopes with shallow soils. Local reafforestation of this grassland may be advantageous for local timber and fuel supplies.

(10) Senambila Land System (160 sq miles)

Steep hills, and rolling uplands with strongly weathered soils, on igneous rock along the central coast and on Kairiru Island.

Geology.—Probably Pliocene: flat-lying, massive, fine-grained gabbro, trachyte, and diabase, locally overlain by thin marine mudstone.

Physical Features.—Hills between sea level and 1400 ft: strongly dissected coastal and central tracts, with cliffs, escarpments, and higher ridges; less dissected inland parts, with lower ridges, rounded hills, and rolling terrain with slump features on weathered slopes; a watershed area, with deeply incised, short coastal rivers, and less incised valleys with narrow floors in the south-west; relief up to 800 ft in the coastal sector and up to 200 ft near the watershed.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	62 sq miles. Northern and north-eastern part of land system	Higher ridges: sharp crests rising to small summits; long, strongly dissected slopes, 20–35°; relief 200–600 ft	Brown forest soils (Nagapam, Yaugiba). Locally friable uniform yellow clays (Turu) on highest ridges. Well drained	Lowland hill forest
2	50 sq miles. Central and western part of land system	Rolling terrain: a complex of rounded hills with broad crests and convex slopes, 5–20°; relief 50–150 ft	Uniform red and yellow clays (Aricone, Numarin, little Boen) and gleyed red earths (Wawat) on rolling land. Meadow podzolic and meadow soils (Solai, Roma) on gently undulating land. Well to poorly drained	Grassland of mixed association, *Themeda–Arundinella*, and *Themeda–Ischaemum* complex. Lowland hill forest remnants in many valleys
3	35 sq miles. Eastern and south-eastern part of land system, interfingering with unit 2	Lower ridges: irregular, narrowly rounded crests, and moderately dissected slopes, 15–30°, with benches and shoulders; relief 100–200 ft	Brown forest soils (Yaugiba, little Kamesal, Kaboibis) and locally gleyed forest soils (Witibi), and shallow black earths (Pagoma) with patches of uniform red clays (Aricone) on small spurs. Mostly well drained	Lowland hill forest with, locally, garden regrowth
4	4 sq miles. Several occurrences south-west of Tring village	Convex hills: rounded summits up to 200 ft high; gullied convex slopes, 20–35°	Gleyed yellow earths (Giri). Commonly strongly truncated. Poorly or excessively drained depending on soil truncation	*Themeda–Arundinella* grassland
5	4 sq miles. Scattered, mainly associated with unit 2, less with units 3 and 4	Colluvial toes and valley fills: irregular concave slopes, 5–10°, broken by small slump scarps, and valley fills up to 100 yd wide	Gleyed yellow earths (Giri) and podzolic red earths (Rabiawa). Poorly to very poorly drained	Lowland hill forest with some garden regrowth, and *Themeda–Ischaemum* grassland complex where associated with unit 2
6	3 sq miles. Along coast and bounding valleys of north-flowing rivers	Cliffs and escarpments: coastal cliffs up to 200 ft high; closely dissected coastal and inland escarpments up to 800 ft high; slopes 40–50°	Presumably shallow stony brown soils and lithosols. Well to excessively drained	Lowland hill forest
7	2 sq miles. Scattered, mainly associated with unit 2, less with units 3 and 4	Valley bottoms: up to 50 yd wide	Plastic heavy clay young alluvial soils. Poorly to very poorly drained	Mixed flood-plain forest and sago palm forest

Population and Land Use.—2000 people using 7 sq miles of units 2, 3, and 5 at low to moderate intensity. Land use is mostly in the north-west part of the land system.

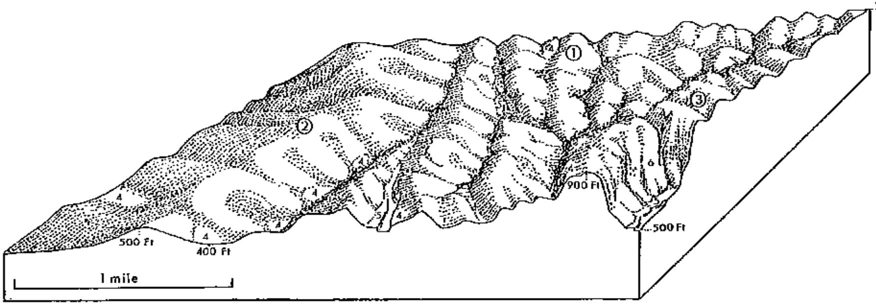
Assessment.—Land of unit 1 is very marginal for grazing or tree crops and is best kept under forest. Forest exploitation, though difficult, might be possible. Land of units 2, 5, and 7 is generally moderately suitable for mixed farming. Soil fertility and drainage problems locally require attention, and most of this land needs erosion-control measures when used for arable crops. Ley farming, with tree crops on steepest slopes, is recommended. Unit 3 appears to be moderately suitable for tree crops and grazing. It comprises large areas of forest of moderate commercial value, which could technically be rather easily exploited. Land of units 4 and 6 can be used only for extensive grazing or is unexploitable.

(11) Passoram Land System (550 sq miles)

Low hills and local rolling uplands of sedimentary rocks with complex soil pattern, north of Angoram, near Maprik, and west of Wewak.

Geology.—Pliocene: massive marine mudstone and siltstone, with areas of marl and coral limestone; gentle southward dips on south limb of coastal anticline in less uplifted eastern part.

Physical Features.—Hills between 150 and 1200 ft; areas of close but moderate dissection, with rounded topography on mudstone and siltstone, and flat-crested limestone ridges with escarpments and karst features; locally remnant upland surfaces with rolling topography; close, branching pattern of drainage, with short, rounded tributary valley heads and with narrow alluvial floors in the main valleys; relief mainly up to 200 ft, with limestone escarpments up to 500 ft locally.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	370 sq miles. Throughout land system	Low hill ridges: short, undulating, rounded crests; moderately dissected slopes 15–30°, broken by benches; relief 100–200 ft	Mainly brown forest soils (Nagapam, less Kamesal). Locally gleyed forest soils (Witibi). Very locally uniform yellow clays (Boen), shallow black earths (Pagoma), and dark colluvial soils (Kwaliangu). Mostly well drained, locally poorly drained	Mostly lowland hill forest with areas of secondary bamboo brake and garden regrowth in Maprik area. Some *Polytoca–Sorghum* grassland and some mixed association grassland
2	130 sq miles. Scattered small and large occurrences throughout land system but mainly in southern part, especially east of Nagam River	Rolling terrain: broad ridge crests and hill tops; convex slopes, 5–20°; relief 50–150 ft	Mainly meadow soils (Roma, less Yari) and meadow podzolic soils (Teringi, Parua, Yambi). Locally gleyed yellow earths (Giri). Very locally dull meadow podzolic soils (Naupi), gleyed forest soils (Witibi), and brown forest soils (Kamesal). Poorly drained, but liable to rapid drying out of the topsoil	Mainly *Themeda–Ischaemum* grassland complex with some *Ophiuros–Imperata* grassland and mixed association grassland. Patches of lowland hill forest but mostly of secondary nature
3	95 sq miles. Around Passam village, north of Angoram, and in isolated hills north-east of Timbunke	Limestone ridges: very close pattern of short, flat-crested accordant ridges; steep, convex slopes, 20–35°; deep sink-holes; relief 100–200 ft	Rendzinas (Passam) and black earths (Tonembe). Also lithosols north-east of Timbunke. Well drained	Lowland hill forest with locally much garden regrowth. *Themeda–Arundinella* grassland north-east of Timbunke
4	25 sq miles. Scattered throughout land system, associated with units 1 and 2	Colluvial aprons: concave slopes, 2–10°, up to 100 yd long	Dark colluvial soils (Winge, Sima). Uniform yellow clays (Boen). Meadow soils (Roma) and meadow podzolic soils (Yambi). Imperfectly to poorly drained	Lowland hill forest with secondary phases; *Ophiuros–Imperata* grassland and *Themeda–Ischaemum* grassland complex. Some *Polytoca–Sorghum* grassland
5	20 sq miles. Scattered throughout land system along larger streams	Alluvial terraces and flood-plains: discontinuous terraces up to 200 yd wide and up to 10 ft above flood-plains; flood-plains up to 50 yd wide, regularly flooded	Plastic heavy clay young alluvial soils. Poorly to very poorly drained	Mixed flood-plain forest and sago palm swamp
6	5 sq miles. Along valleys of major streams near Passam, associated with unit 3	Limestone escarpments: 200–500 ft high; concave slopes, 35–45°, moderately dissected by small tributary streams and gullies	Dark colluvial soils (Winge) and in the upper part rendzinas (Passam). Well to excessively drained	Lowland hill forest

Population and Land Use.—14,500 people using 59 sq miles chiefly of unit 1 but also of units 2–4 at moderate to high intensity. Land use is concentrated in the occurrences of this land system near Maprik, elsewhere it is little used or unused.

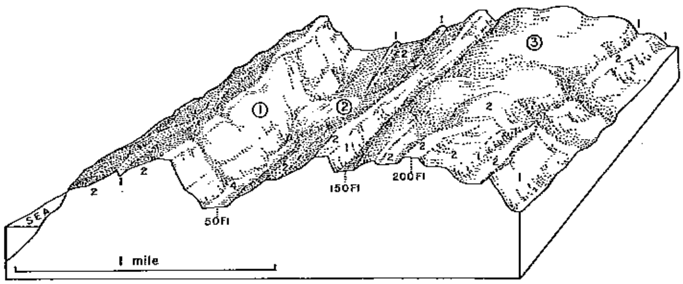
Assessment.—Land of unit 1 and part of unit 3 appears to be moderately suitable for tree crops or grazing, but the provision of access roads into large areas of this land may present problems, because of the broken nature of the terrain and the scarcity of road-building materials. There are large areas of forest of moderate commercial value, where forest exploitation could well precede further development. Scattered throughout unit 3 and also comprising unit 6 occurs land with little or no land use potential on very steep slopes with very little soil. Land of units 2 and 4 is generally more suitable for grazing than for arable crops, because of impermeable soils, commonly low soil fertility, and slight erosion hazards. Yet arable crops may contribute to a mixed farming system, possibly with ley pastures, and with tree crops on steepest slopes. Land of unit 5 is best used for pastures.

(12) Muschu Land System (12 sq miles)

Raised coral reefs and small plateaux on Muschu Island and Wewak headland.

Geology.—Probably upper Pliocene: fairly massive coral limestone, with minor outcrops of underlying Pliocene marine siltstone.

Physical Features.—Hills between sea level and 240 ft: coral platforms and ridges with steep rocky margins and linear depressions, and undulating summit areas on siltstone. Relief up to 200 ft. No surface drainage.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	6 sq miles. Throughout land system	Rocky slopes: platform margins, 20–35°, with numerous coral reef outcrops; small ridges of coral debris up to 15 ft associated with units 2 and 4	Rendzinas (Passam). Locally shallow uniform red clays on limestone (Muschu) and lithosols. Excessively drained	Lowland hill forest, coconut plantation, and some *Ophiuros–Imperata* grassland
2	3 sq miles. Many small occurrences throughout land system, closely associated with unit 3	Small plateaux and depressions in limestone at higher levels	Uniform red clays on limestone (Muschu). Well drained	Lowland hill forest and garden regrowth. Local areas of *Ophiuros–Imperata* grassland and coconut plantation
3	2 sq miles. Small areas in centre of land system surrounded by unit 1	Broad rises on siltstone: slightly rounded crests and steeper margins, 5–15°; relief 20–40 ft	Uniform yellow clays (Boen), gleyed forest soils (Witibi), and locally brown forest soils on steeper slopes. Imperfectly to poorly drained	Lowland hill forest, secondary forest, garden regrowth, and coconut plantation
4	1 sq mile. Associated with unit 2	Low-lying flat surfaces in limestone	Old alluvial clay soils (Dumpu) and plastic heavy clay young alluvial soils underlain by coral. Well drained	Lowland hill forest and garden regrowth. Local areas of *Ophiuros–Imperata* grassland and coconut plantation

Population and Land Use.—500 people using 2 sq miles mostly of units 2–4 at moderate intensity. Over 1 sq mile of non-indigenous plantation.

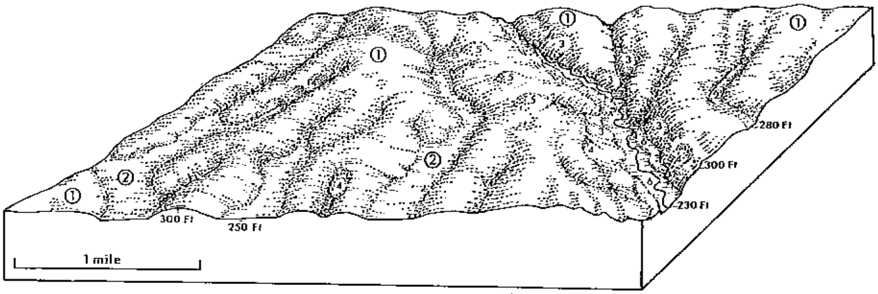
Assessment.—Good arable land is found in units 2 and 4, and land of poorer quality in unit 3, but erosion control measures are locally required. Unit 1 land is moderately suitable to marginal for tree crops and grazing, because of steep slopes, shallow soils, and stoniness. The land system has timber resources of moderate commercial value.

(13) Kworo Land System (390 sq miles)

Undulating to low hilly terrain with strongly weathered soils and grassland in the central western part of the area.

Geology.—Pleistocene: marine mudstone and siltstone in the east; little-consolidated pebble gravel, sand, and clay, west of the Nagam River; unconformably overlying south limb of coastal anticline, with very gentle southerly dips.

Physical Features.—Hills between 250 and 400 ft: with moderate slopes, rounded and locally gravelly crests; extensive remnant upland surfaces with minor slump scarps; shallow, unchannelled tributary valleys and entrenched main drainage with alluvial flood-plains and terraces; relief up to 80 ft.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	260 sq miles. Throughout land system	Undulating terrain: broadly rounded crests, with convex slopes, 2–10°; extensive pitted land surface; relief 20–80 ft	Predominantly meadow podzolic soils, commonly dull and sandy (Kworo, Minjim, Parua, Yambi, Kiniambu, Soandagum, Urimo, Naupi). Very locally podzolic red earths (Komburaga), meadow soils (Yari, Roma), and dark colluvial soils (Kwaliangu). Poorly drained but liable to quick drying out of topsoils	*Themeda–Ischaemum* grassland complex. Patches of garden regrowth and lowland hill forest remnants in northern part, also some *Ophiuros–Imperata* and mixed association grasslands
2	60 sq miles. Throughout land system associated with unit 1, mainly in southern part	Tributary valley heads: shallow, unchannelled depressions up to 200 yd wide	Meadow podzolic soils (Yambi), commonly dull and sandy (Kiniambu, Urimo), meadow soils (Yari, Roma), and alluvial black clays (Mungin). Very poorly drained to swampy	*Ischaemum–Apluda* grassland and *Scleria* sedge swamp
3	30 sq miles. Along well-defined drainage lines. Benches along major streams	Valley-side slopes and benches: concave slopes, 8–20°, rising to 80 ft above valley floors, and gently sloping surfaces up to 300 ft wide forming benches with locally deeply pitted surfaces	Predominantly brown forest soils (Nagapam, Kamesal), and gleyed soils (Witibi) and very locally shallow black earths (Tonembe). Locally on gentle slopes red earths (Ravendagum, Rabiawa) and meadow soils (Roma). Well to poorly drained	Lowland hill forest and garden regrowth
4	20 sq miles. Scattered small occurrences, mainly close to well-incised streams and on steepest slopes	Slump scarps and toes: uneven, gullied surfaces backed by escarpments up to 10 ft high	Scarps formed in meadow podzolic soils or podzolic red earths (Komburaga). Toes range from dark colluvial soils (Winge) to yellow earths (Kumbi). Imperfectly to excessively drained	*Themeda–Arundinella* grassland and *Themeda–Ischaemum* grassland complex
5	10 sq miles. Scattered small occurrences in northern and central part of land system	Gravel-capped crests: flattish-crested rises, 20–40 ft high and up to 200 yd diam.; smooth, convex slopes, up to 10°, with stone stripes	Gravelly meadow podzolic soils (Teringi), locally podzolic red earths (Rabiawa) and gleyed red earths (Tring). Excessively drained but with poorly drained subsoils	*Themeda–Arundinella* grassland
6	10 sq miles. Along major streams traversing land system	Alluvial terraces and flood-plains: discontinuous terraces up to 100 yd wide, 5–10 ft above flood-plains; flood-plains up to 50 yd wide, regularly flooded	Plastic heavy clay young alluvial soils and medium-textured young alluvial soils, the latter mostly in the upper valleys. Imperfectly to poorly drained	Alluvium forests. Locally sago palm swamp

Population and Land Use.—3300 people using 17 sq miles of units 1 and 3 at moderate intensity almost exclusively in the northern occurrences of the land system.

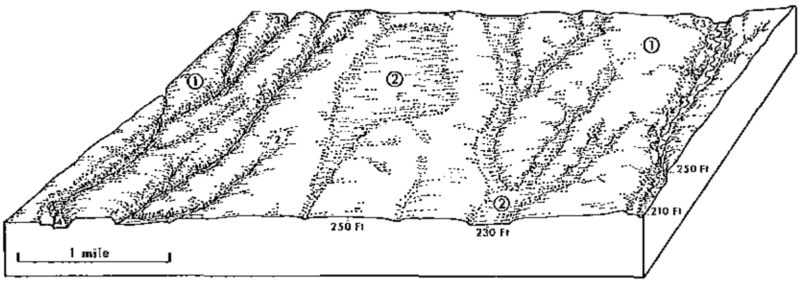
Assessment.—Very low soil fertility forms a serious problem in a very large part of this land system, particularly units 1, 2, 4, and 5. Any form of land use here will depend for its success on the solution of this problem, which involves both immediate responses to and residual effects of N, P, K, and trace element applications. Poor soil moisture conditions (impermeable waterlogged subsoils and sandy drought-sensitive topsoils) and slight erosion hazards tend to make this land more suitable for grazing than for arable crops, although trials with the latter should be continued, preferably in a ley farming system. Large areas with pitted land surfaces require grading both for cropping and for grazing. Swampy land of unit 2 has less serious fertility problems and may be used for wet rice-growing or for pastures after improvement of the surface drainage. Unit 3 comprises a complex of land suitable for arable crops with erosion control measures, land for tree crops, and grazing land, without serious fertility problems. Some poorly drained arable land is found in unit 6, half of which is suitable only for grazing, due to flood hazards.

(14) Yambi Land System (600 sq miles)

Flat to gently undulating, poorly drained upland grass plains mainly in the central western part of the area.

Geology.—Quaternary: alluvial silt and clay; minor gravel and sand on valley margins.

Physical Features.—Inactive depositional surfaces between 150 and 400 ft: gently sloping, ill-drained plains with broad, shallow tributary valleys, and steeper slopes with valley-side benches near through-going rivers entrenched up to 50 ft below the plain surface.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	360 sq miles. Throughout land system	Plains: flat or gently undulating surfaces with slopes less than 2°; overall southward gradient of 10 ft per mile; commonly densely pitted surfaces	Meadow podzolic soils (mainly Yambi, little Minjim, Parua, Solai) and meadow soils (mainly Roma, little Yari). Rarely dull meadow podzolic soils (Soandagum, Urimo) and alluvial black clays (Mungin). Poorly drained. Locally liable to quick drying out of topsoils	*Themeda–Ischaemum* grassland complex with locally narrow fringes of lowland hill forest. Some *Ischaemum–Apluda* grassland with *Scleria* sedge swamp in holes of pitted surfaces
2	170 sq miles. Throughout land system, closely associated with unit 1	Drainage depressions: unchannelled floors up to 20 ft below unit 1; up to 1 mile wide in upper sectors, narrowing down-valley to 50 yd wide	Mainly meadow soils (Roma, Mindumo) and alluvial black clays (Kasamp). Also meadow podzolic soils (Yambi). Very poorly drained to swampy	*Scleria* sedge swamp and locally sago palm swamp. *Ischaemum–Apluda* grassland on less swampy sites
3	50 sq miles. Along well-defined drainage lines. Benches *only* along major streams	Valley-side benches and slopes: gently sloping surfaces 10–20 ft below unit 1 and up to 200 yd wide with locally deeply pitted surfaces; valley slopes, 10–20°, rising 10–50 ft above valley floors	Mainly gleyed forest soils (Witibi) and dark colluvial soils (Kwaliangu). Locally brown forest soils (Nagapam) and meadow soils (Roma). Sporadic uniform yellow clays (Boen) and gleyed red earths (Tring). Mostly poorly drained	Lowland hill forest and small areas of *Themeda–Ischaemum* grassland complex
4	10 sq miles. Along streams	Alluvial terraces and flood-plain: discontinuous terraces up to 100 yd wide and 5–10 ft above flood-plains; flood-plains up to 50 yd wide	Plastic heavy clay young alluvial soils. Poorly drained	Alluvium forests with some gardens and regrowth. Sago palm swamp

Population and Land Use.—4400 people with village sites on unit 1 and using 6 sq miles of units 3 and 4 at moderate intensity. These people mainly use nearby areas of Nagam land system.

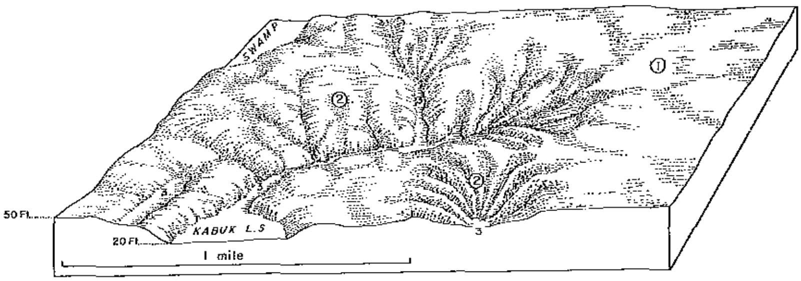
Assessment.—By far the largest part of this land system (units 1 and 2) is probably suitable for only a limited range of crops, because of its waterlogged impermeable soils, which require improved surface drainage even when this land is used for pastures, for which it appears to be most suitable. Improved drainage is particularly necessary on unit 2 land, but this may also offer good possibilities for wet rice-growing. In addition, serious soil fertility problems are involved in the largest part of unit 1 and a small part of unit 2, and must be solved before such land can be properly developed. Pitted land surfaces make grading necessary on large parts of unit 1, for pastures as well as arable crops. Unit 3 land is mostly arable, but adequate erosion control measures are necessary, and the soils are commonly slowly permeable. Locally it can be used only for grazing or tree crops. Land of unit 4 is mostly grazing land, because of flood hazards, but may be partly used for arable crops, although it requires much-improved drainage.

(15) Bosman Land System (80 sq miles)

Flat to undulating grassland platform in the south-east of the area.

Geology.—Quaternary: estuarine clay and sand, with coral limestone exposed in lower parts of disscected margin.

Physical Features.—Inactive depositional surfaces between 20 and 60 ft; a raised coastal platform with gently undulating upper surface with shallow valleys, and steep dissected margins.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	50 sq miles. Throughout land system	Plains: flat or gently undulating surface with slopes less than 2°; relief up to 20 ft	Meadow soils (Roma) and locally meadow podzolic soils (Yambi); near Ombas village alluvial black clays (Tumunum). Poorly drained	Predominantly *Ophiuros–Imperata* grassland with *Ischaemum–Apluda* grassland and very locally swamp woodland
2	22 sq miles. Along edges of land system and valleys penetrating towards centre of land system	Marginal slopes: short, slightly dissected slopes, 5–15°, with benches up to 100 yd wide; relief up to 20 ft	Brown forest soils (Nagapam) and presumably also gleyed forest soils (Witibi). Well to imperfectly drained	Lowland hill forest
3	8 sq miles. Throughout land system mainly surrounded by unit 2	Drainage depressions: unchannelled floors up to 200 yd wide and 10 ft below unit 1, passing downvalley into dissection gullies of unit 2	Presumably alluvial black clays (Kasamp, Mungin) and plastic heavy clay young alluvial soils. Very poorly drained to swampy	Sago palm forest and sago palm swamp, *Phragmites* swamp

Population and Land Use.—Nil.

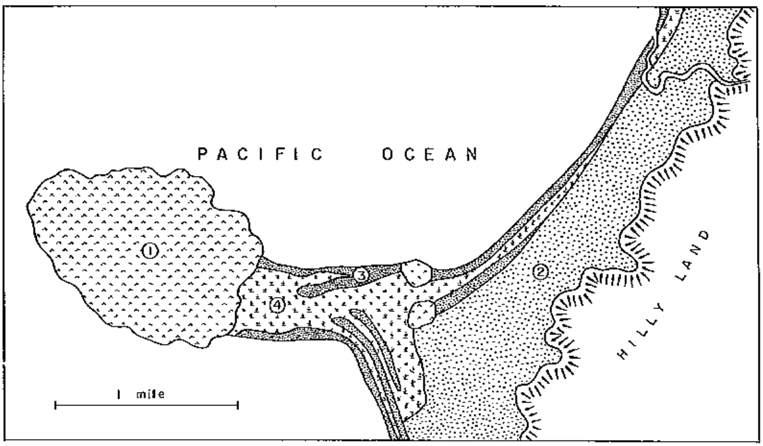
Assessment.—Land of unit 1 is most suitable for grazing, but requires improved surface drainage. A limited range of arable crops may be grown on the waterlogged impermeable soils of unit 1, whilst wet rice appears to have prospects in swampy unit 3. Unit 2 land is mostly suitable for arable crops, but requires rather intensive erosion control measures.

(16) Madang Land System (11 sq miles)

Discontinuous narrow coastal plain including coral headlands and small beaches.

Geology.—Quaternary: alluvium, littoral sand, and coral limestone.

Physical Features.—Inactive depositional surfaces between sea level and 50 ft: coastal plains, with coral headlands, fringing reefs and coral islands, sandy beach ridges, and swales, and small alluvial plains dissected 5–20 ft by transverse drainage.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	7 sq miles. Coral headlands and offshore islands	Raised coral reefs: flat, gently undulating, or slightly stepped surfaces up to 50 ft above sea level	Rendzinas (Passam) and lithosols. Excessively drained	Strand woodland and coastal plain succession
2	5 sq miles. On landward side of land system, only on mainland	Alluvial plains: flat or gently sloping surfaces; small colluvial aprons sloping up to 5° on inland margins	Medium-textured young alluvial soils. Well to poorly drained	Coastal plain succession
3	1·5 sq miles. Locally along coast	Beach ridges: sand ridges with rounded crests up to 8 ft high and 100 yd wide	Presumably coarse-textured old (Nubia) and young alluvial soils. Rendzinas (Rempi) on Muschu Island. Well to excessively drained	Strand woodland and coastal plain succession
4	1·5 sq miles. Between ridges of unit 3	Swales: linear, concave depressions up to 40 yd wide; some wider back swamps	Presumably marine sands and muds. Rendzinas (Rempi) on Muschu Island. Poorly to very poorly drained	Sago palm swamp, mangrove woodland

Population and Land Use.—1500 people using over 3 sq miles of units 1–3 at moderate to high intensity.

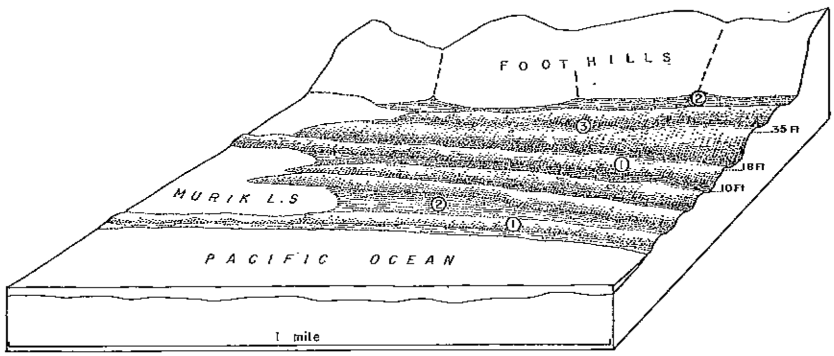
Assessment.—This land is generally suitable for most types of agriculture, although the most sandy soils are best used for tree crops and the poorly drained land for arable crops and grazing. Some stony land in unit 1 and some mangrove swamp land in unit 4 is virtually useless.

(17) Nubia Land System (15 sq miles)

Sandy beach ridges and swales along the coast.

Geology.—Quaternary: littoral sand.

Physical Features.—Inactive depositional surfaces between sea level and 25 ft: parallel low beach ridges separated by swales, and older, higher beach ridges more inland close to the foot of coastal hills.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	10 sq miles. Throughout land system	Lower beach ridges: long sand ridges with rounded crests up to 8 ft high and up to 200 yd wide; includes present beach	Coarse-textured old alluvial soils (Nubia) and young alluvial soils. Well to poorly drained	Strand woodland and coastal plain succession mainly of grasses
2	3 sq miles. Between ridges of unit 1	Swales: concave, linear depressions 20–60 yd wide	Soils similar to those in unit 1. Poorly to very poorly drained	Sago palm swamp and some *Phragmites* swamp
3	2 sq miles. At Wewak Mission and But	Higher beach ridges: short sand ridges with rounded crests up to 25 ft high and 80 yd wide; steeper seaward slopes	Coarse-textured old alluvial soils (Nubia). Well to excessively drained	Coastal plain succession

Population and Land Use.—2300 people using over 4 sq miles of units 1 and 3 at moderate to high intensity.

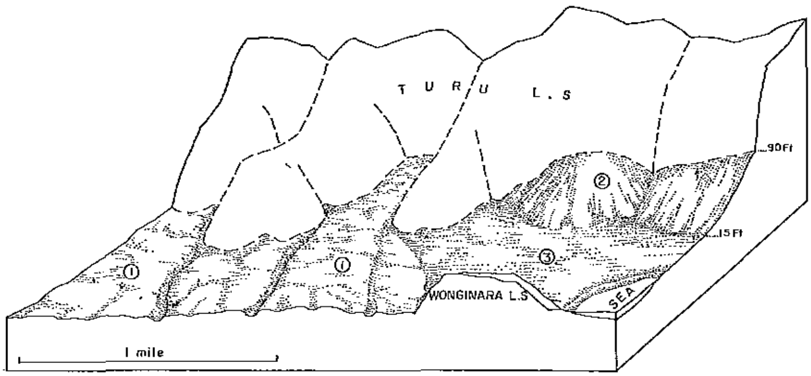
Assessment.—This land is generally suitable for most types of agriculture, although somewhat droughty soils (unit 3) are best used for tree crops and poorly drained land (units 1 and 2) for arable crops and grazing. Some poorly drained land of unit 2 is suitable only for pastures.

(18) But Land System (8 sq miles)

Talus, fans, and plains near the coast.

Geology.—Quaternary: alluvium and colluvium, commonly with angular gravel.

Physical Features.—Inactive depositional surfaces between 10 and 100 ft: steep gravelly talus and gently sloping fans below coastal escarpments, extending from sea level to 100 ft, merging into ill-drained flats in lowest parts.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	4 sq miles. On coastal side of unit 2	Colluvial aprons: slopes 2–4°, hummocky surfaces, locally dissected by gullies	Medium-textured old alluvial soils (Dumpu, Bembi) and medium-textured young alluvial soils, commonly gravelly. Well to imperfectly drained	Garden regrowth with small patches of mixed grassland and well-drained alluvium forest
2	2 sq miles. Discontinuous along foot of mountains	Talus: slightly concave steep short slopes 10–20°	Ranging from medium-textured young alluvial soils with some gravel to almost pure gravel beds. Well to excessively drained	Garden regrowth with some lowland hill forest remnants
3	2 sq miles. On coastal side of unit 2 and on landward side of some coastal hill ridges	Plains: fairly level surfaces with parallel depressions and channels and few small beach ridges	Medium-textured young alluvial soils. Poorly to very poorly drained	Mixed flood-plain forest. Locally sago palm swamp and coastal plain succession

Population and Land Use.—2600 people using over 7 sq miles of all units at moderate to very high intensity, except the gravelly sections of units 1 and 2 and the swampy parts of unit 3.

Assessment.—This land system comprises predominantly arable land, with locally poorly drained or droughty soils and slight erosion hazards. The steepest land of unit 2 is suitable only for grazing or tree crops.

(19) Nagam Land System (340 sq miles)

Flood-plains and low river terraces throughout the area.

Geology.—Recent: alluvial silt and clay with some mainly fine gravel.

Physical Features.—Active depositional surfaces: alluvial flood-plains generally with narrow upper sectors with high and low terraces and locally braided river-courses; and with wide lower sectors, with meandering river-courses, drainage terminals, and other ill-drained areas.

This land system is not illustrated, because the distribution of the units is partly indistinct on aerial photographs and partly regional and therefore deducible from the land system map.

Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	130 sq miles. Greater part of the coastal plain and forming a complex pattern with unit 4 on the plains north of the Sepik River	Flood-plains up to 4 miles wide: flat to gently undulating, hummocky surfaces little dissected by channels. Liable to local flooding in the wet season	Medium-textured young alluvial soils. Locally near coast: medium-textured old alluvial soils (Dumpu) and coarse-textured young alluvial soils. Well to imperfectly drained	Well-drained alluvium forest, locally garden regrowth
2	115 sq miles. Small areas of the coastal plain but predominantly a part of the complex pattern with unit 4 in plains north of the Sepik River		Plastic heavy clay young alluvial soils with locally medium-textured alluvial soils. Poorly to very poorly drained	Mixed flood-plain forest
3	50 sq miles. Greater part of the narrow valleys	Narrow flood-plain and low terraces: flood-plain not wider than 200 yd; terraces 4–10 ft above flood-plain not wider than 400 yd. Partly regularly and partly rarely flooded	Medium-textured young alluvial soils, rarely coarse-textured in the flood-plains. Imperfectly to well drained	Well-drained alluvium forest and locally river terrace succession; garden regrowth
4	25 sq miles. Scattered. In association with units 1 and 2, much less with unit 3	Shallow depressions: flood channels and enclosed shallow depressions up to 200 yd wide; up to 6 ft below units 1 and 2	Plastic heavy clay young alluvial soils with locally medium-textured young alluvial soils. Very poorly drained to swampy	Sago palm forest and sago palm swamp
5	18 sq miles. Locally in upper parts of narrow river valleys	Higher terraces: discontinuous surfaces up to 300 yd wide, 15–25 ft above the flood-plains	Medium-textured and plastic heavy clay young alluvial soils. Locally along southern rivers: old alluvial soils (Dumpu, Ouarara), meadow soils (Roma), and alluvial black clays (Mungin). Imperfectly to well drained but locally poorly to very poorly drained	Well-drained alluvium forest with locally mixed flood-plain forest; garden regrowth
6	2 sq miles. Along Sowam, Hawain, and Screw Rivers where they emerge from the mountains	River channels: shifting braided courses up to 300 yd wide, with sand bars and banks of cobble gravel		Herbaceous river terrace succession

Population and Land Use.—6800 people living on the land system, plus large numbers of people from closely adjoining land systems, using 45 sq miles of units 1, 3, and 5 at moderate to very high intensity. The high to very high land use intensity is associated with river terraces in the Maprik area. The moderate land use intensity is associated with the larger alluvial plains near the coast and north of the Sepik River.

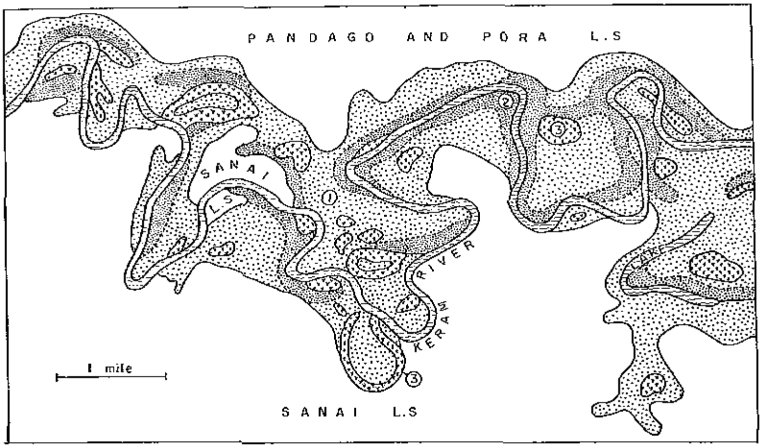
Assessment.—This land system comprises land with fertile soils, including the largest area of first-class land (60 sq miles) in the survey region, which land can be used for many different types of agricultural production. In units 2 and 5 it contains much poorly drained land, which appears to be suitable for arable crops as well as grazing after drainage improvement, although the range of crops may be limited on land with slowly permeable soils. The very poorly drained land of unit 4 is suitable only for grazing and, probably better, for wet rice-growing. At present flooding strongly restricts the possibilities for arable cropping in parts of units 1 and 2 and all of unit 3, but flood protection should be possible on a large proportion of this land, thus considerably increasing its potential for arable crops and tree crops. Where flood control is not feasible, grazing is the most suitable form of land use. Most of the area is covered with tall forest, the value of which is probably insufficient to pay for the cost of total land clearing.

(20) Misinki Land System (35 sq miles)

Forested levees and back plains along the Keram River and Pora Pora Creek.

Geology.—Recent: alluvial clay and silt.

Physical Features.—Active depositional surfaces: continuous levee belts up to 2 miles wide; levees, back slopes, and flood-plain margins with enclosed depressions.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	23 sq miles. Throughout land system	Plains: up to ½ mile wide; flooded 3–4 ft in wet season	Plastic heavy clay and more rarely medium-textured young alluvial soils. Locally alluvial black clays (Mungin). Poorly to very poorly drained	Mixed flood-plain forest with locally river terrace succession
2	10 sq miles. Adjoining present and former stream-courses	Levees: extending up to 200 yd from vertical river banks, and up to 8 ft above unit 1; back slopes 1–3°; flooded for short periods in wet season up to 3 ft depth. Locally not flooded	Medium-textured and also plastic heavy clay young alluvial soils. Imperfectly to well drained	Levee forest
3	2 sq miles. Mainly surrounded by unit 1	Enclosed depressions: up to 400 yd in extent, and deserted meander loops; deeply flooded during wet season	Plastic heavy clay young alluvial soils and black peat soils (topsoil). Very poorly drained to swampy	*Phragmites* swamp

Population and Land Use.—600 people using small areas of land near village sites on unit 2 at high to very high intensity.

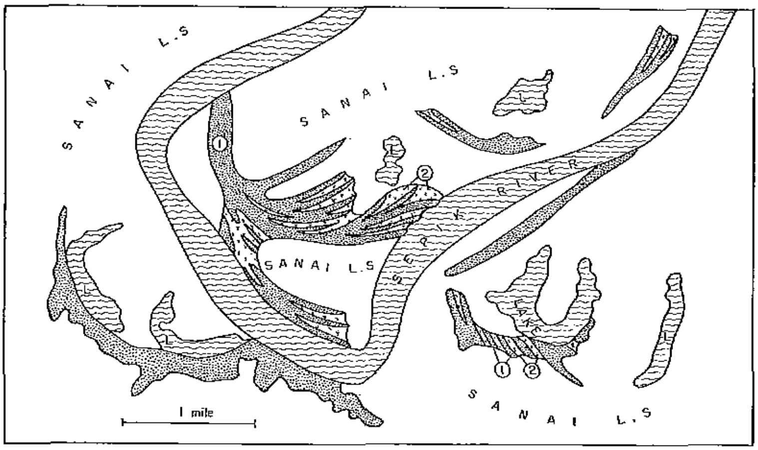
Assessment.—In its present state most of this fertile land is suitable only for grazing during the long flood-free season, but arable crops can be grown during this period on unit 2 land. Clearing of the dense, poor forest would be costly. It would seem possible to protect a large proportion of the land against flooding by surrounding it with low levee banks and by increasing the discharge of flood water through channels dug across the levees into the surrounding swamps. Much of the reclaimed land would be very suitable for grazing or wet rice-growing, but, because of the heavy clay soils, for only a limited range of crops.

(21) Palimbai Land System (40 sq miles)

Narrow, discontinuous levees in the Sepik flood-plain.

Geology.—Recent: alluvial silt and clay.

Physical Features.—Active depositional surfaces: discontinuous narrow levees and adjacent higher flood scrolls in parallel or fan-shaped patterns.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	30 sq miles. Throughout land system	Levees and higher flood-plain scrolls: levees up to 10 ft above back plain, extending up to 150 yd from vertical river banks, with back slopes 2–5°; rounded scroll crests up to 6 ft high and 50 yd wide. Flooded 2–3 ft during the wet season	Medium-textured young alluvial soils. Rarely plastic heavy clay young alluvial soils. Commonly very poorly to poorly drained. Highest parts imperfectly to well drained	Woody aspect of the rive scroll succession and som levee forest
2	10 sq miles. Associated with scrolls of unit 1	Scroll swales: linear, concave depressions up to 50 yd wide; flooded 5–9 ft during wet season	Plastic heavy clay and medium-textured young alluvial soils. Very poorly drained to swampy	Herbaceous aspect of river scroll succession

Population and Land Use.—4100 people using small areas of land near village sites on unit 1 at high to very high intensity.

Assessment.—Grazing or cultivation of short-term arable crops during the flood-free period in the dry season is possible in unit 1 which is already densely settled. Land of unit 2 is virtually useless, because of its swampiness and prolonged deep flooding.

(22) Pandago Land System (260 sq miles)

Sago swamps throughout the area, but mainly in the south.

Geology.—Recent: alluvial clay and silt with minor peat.

Physical Features.—Active depositional surfaces: flood-plain swamps subject to seasonal flooding, and comprising low parts of flood-plains and blocked valleys.

Land Form.—Flood-plain swamps: level or slightly hummocky surfaces with a few small drainage channels; normally flooded 2–4 ft during wet season, rarely higher.

Soil and Drainage Status.—Plastic heavy clay and locally medium-textured young alluvial soils. Also black peat soils (deep and subsoil), especially in the lower reaches of the Sepik swamps. Very poorly drained to swampy.

Vegetation.—Sago palm forest and sago palm swamp.

Population and Land Use.—Nil, but locally used as a major source of sago by people living on surrounding land systems.

Assessment.—Apart from the exploitation of its relatively small sago resources, this land could at present only be converted into very poor grazing land and in the most poorly drained areas only be used for the growing of swamp rice varieties. A large proportion may be converted into polders, protected from flooding and with artificial water control. Because of the poor physical properties of the fertile heavy clay soils, such land would be primarily suitable for grazing and wet rice-growing. Locally, medium-textured and peaty soils would allow varied permanent cultivation of reclaimed land. In determining the possibilities for reclamation, which are academic at present, attention should be given to the influence of such works on the flood regime in the remaining part of the Sepik flood-plain swamps.

(23) Kabuk Land System (200 sq miles)

Sago–*Phragmites* swamps in the Sepik flood-plain.

Geology.—Recent: peat and alluvial clay.

Physical Features.—Active depositional surfaces: permanent flood-plain swamps in lower parts of the Sepik flood-plain and blocked tributary valleys.

Land Form.—Flood-plain swamps; flooded up to 4 ft during the wet season.

Soil and Drainage Status.—Raw peat, black peat soils (subsoil), organic muds, and plastic heavy clay young alluvial soils. Swampy.

Vegetation.—Sago palm–*Phragmites* swamp, locally merging into low sago palm swamp.

Population and Land Use.—Nil.

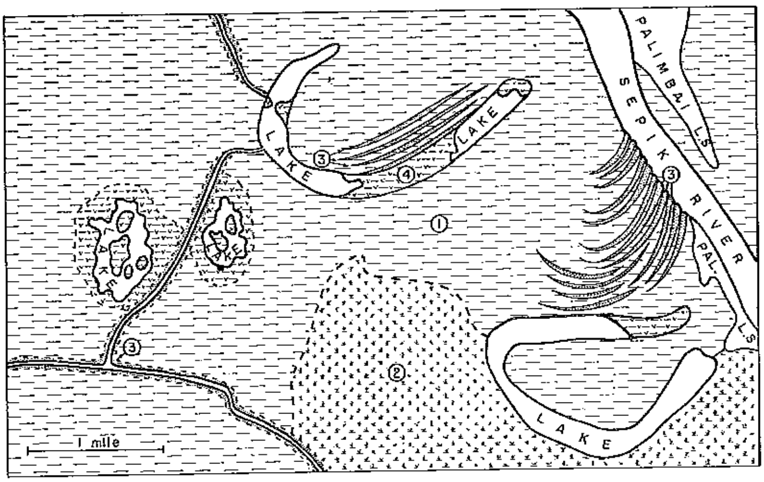
Assessment.—This land system has no agricultural potential in its present state. Reclamation by empoldering would make most of the land suitable mainly for wet rice-growing or grazing, as the very heavy clay soils appear to be almost unsuitable for arable crops. Some areas with raw peat soils and organic muds do not seem suitable for reclamation at all. As empoldering would be technically difficult and might increase flooding in the remaining part of the Sepik flood-plain swamps, it is not very attractive, even from an academic point of view.

(24) Sanai Land System (580 sq miles)

Grass swamps with severe seasonal flooding in the Sepik flood-plain.

Geology.—Recent: peat and alluvial clay.

Physical Features.—Active depositional surfaces: back-plain swamps of the Sepik River, with low scrolls and levees and oxbow and flood-plain lakes; subject to severe flooding by the main stream.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	360 sq miles. Throughout land system	Flood-plain swamps: extensive low areas, and locally low scrolls and swales; flooded 8–10 ft in wet season	Mainly black peat soils (deep and topsoil), organic muds; also alluvial black clays (Mungin) and plastic heavy clay young alluvial soils. Swampy	Mixed grass swamp
2	190 sq miles. Throughout land system but mostly in eastern part	As unit 1; flooded up to 6 ft in wet season	Alluvial black clays (Mungin) and black peat soils (topsoil), rarely organic muds. Swampy	*Phragmites* swamp
3	20 sq miles. Throughout land system along rivers and channels	Levees and flood-plain scrolls: crests up to 30 yd wide and up to 6 ft above unit 1 or 2; flooded up to 6 ft in wet season	Plastic heavy clay young alluvial soils and alluvial black clays (Mungin) on levees. Medium-textured alluvial soils on young scroll ridges. Levees very poorly drained. Scroll rises very poorly to well drained	River scroll succession; locally gardens
4	10 sq miles. Along edges and in the middle of swamp lakes and cut-off meanders	Lake margins, lake islands, and oxbow plugs	Organic muds along lakes. Medium-textured young alluvial soils in oxbow plugs. Presumably organic soils. Swampy to very poorly drained	Herbaceous swamp and aquatic vegetation

Population and Land Use.—4200 people with village sites associated with high to very high intensity land use on unit 3. In addition, 1300 people are in one village, Kambaramba, situated in unit 2. Sago processing is the chief form of subsistence of this population.

Assessment.—Except for unit 3, this land system has no agricultural potential and reclamation appears to be impossible, because of the very severe flooding. Small areas of unit 3 are at present used for native gardens during the dry season, or could be grazed during this period, but such land use would be insignificant.

(25 Pora Land System (120 sq miles)

Forested swamps with organic soils in the south-east of the area.

Geology.—Recent: peat and minor unconsolidated alluvial clay.

Physical Features.—Active depositional surfaces: permanent swamps of the lower flood-plain of the Sepik River.

Land Form.—Flood-plain swamps; probably flooded to 3–4 ft in the wet season.

Soil and Drainage Status.—Little information; only raw peat and black peat soils (deep) were observed. Swampy.

Vegetation.—*Campnosperma*–sago palm forest with swamp woodland in the south, dominated by *Pandanus*. Some sago palm–*Phragmites* swamp.

Population and Land Use.—Nil.

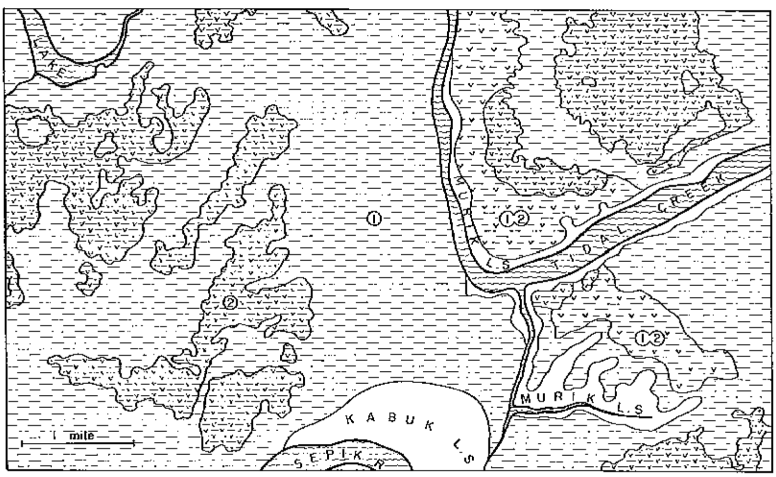
Assessment.—This land system has no agricultural potential in its present state. As it has mostly very fertile peat soils, reclamation into polders would result in a large area of land, which would be suitable for intensive arable cropping and grazing, preferably in mixed farming systems. Artificial water control should keep the ground-water levels as high and constant as possible, to avoid undue lowering of the land surface by shrinkage and oxidation of the peat. The idea of reclamation is purely academic at present and unstable subsoil conditions might make empoldering very difficult. Moreover, much attention should be given to the influence that reclamation is likely to have on the flood regime in the remaining part of the Sepik flood-plain swamps.

(26) Kobar Land System (220 sq miles)

Forest and woodland swamps with organic soils in the freshwater tidal zone of the Sepik River mouth and near Wewak.

Geology.—Recent: estuarine peat, clay, and sand.

Physical Features.—Active depositional surfaces: littoral swamps, 1–2 ft above sea level, with narrow tidal creeks; subject to freshwater flooding.



Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	130 sq miles. Throughout land system	Coastal plain swamps: flat or hummocky surfaces several miles in extent. Water-table permanently above land surface. Locally slight tidal influence	Organic muds, raw mangrove peat, black peat soils (deep). Swampy	Swamp forest and swamp woodland, also some sago palm swamp
2	90 sq miles. Throughout land system			Sedge–fern swamp; some herbaceous swamp
3*	1 sq mile. Along Sepik River and coast	Levees and beach ridges: 2–5 ft above water level, 50–150 yd wide	Medium- and coarse-textured young alluvial soils. Poorly to imperfectly drained	Levee forest and strand woodland

Population and Land Use.—400 people with village sites on unit 3. Sago processing and fishing are the chief forms of subsistence of this population.

Assessment.—This land system has no agricultural potential and cannot be reclaimed, because of the absence of real soils. As the seasonal changes in water levels are small, it may be possible to convert parts of this land into freshwater fish ponds by dredging out the vegetation, raw peat, and mud, and creating basins of open water.

* Not shown on plan.

(27) Murik Land System (100 sq miles)

Tidal mangrove swamps near the Sepik River mouth and Wewak.

Geology.—Recent: estuarine mud and peat.

Physical Features.—Active depositional surfaces: littoral swamps below high-water mark, with branching tidal creeks.

Unit	Area and Distribution	Land Form	Soil and Drainage Status	Vegetation
1	*100 sq miles. Throughout land system*	*Tidal flats with rise and fall of* water levels 1–3 ft	Raw *mangrove peat. Swampy*	Mangrove woodland
2	1 sq mile. Along coast	Beach ridges: 2–3 ft high, 20–100 yd wide	Coarse-textured young alluvial soils. Poorly to imperfectly drained	Strand woodland

Population and Land Use.—400 people with village sites on unit 2. Sago processing and fishing are the chief forms of subsistence of this population.

Assessment.—This land system has no agricultural potential, apart from the possible exploitation of the mangrove resources. It may also offer possibilities for the construction of brackish-water fish ponds.

PART III. CLIMATE OF THE WEWAK–LOWER SEPIK AREA

By Jennifer M. Arnold*

I. Introduction

Trewartha (1937) has classified the area as having a tropical rain forest climate of the monsoon variety. It experiences uniformly high temperatures and very high precipitation from the prevailing monsoons, although it could be called relatively dry by New Guinea standards (Fig. 4). There is considerable cloud cover all the

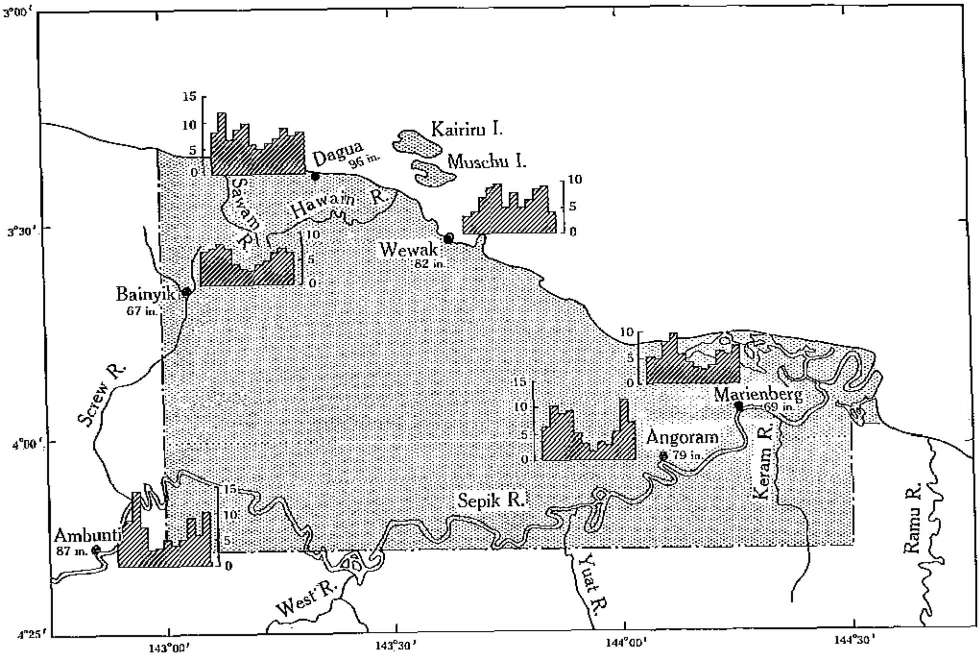


Fig. 4.—Location of rainfall recording stations with annual total and histograms of average monthly rainfall (in.).

year, cloud tending to build up during the afternoon and to clear at night. Humidity frequently reaches saturation at night, so that dews and fogs are common. Rainfall is generally higher along the north coast and in the mountains (Dagua, 96 in.; Wewak, 82 in.; and probably well over 100 in. in the mountains) than in the Sepik plains south of the mountains (Bainyik, 67 in.; Angoram, 79 in.; Marienberg, 69 in.).

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The weather is controlled by the position of the equatorial trough, a low-pressure belt that moves between 10–15°N. in July and 5–10°S. in January. The fluctuation of the equatorial trough brings the survey area into the influence of the south-east trades and the north-east trades in turn.

The south-east trades appear in April, become fully established in mid May, and their influence continues until the middle of October. The winds are generally constant in direction, and during this season all weather stations in the area, with the exception of Wewak, experience their driest months.

The northern hemisphere north-east trades, which acquire a north-westerly direction after crossing the equator, are generally known as the north-west monsoon. They become established in the area by December and remain until the end of March. The winds are not as constant in direction as the south-easterlies. Most of the area receives a large proportion of its rainfall in this season.

In the weeks between the two major seasons the "doldrums" prevail, with winds of variable direction and frequent afternoon thunderstorms. At most stations the wettest months occur in these times.

II. General Climatic Features

(a) *Availability of Data*

Because a network of recording stations was only built up in the 1950s, climatic data for the area are sparse. However, three stations in this area have short records dating from between the two world wars. The data used in compiling this report can provide only a general picture of distribution and intensity of rainfall, its variability, and the effects of the rainfall seasons on the temperature and humidity regimes.

Rainfall data from six stations have been used, and only years with complete records have been included.* The records used are: for Wewak, 7 years prior to World War II and 3 years 1955–57; for Marienberg, 11 years prior to 1934; for Ambunti, 6 years prior to 1934; for Angoram, 5 years 1952, 1953, 1955–57; for Dagua, 3 years 1952–54; and for Bainyik, 8 years 1951–58.

Where daily data were available, probability tables have been prepared to show the chances of occurrence of daily rainfall within specified ranges. Where only monthly data were available, probability tables for monthly rainfall have been computed.

Temperature records for Angoram, Lumi, and Aitape for 1957 are included. Though Aitape and Lumi are well outside the area they have been used as examples of a coastal station and an inland station at higher altitude respectively.

(b) *Rainfall*

The position of a particular station in relation to the prevailing air streams, and to the topography of the surrounding country, plays an important part in the amount and distribution of its rainfall. Average annual rainfall for each of the stations men-

* This Part was compiled in 1960.

TABLE 1

RAINFALL CHARACTERISTICS* FOR SIX STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Dagua (3 yr of records, 1952–54)													
Mean rainfall (in.)	8·39	12·36	7·03	8·86	10·03	5·91	5·16	6·19	7·17	8·92	7·56	8·32	95·90
Mean number of rain days	12	15	12	10	8	9	11	10	11	14	13	13	138
Mean rain per wet day	0·70	0·82	0·60	1·89	1·25	0·68	0·48	0·64	0·63	0·62	0·57	0·64	0·69
Wewak (3 yr of records, 1955–57)													
Mean rainfall (in.)	3·72	4·63	7·24	9·21	9·68	5·30	8·17	5·22	6·76	8·96	9·21	4·28	82·39
Mean number of rain days	13	14	17	19	20	15	17	15	13	16	16	18	194
Mean rain per wet day	0·28	0·33	0·43	0·49	0·49	0·35	0·48	0·35	0·51	0·55	0·56	0·24	0·42
Angoram (5 yr of records, 1952–53, 1955–57)													
Mean rainfall (in.)	6·67	10·53	9·11	9·52	5·46	3·46	2·12	3·54	3·37	5·57	11·87	7·48	78·79
Mean number of rain days	16	17	20	20	14	10	11	11	11	14	16	17	172
Mean rain per wet day	0·43	0·63	0·45	0·49	0·39	0·35	0·31	0·31	0·32	0·40	0·75	0·44	0·46
Marienberg (8 yr of records, 1916, 1921–22, 1929–33)													
Mean rainfall (in.)	5·45	5·31	8·44	9·86	5·98	4·30	3·40	3·34	3·66	6·44	5·94	7·24	69·36
Ambunti (6 yr of records, 1926, 1929–33)													
Mean rainfall (in.)	8·01	8·88	14·31	7·71	3·48	3·53	5·30	4·21	5·26	9·47	6·45	10·53	87·14
Mean number of rain days	14	18	20	17	12	12	15	12	14	17	12	20	183
Mean rain per wet day	0·57	0·49	0·72	0·45	0·29	0·29	0·35	0·35	0·38	0·56	0·54	0·53	0·48
Bainyik (8 yr of records, 1951–58)													
Mean rainfall (in.)	6·52	7·22	8·17	7·11	4·07	3·10	2·88	3·99	4·69	6·13	7·09	5·88	66·85
Mean number of rain days	15	15	18	16	11	9	9	11	12	11	16	15	160
Mean rain per wet day	0·42	0·43	0·46	0·44	0·37	0·33	0·32	0·37	0·38	0·54	0·46	0·38	0·42

* Data from Bureau of Meteorology (1940) and daily rainfall records.

tioned above is less than 100 in. but it is probable that in some parts of the mountains, for which records are not available, totals in excess of 100 in. are received regularly. A large part of the area along the lower reaches of the Sepik River and to the north of the river has an average annual rainfall of less than 80 in., e.g. Marienberg 69 in., Angoram 79 in., and Bainyik 67 in. Higher up the river at Ambunti, near the boundary of the survey area, the annual average has risen to 87 in. On the coast, Wewak and Dagua have annual averages of 82 in. and 96 in. respectively.

(i) *Distribution and Intensity.*—Table 1 and Figure 4 show the average rainfall characteristics of the six stations. With the exception of Wewak, all stations receive about 40% of their average rainfall in the four months from December to March, and experience their driest months from June to September when the south-east trades control the weather.

The effect of local topography on rainfall distribution is illustrated by a comparison between Wewak and Dagua. Wewak receives a considerably lower rainfall than Dagua, with lower monthly totals during the north-west season and rather similar totals for the remainder of the year. Wewak has about the same number of wet days as Dagua during the north-west season but has a lower intensity of rain per wet day. The lower average rainfall at Wewak can probably be attributed to the sheltering effect of Kairiru and Muschu Islands, which are situated a few miles to the north-west of the station.

It is evident that the highest monthly totals are recorded at most stations during the doldrums. Intensity of rainfall expressed as average rain per wet day is also at its highest at this time. It is at its lowest during the south-east season for all stations except Wewak. As can be seen from Table 2, the higher rainfall in the north-west season at all stations except Wewak is due both to a greater number of wet days and to heavier rain per wet day.

TABLE 2

INTENSITY OF SEASONAL RAINFALL

Station	Total Number of Wet Days		Number of Days Receiving $>0\cdot50$ in.	
	North-west	South-east	North-west	South-east
Wewak	69	70	14	17
Angoram	83	49	33	9
Bainyik	68	43	22	9

Table 3 shows the number of days per month when falls in the specified ranges can be expected. In general, one-half to two-thirds of the total number of wet days record totals of 0·25 in. or less and the proportion of days recording falls in this range is higher in the drier season.

Table 3 also shows the frequency of daily falls in excess of 2·00 in. and 4·00 in. Falls of this order, which could be expected to cause rapid flooding of creeks and low-lying land, can be expected on about six days per year at Angoram and Wewak but only on two days at Bainyik. Totals in excess of 4·00 in. can be expected on about one day per year at Angoram and Wewak, while at Bainyik a day with such a

TABLE 3

NUMBER OF RAIN DAYS ON WHICH FALLS WITHIN SPECIFIED RANGES CAN BE EXPECTED*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
						Range 0·01–0·25 in.							
Angoram	7·8	8·6	12·0	10·6	9·2	6·4	7·2	6·8	8·0	8·2	7·0	8·8	110·6
Bainyik	7·0	8·0	8·7	7·7	7·3	4·8	5·0	5·1	6·0	4·7	7·3	7·5	79·1
Wewak	8·7	8·3	9·3	11·0	12·3	9·0	10·7	9·3	6·7	6·7	9·0	12·0	113·0
						Range 0·26–0·50 in.							
Angoram	3·6	2·6	4·0	2·8	2·6	1·6	1·4	2·0	1·0	2·0	3·0	5·8	32·4
Bainyik	3·1	3·7	3·7	3·0	1·7	1·7	1·5	1·9	3·3	1·5	1·1	2·1	28·3
Wewak	1·3	2·6	3·3	1·3	1·3	3·0	3·0	3·0	2·0	3·6	3·0	3·6	31·0
						Range 0·51–2·00 in.							
Angoram	5·8	4·4	5·8	5·4	4·2	1·2	0·8	2·4	1·8	3·2	4·2	3·8	43·0
Bainyik	3·5	4·3	5·1	4·7	2·7	1·7	1·3	1·8	3·0	4·0	5·0	4·7	41·8
Wewak	3·3	2·3	3·3	5·0	5·3	3·0	2·0	2·6	3·6	5·3	3·6	2·3	41·6
						In excess of 2·00 in.							
Angoram	0·4	1·0	0·4	0·8	0·2	0·4	—	—	0·2	0·4	1·6	0·4	5·8
Bainyik	0·2	0·2	0·2	0·3	0·2	—	0·2	0·2	—	0·5	0·2	—	2·2
Wewak	—	0·3	0·6	1·0	0·6	0·3	1·3	—	1·0	0·6	0·6	—	6·3
						In excess of 4·00 in.							
Angoram	0·2	0·4	—	—	—	—	—	—	—	—	0·8	—	1·4
Bainyik	—	—	—	—	—	—	—	—	—	0·2	—	—	0·2
Wewak	—	—	—	—	0·3	—	0·3	—	—	—	0·3	—	0·9

* Data from daily rainfall records.

TABLE 4

EXPECTED OCCURRENCE OF PERIODS OF PERSISTENT RAIN

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
						Periods of more than 2 consecutive days							
Angoram	1·8	2·6	3·4	2·6	1·2	1·4	0·6	1·2	1·4	1·4	1·8	2·4	21·8
Bainyik	2·0	1·6	2·6	1·6	1·7	0·6	0·6	0·6	1·6	1·0	1·4	1·6	16·9
Wewak	2·0	1·3	2·7	2·3	2·7	2·0	2·0	1·7	0·7	2·0	1·3	1·7	22·4
						Periods of more than 5 consecutive days							
Angoram	0·2	0·8	1·0	0·8	0·8	—	—	—	0·2	—	0·4	0·2	4·4
Bainyik	0·7	0·7	0·6	0·7	0·1	—	0·1	0·1	—	0·1	0·7	0·3	4·1
Wewak	—	0·7	1·0	1·3	1·3	0·7	0·3	0·7	0·3	0·7	0·3	1·3	8·6
						Periods of more than 10 consecutive days							
Angoram	—	—	0·2	0·2	—	—	—	—	—	—	—	—	0·4
Bainyik	—	0·6	—	0·1	—	—	—	—	—	—	0·3	—	1·0
Wewak	—	—	—	—	0·3	0·3	—	—	—	—	—	0·3	0·9

total can be expected one year in five. At Angoram these very heavy falls are most likely to occur in February and November, at Wewak in April and September, and at Bainyik in October.

(ii) *Variability*.—The variability of annual rainfall expressed as mean deviation from the mean is in the vicinity of 12% for stations having at least 10 years of records. This order of variability is low compared with that of stations in Australia with high average (e.g. Darwin 17%, Innisfail 18%).

(iii) *Persistent Rain*.—Table 4 shows the number of periods of persistent wet weather expected to occur at Angoram, Bainyik, and Wewak. Periods in which rain is recorded on more than two consecutive days occur frequently, and at least one can be expected in all but the driest months. About four periods of more than five consecutive days of rain can be expected at the two inland stations and twice this number at Wewak. Periods of more than 10 consecutive rain days can be expected on the average of one per year at Bainyik and Wewak but they are less frequent at Angoram.

(*c*) *Temperature*

Temperature records for 1957 for Aitape, Lumi, and Angoram (Fig. 1) are shown in Table 5.

In this region there is a very narrow range of temperature throughout the year with mean annual temperatures of 75–80°F.

For a particular station there is very little difference between monthly values of average maximum temperature. In 1957, maxima at Aitape on the coast ranged from 83·7°F in February to 86·5°F in May and 86·4°F in November. Inland at Angoram, which is situated on low-lying land near the Sepik River, monthly maxima were higher, ranging between 87·3°F in January and 93·0°F in October. Lumi, at an elevation of about 1600 ft, had lower monthly maxima ranging from 79·7°F in July to 83·0°F in November.

Monthly minima have an annual range of only two or three degrees. At Aitape they varied between 72·6°F in July and 74·3°F in May; at Angoram the range was between 68·6°F in September and 71·4°F in February.

The diurnal range in temperature is greatest at the end of the dry season and smallest at the height of the wet season.

Reliable information concerning the effect of altitude on temperature is lacking, but Hounam (1951) quotes the following figures as approximations of mean temperatures at various altitudes:

Sea level	81°F
3000 ft	69°F
6000 ft	61°F

The mean temperature for 1957 at Aitape (sea level) was 79·4°F and that at Lumi (1590 ft) was 75°F. The drop in temperature with altitude is quite close to that indicated by the above figures.

TABLE 5

MEAN MONTHLY TEMPERATURES (°F) FOR THREE STATIONS FOR 1957*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						Aitape							
Mean maximum	85·3	83·7	84·9	85·3	86·5	86·0	85·9†	85·8	85·3	86·3	86·4	85·2	85·6
Mean minimum	73·2	73·5	73·5	73·4	74·3	73·6	72·6	73·0	72·7	72·9	73·7	74·0	73·4
Mean‡	79·2	78·6	79·2	79·3	80·4	79·8	79·2†	79·4	79·0	79·6	80·0	79·6	79·4
						Angoram							
Mean maximum	87·3	88·4	88·2	88·4	89·6	88·8	90·1	91·6	90·7	93·0	92·8	92·6	90·1
Mean minimum	71·2	71·4	70·4	69·3	70·8	70·0	69·2	68·9	68·6	69·4	69·8	69·1	69·8
Mean‡	79·2	79·9	79·3	78·8	80·2	79·4	79·6	80·2	79·6	81·2	81·3	80·8	80·0
						Lumi							
Mean maximum	82·1	80·2	81·0	81·0	81·8	80·9	79·7	80·5†	80·8	81·5	83·0	81·9	81·2
Mean minimum	68·9	69·0	69·0	68·9	69·5	69·1	68·3	67·5†	68·1	68·4	68·9	69·8	68·8
Mean‡	75·5	74·6	75·0	74·9	75·6	75·0	74·0	74·0†	74·4	74·9	75·9	75·8	75·0

* Data from monthly statistical summaries of Bureau of Meteorology.

† Estimated.

‡ Obtained from (mean maximum temperature+mean minimum temperature)/2.

(*d*) *Humidity*

Relative humidity is high throughout the year, usually being between 75 and 85% at 9 a.m. and dropping by 5 to 10% at 3 p.m. The monthly distribution of average humidity usually corresponds with the monthly rainfall distribution.

A greater range of relative humidity is experienced inland than on the coast. Inland it may fall as low as 50% during the day, but at night saturation point is reached frequently even during the dry season. Consequently dews are common at all seasons. Fogs do not occur along the coast but are common inland, particularly on the plains along the Sepik River.

(*e*) *Wind*

The major weather controls in terms of seasonal wind circulation have been summarized in Section I. The trade winds and the winds experienced during the transition period between the monsoons are generally light, the average velocities of the south-east trades and the north-west monsoons being about 10 knots and 6 knots respectively. However, high winds occurring as squalls with rain and thunder are not infrequent, particularly during the doldrums, and there have been reports from coastal stations of winds approaching gale force lasting several days. Some coastal stations have also reported damage caused by wind.

Land and sea breezes are of some importance 10 to 15 miles inland from the coast, and mountain and valley winds are evident at some localities further inland. In some instances the local winds are strong enough to mask the presence of the seasonal winds, but in general the weather pattern is a response to the major weather controls, particularly in terms of rainfall distribution.

III. Climate in Relation to Land Use

It is evident that the high uniform temperatures experienced in the area are very suitable for plant growth, which could, however, be limited by other climatic conditions. The major factors likely to influence growth would appear to be water shortage at certain times of the year and persistent cloudiness and rainy weather at other times.

The lack of data precludes the use of the Penman (1948) method of estimating the rates of evaporation in the area. However, estimates of evapotranspiration for stations that record temperature have been obtained by means of the formula of Thornthwaite (1948). The estimated potential evapotranspiration for these stations ranges between 4·5 in. and 5·5 in. per month. An arbitrary value of 5·0 in. per month has been applied to stations for which rainfall data are available, in order to assess the adequacy of rainfall.

Figure 5 shows average rainfall for each of the six stations compared with the potential evapotranspiration of 5·0 in. per month. The Thornthwaite formula allows for excess rainfall to be stored in the soil up to a maximum of 4·0 in. At all stations except Wewak and Dagua there is an average of at least four months during the south-east season when potential evapotranspiration exceeds rainfall. For about the first two months the water stored in the soil supplies the additional moisture but after that there is a water deficit.

If the data are considered on the basis of individual years a more varied picture of conditions emerges. A budget was drawn up for each station in which monthly potential evapotranspiration and monthly rainfall respectively depleted and supplemented the available water. It was assumed that soil water was available to plants to a maximum value of 4·0 in. The results of this analysis are shown in Table 6.

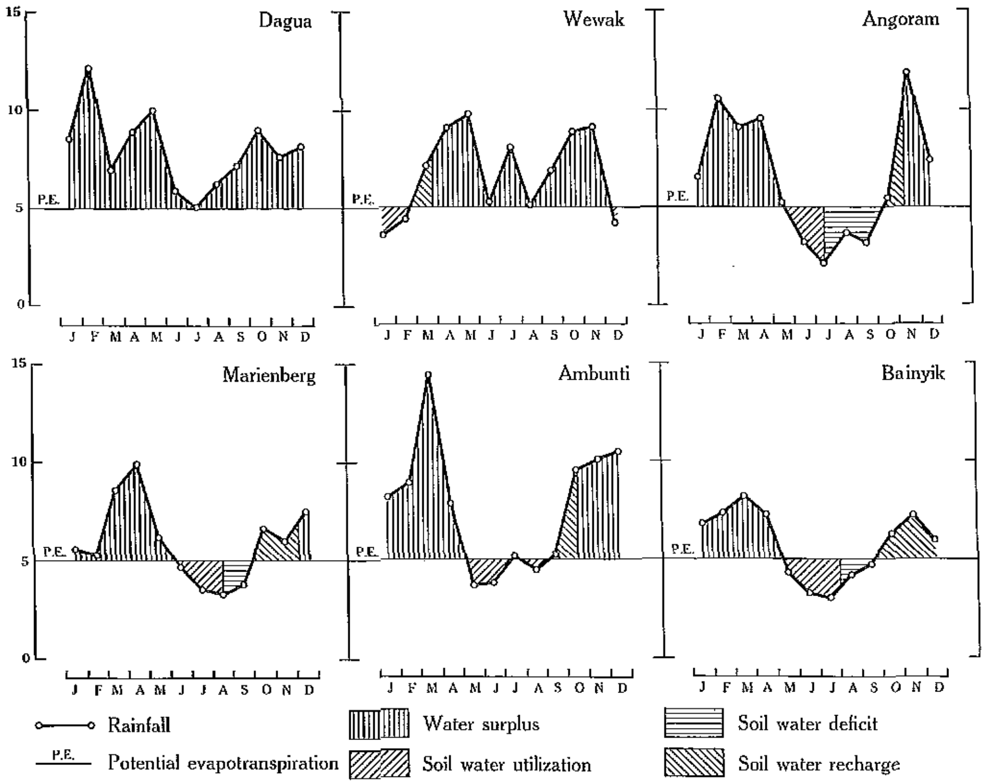


Fig. 5.—Relationship between average monthly rainfall and evapotranspiration, and soil moisture storage.

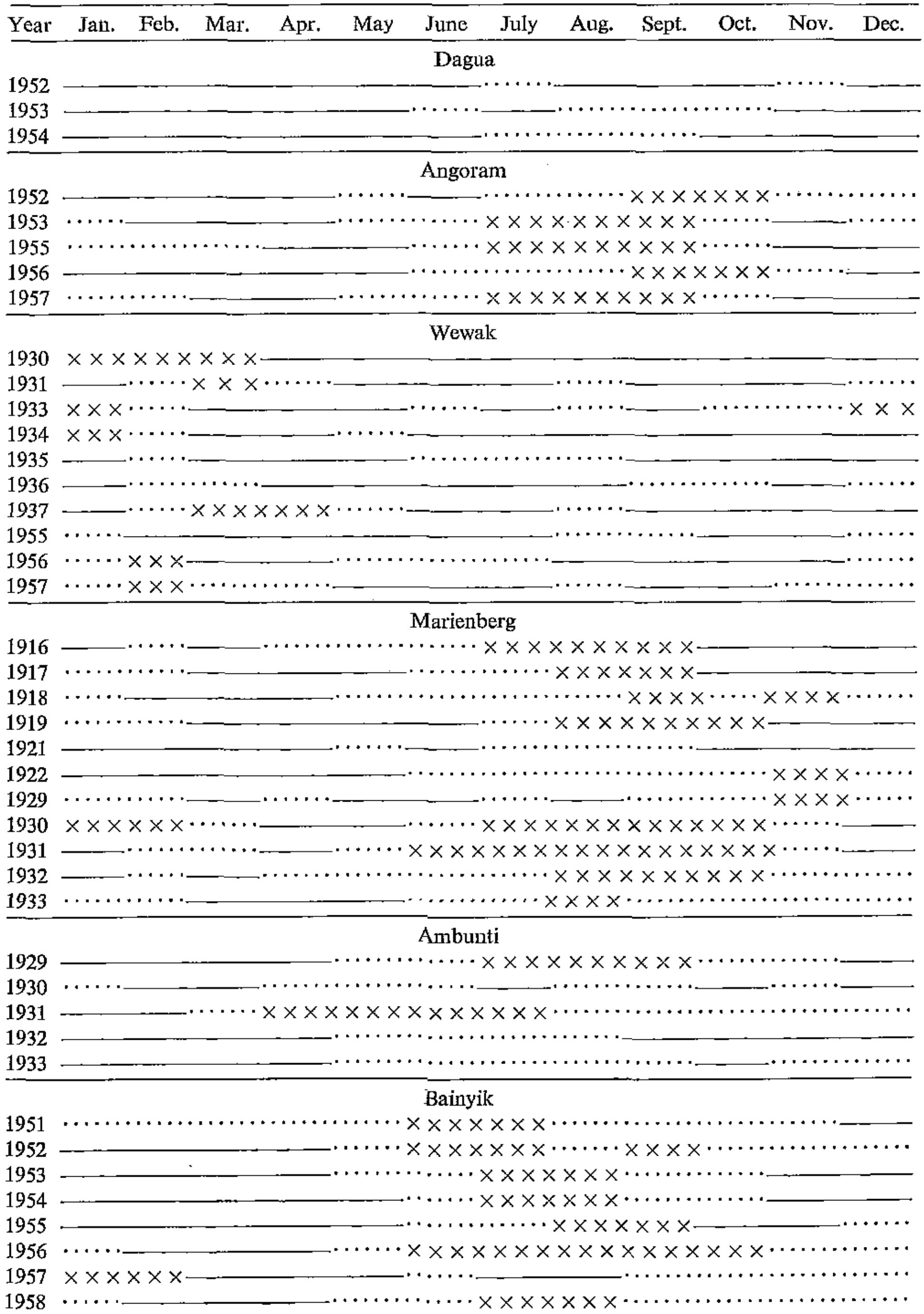
It can be seen that some periods of water shortage are experienced at every station except Dagua. Here, during three years, there was never a period of water deficit, because when potential evapotranspiration exceeded rainfall the difference was made good by soil storage. At Wewak short periods of water deficit occurred during the north-west season and at the beginning of the south-east season, but were not experienced every year. At the remaining four stations periods of water deficit of two to five months' duration occurred in most years, usually commencing about the middle of the south-east season and occasionally extending well into the north-west season.

This analysis can be regarded only as a rough guide to conditions in the area and the following points should be taken into account.

(1) The arbitrary value of 5·0 in. per month for potential evapotranspiration gives no indication of seasonal variations or of differences between stations.

TABLE 6

AVAILABILITY OF WATER* FOR PLANT GROWTH



* Water surplus, ——; depletion of soil water storage, ······; water deficit, ×××.

(2) The duration of periods of water shortage can be either masked or exaggerated by the use of monthly data. On the one hand, an analysis on a fortnightly or weekly basis can frequently indicate a period of water deficit not evident from a monthly analysis. Conversely, a detailed analysis can demonstrate that during a protracted period of water shortage, occasional weeks occur in which water is available for plant growth. This latter feature can be appreciated when it is realized that rainless periods rarely last longer than two weeks.

TABLE 7

PERCENTAGE CHANCE OF RECEIVING RAINFALL TOTALS IN EXCESS OF SPECIFIED AMOUNTS*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					2·00 inches							
Ambunti	100	100	100	80	80	80	100	80	100	100	100	100
Angoram	100	100	100	100	100	80	60	100	80	100	100	100
Bainyik	100	100	100	100	86	86	57	86	100	100	100	100
Dagua	100	100	100	100	100	100	100	100	100	100	100	100
Marienberg	100	100	100	100	100	73	100	73	82	100	91	100
Wewak	72	100	86	100	100	86	100	100	100	100	100	86
					5·00 inches							
Ambunti	80	100	80	60	—	20	60	40	40	100	40	60
Angoram	60	80	100	100	40	20	—	20	—	60	100	80
Bainyik	87	87	100	87	25	—	12	37	50	62	100	75
Dagua	66	100	100	100	100	66	33	66	33	100	66	100
Marienberg	54	54	100	82	73	27	—	27	18	45	64	10
Wewak	57	29	57	71	86	71	86	57	86	71	86	71
					8·00 inches							
Ambunti	60	40	60	60	—	—	—	—	20	80	20	60
Angoram	40	60	60	80	20	—	—	—	—	20	80	40
Bainyik	14	14	57	43	—	—	—	—	—	14	29	—
Dagua	66	66	33	33	66	33	33	33	33	33	33	66
Marienberg	18	18	55	55	18	9	—	—	—	36	18	27
Wewak	14	—	29	43	43	43	43	14	86	43	72	14
					12·00 inches							
Ambunti	20	20	40	20	—	—	—	—	—	20	20	40
Angoram	—	40	20	—	—	—	—	—	—	—	40	20
Bainyik	—	—	14	—	—	—	—	—	—	—	—	—
Dagua	33	66	—	33	33	—	—	—	33	33	—	—
Marienberg	—	—	9	36	—	—	—	—	—	—	—	—
Wewak	—	—	—	14	29	—	14	14	57	29	—	14

* Data from monthly rainfall records from Bureau of Meteorology.

(3) Maximum soil water storage of 4·0 in. is an average value only and the actual value varies according to the type of soil.

Table 7 illustrates some other aspects of the reliability and uniformity of the monthly rainfall in the area. The strong probability of the occurrence of water stress for the stations south of the coastal ranges can be deduced from the percentage chance of receiving monthly totals in excess of 5·0 in., the assumed amount of monthly evapotranspiration. In fact, Dagua is the only station where such amounts can be regularly expected for most of the year. On the other hand, there is for all stations a high probability of receiving more than 2·0 in. of rain per month throughout the year, which indicates that water stress is not likely to be severe.

Table 7 also brings out the uniformity of the coastal rainfall, especially at Dagua, in comparison with that of the Sepik plains, especially at Ambunti and Angoram. The rapidly decreasing chances of receiving monthly totals in excess of 8 and 12 in. are an indication of the general uniformity of the rainfall in the area, and especially of the small probability of receiving very heavy falls or persistent rain during the south-east season.

Cloud cover is considerable throughout the year and the change from season to season is not great, ranging from three-eighths to five-eighths, though as would be expected there is an increase during the wetter months. Table 4, which has been discussed in an earlier section, shows that periods of persistent rain lasting for more than five consecutive days occur quite frequently, but are usually restricted to the wetter months.

The agricultural implications of the data presented above are:

(1) The coastal climate is generally suitable for year-round growth of crops. At the same time, this well-distributed rainfall will be detrimental to crops requiring dry sunny periods for maturing, and may also hamper mechanical harvesting and land preparation.

(2) The climate of the Sepik plains poses definite limitations on the growing of crops throughout the year. This means that seasonal planting must be practised, especially for crops that need dry weather when reaching maturity. This climate offers better possibilities for mechanized farming. Supplementary irrigation during the south-east season might be worth consideration at a later stage of development.

(3) The general uniformity and low probability of excessive rainfall tend to reduce flood and erosion hazards and to simplify land drainage measures and agricultural operations in general.

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PART IV. GEOMORPHOLOGY OF THE WEWAK–LOWER SEPIK AREA

By E. Reiner* and J. A. Mabbutt†

I. Physical Regions

Six physical regions have been recognized and are shown in Figure 6. From north to south, these are described below.

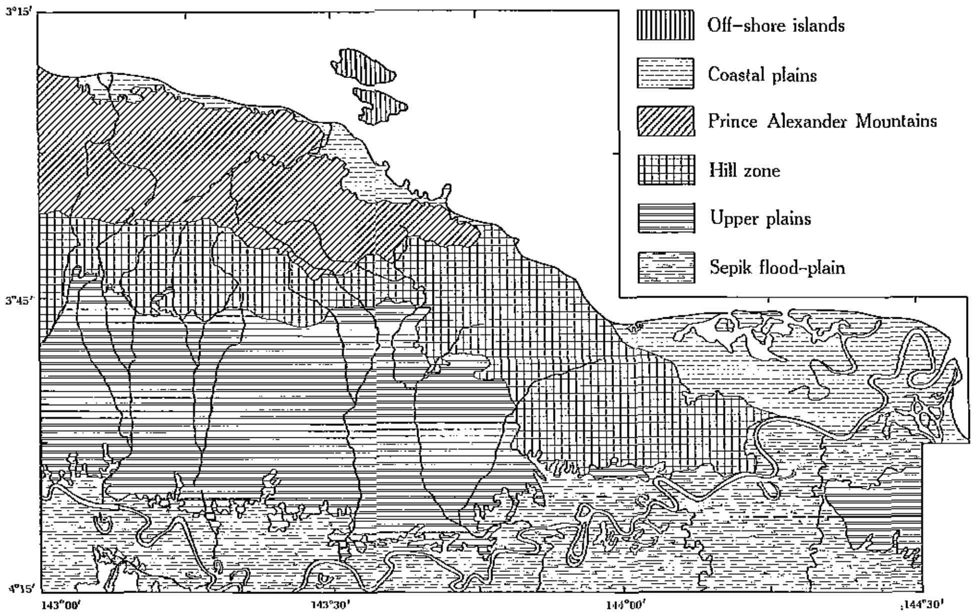

Fig. 6.—Physical regions.

(a) *Offshore Islands*

These comprise five islands between 2 and 6 miles offshore and lying north-north-west of Wewak. They include two types.

(i) *Volcanic Island of Kairiru* (21 sq miles).—This island consists of dissected slopes rising steeply to 3400 ft above sea level from a coastline that is generally steep and rocky.

(ii) *Four Coral Islands.*—The largest of these is Muschu (15 sq miles), separated from Kairiru by a deep narrow strait. This island consists of a coral reef which has

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been upraised to 240 ft above sea level, and a siltstone platform on which the reef has formed and which is exposed in the higher parts. The three smaller islands (Karasau, Yuo, and Raboin) are low reefs.

(*b*) *Coastal Plains*

The coastline is 140 miles long with deep water inshore. The coastal plain is separated into two parts by the rocky coast between Nightingale Bay and Kaup.

The longer western sector consists mainly of narrow talus benches, generally less than ½ mile wide and rising to 40 ft above sea level. These benches are broken by the peninsulas of Wom, Wewak, and Moem, which are former islands now linked with the mainland by beaches. In two areas west of Wewak, the narrow bench gives place to delta plains up to 6 miles wide: the Sowam plain in the extreme west, and the Hawain plain. Throughout this sector, the coastal plain is backed by a steep fault scarp.

The sector east of Kaup forms part of the depositional plain of the Sepik mouth and extends up to 10 miles inland. It consists of a narrow sandy beach behind which are the Murik lagoons, and of mud flats which are tidal in part and lie within 2 ft of high water. The plain extends to the Sepik channel in the south-west; it is limited by a low escarpment that is a continuation of the rocky coast to the north-west.

(*c*) *Prince Alexander Mountains*

These form part of the coastal ranges of New Guinea and occur in the north-west of the survey area, where they extend for 60 miles from east to west. In the west, they form a tract up to 15 miles wide, but they narrow eastwards and die out west of Nightingale Bay. They form a closely dissected complex of narrow ridges, escarpments, and upland benches, mainly with a west-north-west trend. The general altitude decreases from about 3000 ft in the west to 1000 ft in the east, and the summit is Mt. Turu (3985 ft above sea level).

The Prince Alexander Mountains form the divide between the shorter coastal rivers such as the Sowam, Hawain, and Brandi, and the longer south-flowing rivers such as the Screw and the Nagam. In the east the watershed lies less than 5 miles inland, but it has been displaced southwards as far as Mt. Turu by the Hawain and Sowam Rivers. The drainage is deeply incised throughout and two structural directions are apparent in the trend of the upper valleys, one west-north-west, the other almost north to south.

(*d*) *Hill Zone*

This is a closely dissected belt of mudstones and siltstones south and south-east of the Prince Alexander Mountains. The hill zone broadens from about 5 miles in the west to approximately 15 miles in the east. It forms the rocky coast between Nightingale Bay and Kaup, and also borders the Sepik between Angoram and Marienberg. The altitude generally decreases from north to south and from west to east, from 1200 ft to less than 250 ft above sea level. Relief decreases similarly from about 600 ft to as little as 50 ft. A distinction can be made between a western and a south-eastern tract.

The western part consists of close-set ridges and hills, with narrow summits in the higher parts and more rounded crests in the south. Slopes are steep, except in the lowest, southernmost hills. It is traversed by parallel rivers draining south to the Sepik plain.

The south-eastern part is also closely dissected, but the hills and ridges generally have accordant summits, giving the area the aspect of a dissected plateau. This part of the hill zone has a branching network of smaller valleys.

Throughout the hill zone the trunk rivers are flanked by narrow alluvial plains and terraces.

(e) Upper Plains

These are mainly confined to the western half of the survey area where they extend up to 20 miles south of the hill zone. They consist of a very even plain with an average fall of 10 ft per mile towards the Sepik, ranging between 200 and 400 ft above sea level in the west and between 150 and 350 ft in the east. The plains occupy valley embayments in the hill zone in the north, and widen southwards, terminating in a terrace between 20 and 30 ft above the Sepik flood-plain. In general, the upper plains end about 6 miles north of the Sepik, but meet the river at Pagwi and Timbunke to form a high, flood-free bank. In detail, the southern edge is highly fretted with several detached "islands" within the flood-plain. The upper plains are a depositional surface mainly of clays but with sands and gravels in the north and on valley margins. The surface is generally flat and ill drained, with a pronounced microrelief, but low gravel-strewn hills up to 100 ft high occur in the northern parts, particularly in the embayment south of the hill zone.

The large south-going valleys are narrowly entrenched up to 100 ft below the plains in the north, decreasing to 20 ft in the south. The rivers are flanked by narrow alluvial terraces, widening out to delta-shaped flood-plains and back swamps along the northern edge of the Sepik flood-plain.

With this region is included the low platform extending eastwards from the Pora Pora Creek to the lower Ramu near Bosman. The gently undulating crest is up to 60 ft above sea level and about 20 ft above the adjacent flood-plain.

(f) Sepik Flood-plain

Only the north part of the flood-plain is included here, for the larger part lies south of the survey area. The flood-plain comprises:

(1) The back plain, which forms the lowest part of the region and which is occupied by swamps and by open lakes such as Chambri Lake in the extreme south-west. The back plain is traversed by deep, narrow waterways (barits), and is diversified by low flood scrolls near its river margin.

(2) The levees, which form a discontinuous belt less than 200 yd wide along the Sepik, but which are continuous along the southern tributaries. They rise between 5 and 10 ft above the back plain.

(3) The channels of the Sepik and its right-bank tributaries. The Sepik River flows close to the north edge of its flood-plain in very large meander loops. Although

many cut-off meanders indicate the instability of the river course (at least three breakthroughs of meander necks are recorded during the last 50 years), there are no signs in the landscape of major shifts in the general position of the river in the past except in the coastal plain tract. The straight-line distance along the river within the survey area is approximately 115 miles, whilst the distance measured along the channel is at least 210 miles. The average fall is slightly less than 1 ft per mile. The width of the channel varies from 160–330 yd in the west near Pagwi to 220–550 yd in the east near Angoram, and reaches 1100 yd in the mouth, which is free of shallow sand-bars lying in front of it. The depth at average low-water level is approximately 40 ft and the current 2 knots.

When in flood, during a period of at least 5 months in the wet season, the river forms a large shallow lake at least 20 miles wide, extending from the higher Sepik plains in the north to the higher ground south of the present survey area. Flood levels may be 20 ft higher than low-water levels in the west, but the difference rarely exceeds 10 ft near Angoram and becomes very small east of Marienberg, where tidal fluctuations predominate. A very rough estimation indicates that the average low-water flow of the Sepik River is probably twenty times, and at flood level probably ten times, that of the Ramu River, which reaches the coast only a few miles further east.

II. Outline of the Geology

The regional geology is shown in outline in Figure 7. The oldest rocks mapped are the schists south of Mt. Turu, but river boulders of gneiss found both north and south of the watershed indicate the probable existence of a crystalline basement in the Prince Alexander Mountains.

The oldest of the overlying sedimentary rocks are Upper Miocene mudstones, which are exposed in river gorges in the south-west of the Prince Alexander Mountains and in the north between the Hawain River and a point south of Wewak. These are overlain with apparent conformity by Pliocene marine mudstones, siltstones, and intercalated conglomerates, sandstones, and coral limestones, locally at least 2000 ft thick. These rocks build the Prince Alexander Mountains and the flanking hill zone, and they are disposed in a broad anticline with its east–west axis near or north of the drainage divide. The anticline is broken by faulting on its north limb, giving rise to numerous tilted fault blocks, mainly with a west-north-west trend. Accordingly, dips are variable in the north of the anticline. The blocks are mainly down-faulted to the north, where faults have determined the steep coastline.

Intrusive and extrusive rocks are associated with the coastal arching. Igneous and metamorphosed igneous rocks including amphibolite, pyroxenite, and gabbro occur in disconnected parts along the axis of the area. The outcrops are interpreted as windows revealing parts of a batholith intruding into the folded Tertiary sediments. Diabase occurs in a dyke-like structure on the coast near Terebu. Rhyolitic, andesitic, and basaltic lavas occur in association with the hypabyssal rocks. They are generally regarded as Pliocene, particularly the basalts on the volcanic island of Kairiru. Submarine tuffs form part of the Pliocene succession in the north-west of the coastal anticline.

On the south limb of the anticline the tilted Pliocene sediments are overlain unconformably by Pleistocene gravel, sand, and clay in the west, but probably conformably by marine siltstones in the east. These beds have gentle southerly dips. Estuarine sediments of probably Pleistocene age form the Bosman plateau in the east.

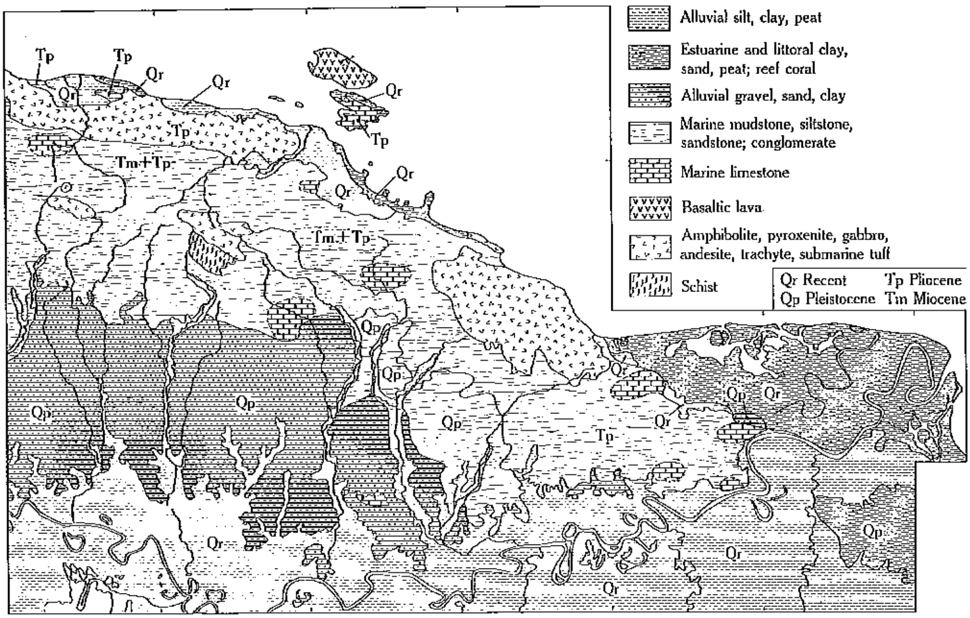

Fig. 7.—Generalized geology.

The southern part of the survey area consists of the Recent alluvia of the Sepik plains. These are unconsolidated silt and clay with peat. Other small areas of Recent alluvia, coral limestone, and littoral sand occur along the coastal plain and on the offshore islands.

III. Geological and Landscape History

In a geologically young area such as New Guinea, geological and geomorphological developments are closely integrated, and for this reason they will here be treated together.

(*a*) *Period of Marine Deposition*

The geological history of the area begins with a trough of marine deposition on the north side of the central ranges of New Guinea in Upper Miocene and Pliocene times. Up to at least 2000 ft of mudstones, siltstones, and intercalated pebble conglomerates and coral limestones were laid down.

(*b*) *First Phase of Uplift and Erosion*

In the late Pliocene or early Pleistocene these deposits were broadly up-arched on an east–west axis. The uplift was greatest in the west of the survey area, where it attained a minimum of 3000 ft, and it decreased eastwards. The growing arch was broken by block-faulting, generally on west-north-west lines. The faulting was strongest in the western area of maximum uplift, and was also particularly pronounced on the north limb of the arch, where parallel faults formed the steep coast. In addition, there was widespread minor cross-faulting. The area of strongest uplift and faulting forms the Prince Alexander Mountains. In the western part of these mountains strong faulting was associated with the intrusion of massive amphibolites, which are exposed in two high parts of the ranges, on Mt. Turu and near the head of the Screw River further west.

In contrast to the down-faulted north limb, where the mountains rise steeply from a deep-water coast, the sediments on the south sides are only moderately uptilted, and form a hill zone which flanks the higher ranges on the south but extends to the coast across the more gently uplifted east end of the arch. Within this zone, faulting is restricted to the border of the Prince Alexander Mountains in the north-west and to the coastal scarp in the north-east. In general, the rocks dip more steeply southwards in the west where dissection has been strongest. The dips decrease eastwards and the rocks are almost subhorizontal in the east of the hill zone, where relief is also less. Maximum uplift in the hill zone was of the order of 1000 ft.

The earth movements that formed the Prince Alexander Mountains and the hill zone were accompanied by volcanism in three areas. In the north-west, basaltic and rhyolitic lavas and submarine tuffs form most of the area between the coast and the inland fault scarp west of the Hawain River. These deposits may attain several hundred feet in thickness. In the north-east, basaltic lavas up to 600 ft thick were extruded between Tring and the coast. It is also probable that the volcanic island of Kairiru came into being in this period. It consists of basalts and tuffs.

As the marine deposits emerged above sea level in the coastal arch, subaerial erosion set in and eventually a broadly undulating surface was eroded across the structure. Planation was only partial in the higher-standing west of the area, but was well developed in the east, where it was aided by the subhorizontal bedding of the rocks.

In the north, the products of erosion were carried to the sea. In the shallowing marine gulf in the south, deposition took two forms. West of the present line of the Nagam River, up to 100 ft of fine quartz gravel and sand were laid down as fans or deltaic deposits. Further east, shallow-water marine mudstones and siltstones continued to form.

(*c*) *Second Phase of Uplift and Erosion*

A second phase of uplift followed. This was also greater in the west than in the east, as shown by the altitude of the former erosion surface which now partially survives in restricted upland areas. In the Prince Alexander Mountains it is at 1000 ft and found west of the lower Hawain River and in the Numoiken area. In the north-west of the hill zone it is at 800 ft, but further east it descends to between 250 and 400 ft above sea level, and also becomes more extensive. The same uplift caused the emergence of older Pleistocene deposits south of the hill margin and led to their dissection to below present base level by south-going tributaries of the newly formed Sepik River, fashioning the low rounded hills on the upper plains. In the north the rock platforms of Muschu Island as well as those on the coastal headlands may have emerged during this phase of uplift.

(*d*) *Formation of the Upper Plains*

This erosional phase was followed by the aggradation of clays and fine sands forming the upper plain surface. These deposits are best developed in a large enclave on the south margin of the hill zone, mainly west of the Nagam River. However, similar deposits occur in small areas as far down-valley as Angoram. Furthermore, it seems reasonable to include with them the clays of the Bosman platform and those on the small coastal shelf north of Boram. The lower level of this depositional surface is mainly between 20 and 30 ft above the present Sepik flood-plain. It is considered that these deposits may have resulted from a relative rise of sea level following a low stand. Aggradation extended back along the length of the Sepik and its tributaries, partly drowning the dissected older Pleistocene gravels. The fine texture of the deposits of the upper plain probably reflects that of the source rocks to the north.

The aggradation was followed by renewed incision of the Sepik and its tributaries. The tributary valleys were narrowly entrenched in at least two phases, and the southern margin of the upper plain was deeply indented. The depth of incision is not known. Since the level of the left-bank tributaries of the Sepik River below the upper plain increases from 25 ft at the flood-plain junction to approximately 100 ft at the border of the hill zone, the entrenchment may have been associated with up-tilting towards the north, possibly associated with renewed movement of the coastal range anticline. Such tilting would also account for the slope of 1 in 500 towards the Sepik on the upper plain, a rather high gradient for such a fine-textured aggradational surface. These same movements may have caused emergence of the estuarine clays in the Bosman platform, which is also on the axis of the anticline.

At the same time, the intense fretting of the south margin of the upper plain by local drainage suggests a lowering of base level along the Sepik plain. It is very possible that this may have been caused by a Pleistocene eustatic lowering of sea level.

(*e*) *Formation of the Flood-plains*

Entrenchment was succeeded by aggradation of the Sepik flood-plain, a process that is continuing. The Sepik channel closely follows the northern edge of the plain, probably owing to displacement caused by the greater depositional power of its southern tributaries, which drain the high central ranges. The scarcity of cut-off meanders north of the river and the absence of upper plain remnants south of it also point to migration of the channel northwards.

Alluviation has also occurred in the south-going tributary valleys. Flights of alluvial terraces occur up to 30 ft above river level, generally increasing in height up-valley and probably indicating fluctuations in load-discharge conditions.

Extensive deposits of sand and silt have also formed at the mouth of the Sepik where the coast has been prograded up to 15 miles. In part, these deposits are deltaic and in part they are tidal, having been laid down in shallow lagoons behind a narrow sandy bar. Some subsidence and coastal regression now appear to be taking place west of the Sepik mouth.

IV. Geomorphology of the Land Systems

The land systems have been separated into two major groups: those formed by erosion and those that owe at least part of their form to deposition. Within the former, relief is the main basis of subdivision. The second group is subdivided into inactive and active surfaces.

(a) *Erosional Land Systems*

(i) *Mountains*.—These land systems largely comprise the Prince Alexander Mountains. They range from sea level to almost 4000 ft, with relief up to 1500 ft. They are the areas of strongest uplift, faulting, and dissection, and generally consist of narrow ridges, steep slopes, and deep winding valleys. There are restricted undulating upland surfaces, mainly below 1000 ft.

Faulting has had a strong influence on the relief of these land systems. The ranges are broken into parallel fault blocks, many of which are strongly tilted, and dips are steep and variable. The major faults have given rise to dissected, west-north-west-trending escarpment zones. These delimit the coast and the southern edge of the mountains, and also form the main watersheds. The faults separate off the east–west-trending upper catchments of larger rivers, such as the Hawain and Sowam in the north and the Screw and Nagam in the south. These rivers appear in part to be antecedent to the faulting, for they turn to cross the fault zones in deep gorges. Locally, fault basins have formed, such as the Kumbusaki basin drained by the upper Screw and the Wonginara basin occupied by a headwater of the Hawain. Cross faults trending slightly east of north have controlled the courses of many upper valleys. Continuing tectonic disturbance is reflected in numerous landslides, particularly in the north-western part of the mountains.

Turu land system comprises the areas of metamorphosed, igneous, and volcanic rocks. It is mainly formed on basalts and submarine tuffs, which extend 5 miles inland from the north-west coast. Turu land system also comprises smaller summit areas formed by amphibolites such as Mt. Turu. On these rocks the relief is greater and more massive.

Nagapam land system consists of the areas of strongest dissection on sedimentary rocks over a basement of gneiss and other metamorphic rocks. It forms the axis of the Prince Alexander Mountains in the west. Relief is up to 2000 ft, but the highest ridges do not exceed 3000 ft above sea level.

Imbia land system is underlain by steeply dipping rocks, which include conglomerate, sandstone, and minor limestones, in the south-west of the Prince Alexander Mountains. These harder rocks have given rise to east–west ridges with very steep slopes. The ridges are traversed by the closely spaced transverse gorges of a south-going drainage.

Numoiken land system forms the axis of the Prince Alexander Mountains in the east, and it is formed mainly of sedimentary rocks with local dolerites and amphibolites, which have been less strongly uplifted than those of the Nagapam land system. Accordingly, relief is less and altitudes are lower, generally below 1200 ft. The undulating upland surface is also more extensive in this land system.

(ii) *Hills.*—These land systems mainly occur in the less strongly uplifted and faulted part of the coastal arch, namely on its southern flank and at its eastern end. As a result, altitudes do not normally exceed 1200 ft and relief is generally less than 600 ft. The upland units consist largely of steep-sided hills and short ridges, with narrow rounded crests. However, in areas of least uplift and dissection there are rolling or plateau-like upland surfaces sufficiently stable for the preservation of deep residual soils. This allows further subdivision of this group of land systems.

In the hilly landscapes tributary valleys have steeply rounded heads and sloping floors with well-developed colluvial aprons; the main valleys are flat-bottomed, with narrow alluvial terraces. There is less structural and tectonic control of relief than in the mountain land systems.

(1) *Hills without Remnant Upland Surfaces.*—The land systems in this group have been arranged in order of decreasing relief.

Kaboibis land system occurs in the west of the hill zone, where rocks have been more strongly uplifted and uptilted, and it is the highest, most dissected hill land system. It is underlain mainly by mudstones that have been dissected into long ridges by deep south-going valleys. Intercalated siltstones and conglomerates form secondary spurs and crests, whilst minor limestones in the east of the area build narrow flat-crested ridges with steep slopes.

Yangoru land system is a small area of low-grade schists in the zone of basement outcrop south of Mt. Turu. It has characteristic steep-sided conical hills up to 400 ft high.

Wonginara land system consists of small fault-bounded foothill basins on the north side of the Prince Alexander Mountains. It is underlain by mudstones and siltstones that have been dissected into rounded hills with slopes of varying steepness. Relief is 200–400 ft.

Kumbusaki land system is a small fault-bounded basin between 800 and 1300 ft above sea level, drained by the upper Screw River. It is floored by very soft mudstones which have given rise to very closely dissected ridges of "badland" character, with between 200 and 400 ft relief.

Winge land system has mudstones and siltstones that have been dissected up to 150 ft to form a complex of low rounded hills and open valleys and steep-sided narrow-crested hills and ridges. It forms the south-western edge of the hill zone between Winge and the Minjim River.

(2) *Hills with Remnant Upland Surfaces.*—The land systems in this group are found mainly in the eastern part of the hill zone, but include the low hilly to rolling terrain south of the hill zone. The land systems are arranged in order of decreasing relief.

Senambila land system is formed mainly of gabbro, trachyte, and diabase in the north-east of the hill zone. Relief is up to 400 ft and altitude generally below 1000 ft. Land forms vary. Smooth rounded hills and broad valley heads with colluvial fills occur in inland parts in the west and south-east, whilst the central and coastal sectors are more steeply dissected with narrow ridges.

Passoram land system is the largest of the hill systems. It consists of mudstones and siltstones, with marls and coral limestones locally. The mudstones and siltstones have been dissected into rounded ridges and hills with up to 200 ft relief and slopes of moderate steepness. The limestones build somewhat broader, flatter-crested ridges with minor karst features. There is a close branching network of small valleys. Passoram land system forms the eastern part of the hill zone. It also occupies the less dissected parts of foothill embayments on the north-east flank of the Prince Alexander Mountains, whilst it occurs again in the south part of the hill zone west of Winge.

Muschu land system is the upraised coral reef at an altitude of 240 ft above sea level on Muschu Island. It is a gently undulating plateau surface, with better-drained depressions and steep rocky bounding slopes.

Kworo land system has been formed by the slight dissection of gravels and siltstones in a broad embayment south of the hill zone. It consists of low rounded hills with up to 80 ft relief, ranging from 250 to 400 ft above sea level. The hills are mantled by fine quartz gravels in the west. There is considerable development of microrelief with stone stripes on slopes greater than 10%, and shallow pitted soils in flatter areas. Small breakaways with slump toes occur near dissecting streams. The valleys are shallow and open, with ill-drained gently sloping heads and narrow alluvial terraces in the lower sectors.

(*b*) *Depositional Land Systems*

These land systems have formed by deposition on both sides of the anticlinal structure of the coastal ranges. They are widespread in the Sepik lowlands but are restricted and discontinuous on the north side of the mountains.

(i) *Inactive Depositional Surfaces*.—These are surfaces which, in the main, are no longer subject to deposition. They are mainly stable, but some dissection is taking place on the margins. They comprise a wide range of deposits, and the only common features are their low elevation and gentle slopes.

Yambi land system is essentially the upper plains, a gently sloping ill-drained surface of silt and clay between 150 and 400 ft above sea level, characterized by many pitted soils. It is traversed by shallow valley depressions, but the lower section of the drainage may be quite sharply incised up to 40 ft. Yambi land system is broken into long strips by the entrenched alluvial valleys of Nagam land system.

Bosman land system is a low gently undulating platform formed of clays standing in the flood-plain near the Sepik mouth. It has an undissected ill-drained surface, and somewhat dissected margins.

Madang land system is a discontinuous plain, rarely more than ½ mile wide and generally less than 30 ft above sea level, extending along the north-west coast and fringing Muschu Island. It comprises sandy beach ridges and swampy swales, small alluvial tracts that cross the land system, and gentle slopes to the foot of the backing hills. Madang land system also includes coral headlands and low coral reef islands.

Nubia land system comprises sandy beach ridges with minor swampy swales extending up to 20 ft above sea level. The land system has a generally discontinuous and restricted occurrence except east of the Sepik mouth where it is relatively extensive.

But land system is a series of rocky talus fans in a zone less than ½ mile wide at the foot of the coastal escarpment in the north-west. The fans rise from sea level to an altitude of 100 ft.

(ii) *Active Depositional Surfaces.*—These surfaces are still being aggraded. They have low gradient and occupy low parts of the area, and most of them are subject to seasonal flooding. The largest occurrence is in the flood-plain of the Sepik and its tributaries, but smaller areas occur in the delta plains of the Hawain and Sowam Rivers.

(1) *Flood-plains.*—These include higher-lying tributary alluvial plains and the levee belts of the Sepik and its southern tributaries.

Nagam land system comprises the alluvial plains of tributaries entering the Sepik flood-plain from the north. In the upper sectors it forms narrow belts up to 1 mile wide, and these open out into lobes up to 7 miles in extent where they enter the Sepik flood-plain. It also includes the delta tracts of the Hawain and Sowam Rivers.

The plains generally lie between 5 and 10 ft above the rivers and are subject to flooding only for short periods of high river flow, but the land system also includes lower ill-drained areas of heavy clay soils that are liable to longer inundation.

Misinki land system comprises the continuous levee belts of southern tributaries of the Sepik River, and is characterized by extensive clays. It is subject to inundation for up to 4 months of the year.

Palimbai land system comprises the narrower, discontinuous levees of the Sepik River, with coarser-textured alluvium. It is liable to flooding for up to 5 months each year.

(2) *Flood-plain Swamps.*—In these land systems, which occupy the lowest parts of the flood-plains, the water-table is close to the surface for most of the year.

Pandago land system consists of relatively better-drained areas subject only to seasonal inundation. It occurs on higher fringes of the flood-plain, whence it extends into the lower parts of tributary valleys of the north side, and also in upper sectors of minor valleys in the upper plains.

Kabuk land system consists of very poorly drained areas in blocked tributary valleys or in lower parts of the flood-plain.

Sanai land system occupies most of the Sepik flood-plain, and is subject to severe seasonal flooding by the main stream. It contains much open water, including the Chambri Lakes, many smaller oxbows, and narrow barits. It is diversified by low flood scrolls near the levee zone.

Pora land system is permanent swamp and forms part of the lower flood-plain between the Keram River and Pora Pora Creek.

(3) *Littoral Swamps.*—These two land systems are found mainly near the mouth of the Sepik and in small areas along the coast to the north-west. They lie within 2 ft of sea level and are generally subject to tidal influence.

Kobar land system consists of permanent freshwater swamps in the littoral zone, and is formed of sands with a peat cover. Although traversed by tidal creeks, it is not subject to marine inundation; flooding is from the land. It occurs throughout the delta tract of the Sepik and forms the hinterland to the Murik lagoons. It also occurs as a broad swale between low sand ridges west of Wewak.

Murik land system comprises tidal mud flats, mainly in the Murik salt-water lagoons.

PART V. PEDOLOGY OF THE WEWAK–LOWER SEPIK AREA

By H. A. HAANTJENS*

I. INTRODUCTION

During this rapid reconnaissance survey no time was available for digging profile pits. Most of the 450 soil observations were made on auger samples, although road cuts were examined wherever possible.

As in most parts of New Guinea, there is a varied soil pattern in the area in response to rapid changes in land form and rock type. Large areas of alluvial and marine plains have immature soils, which can be differentiated mainly according to differences in texture, drainage, and degree and type of topsoil development. Such development is most pronounced on land surfaces no longer subject to active deposition, and on colluvial foot slopes in hilly areas. In low-lying swamps with little or no alluvial sedimentation organic soils have developed.

Predominantly rather shallow brownish soils with more pronounced horizon differentiation (semi-mature soils) occur extensively on unstable hill and mountain slopes. These soils are mainly differentiated according to thickness of solum, colour, texture, and acidity. Shallow soils on calcareous sedimentary rocks and limestone have been separated mainly because of their very dark colour, high pH, and well-developed structure. Gleying is of importance in the separation of some semi-mature soils, particularly plastic clay soils found on poorly drained stable grass plains in the centre of the area.

In contrast to many other parts of New Guinea, there is a rather high percentage of soils with well-developed profiles (mature soils) in the Wewak–Lower Sepik area. Most of these soils occur on large gently undulating to rolling plains of weathered Pleistocene sediments. Since these sediments commonly contain much quartz sand and gravel and include slowly permeable substrata, gleyed soils of very low fertility with texture contrast have commonly developed. Similar soils, but predominantly red and brown in colour, occur locally on better-drained slopes and crests. Prominently red and light grey mottled subsoils, commonly found in all these soils, may be interpreted as incipient lateritization, particularly since horizons rich in iron concretions are also common. All these soils have been subdivided largely on the basis of texture and colour. More uniformly fine-textured and more friable red to yellow-brown mature soils occur locally on stable hill crests and foot slopes as well as near mountain summits. Differentiation between these soils is based on colour, including subsoil mottling, topsoil development, and consistency. Particularly friable yellow-brown clay soils of this group are confined to the highest mountains, where they have developed from mainly igneous rocks under a wet cooler climate.

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II. Soil Classification

(a) *Classification used in this Report*

All soil profiles have been grouped into what are considered to be soil families. This represents the most detailed classification possible for this broad reconnaissance survey and allows the best possible correlation with land forms, rocks, and vegetation. Soil families with definite profile development have been given locality names, but families of peat soils and young alluvial soils, in which profile development is almost entirely due to depositional features and ephemeral water-table gleying, have been given short descriptive names. The young alluvial soil families have been subdivided into phases on the basis of differences in drainage status.

The 55 soil families have been grouped into 15 major soil groups with a sixteenth major group added for the lithosols, which has not been subdivided into families (Table 8).

Table 8

Generalized correlation between major soil groups and great groups of the 7th approximation

Major Soil Group	7th Approximation Great Group
Podzolic red and yellow earths	Typochrults
Uniform red and yellow clays	Ochrudox, some Umbrudox
Gleyed red and yellow earths	Plintochrults, Plintumbrults
Meadow podzolic soils	Umbraquults, Plintaquults
Dull meadow podzolic soils	Argaquolls
Meadow soils	Haplaquolls, Umbraquepts
Gleyed forest soils	Typudalfs
Brown forest soils	Typudalfs, Argudolls, Hapludolls
Shallow black earths	Hapludolls
Rendzinas	Rendolls
Dark colluvial soils	Hapludolls, Haplumbrepts
Alluvial black clays	Umbraquepts, Haplaquolls
Organic soils	Histosols (order)
Old alluvial soils	Hapludolls
Young alluvial soils	Hapludents, Haplaquents
Lithosols	?

These are groups of convenience that appear to suit the local conditions and can be considered as broad morphogenetic units. The lithosols, which have a usually dark solum not more than 6 in. thick overlying more or less weathered siltstone, sandstone, volcanic or metamorphic rocks, or coral limestone, will not be further discussed in this Part.

(b) *Correlation with 7th Approximation*

It is useful to attempt to correlate the classification given above with the 7th Approximation (United States Soil Conservation Service 1960), to make comparisons with similar soils in other countries possible as well as to take a preparatory step to obtaining a uniform general classification of New Guinea soils. The correlation was made primarily on the basis of individual profiles for which analytical data are available. Other soils, particularly of families of which no samples had been collected, were tentatively fitted into this framework.

Podzolic red and yellow earth profiles appear to belong mostly to the Typochrult great group, Psammentic (Kumbi family), Umbric, and Orthic subgroups. Profiles of the Komburaga family are in the Aquic Plintumbrults. Because of unusually high base saturation, one Rabiawa family profile deviates strongly and would have to be considered as an Orthic Argudoll.

Uniform red and yellow clay soils are mostly Ochrudox, but the Aricone family appears to belong to the Umbrudox. They are mostly in the Argillic subgroup,* but the Turu family would be Orthic and the Boen family Aquic. The latter family was never considered as typical for this major group. This is confirmed by the fact that two profiles turn out as Aquic Argudoll and Hapludoll respectively.

The gleyed red and yellow earth profiles are mostly Typic Plintochrults, if the mottled weathering zone can be considered as plinthite. The Giri family presents the greatest difficulties and may include Plintumbrults as well as Eutric Dystrochrepts.

The meadow podzolic soils are mostly Orthic Umbraquults, Ochraquultic Plintaquults, and Aquic Plintumbrults. A few profiles appear to be Aquic Typochrult or Orthic Plintumbrult, while some with unexpectedly high base saturation come in the Orthic Umbraqualfs and Albollic Argaquolls.

The dull meadow podzolic soils generally vary from Udollic or Orthic Argaquoll to Aquollic Typudalf and Aquic Argudoll. One profile of Kiniambu family with low base saturation has to be considered as an Aquic Typumbrult.

The meadow soils appear to include mainly Orthic Haplaquolls, Umbric Ochraquepts, Histic Umbraquepts (Mindumo family), and Mollic Ochraqualfs. A profile of Yari family appeared to be an Ochraquultic Plintaquult and would therefore have been better included with the Yambi family of the meadow podzolic soils.

The gleyed forest soils appear to be mostly Aquic Typudalfs, but it is not unlikely that the group also comprises some Aquic Typochrults and Aquic Dystrochrepts.

The brown forest soils range from Lithic† and Orthic Hapludolls in the least-developed families (Kaboibis, Ambekanya, Yaugiba), through Orthic Argudolls to Mollic, Orthic, and Aquollic Typudalfs in the most-developed family (Nagapam). This trend in soil development is similar to that noted by Haantjens (1967) in the Safia–Pongani area. One profile of the Nagapam family that had to be classified as an Aquic Typochrult probably would have been better placed with the gleyed forest soils.

The shallow black earths are Cumulic, Orthic, and Lithic Hapludolls. This confirms the doubt already felt in the original classification, as to whether these soils could in fact be considered as black earths (Grumusols or Vertisols). A similar dilemma occurred in the Safia–Pongani area (Haantjens 1967).

The rendzinas are clearly Rendolls, but no great group or subgroups have been defined for this suborder.

* Not described in the 7th Approximation. Indicates presence of argillic horizon.

† This subgroup is not listed in the 7th Approximation.

The classification of the dark colluvial soils is not at all clear. They are probably mostly Cumulic and Aquic Hapludolls and Haplumbrepts, but Argudolls probably occur also.

The alluvial black clays appear to vary from Udic Haplaquoll (Tumunum family) and Orthic Umbraquept (Mungin family) to Entic Mazaquert (Kasamp family). This again confirms the field evidence that these soils are transitional between black earths (Vertisols) and other kinds of dark clayey soils.

The organic soils are clearly Histosols, except for the black peat soils (subsoil), which are in fact Hydraquents overlying Histosols.

The old alluvial soils are Entic Hapludolls, but may include profiles of Cumulic and Orthic Hapludolls.

The young alluvial soils are, depending on their drainage status, Orthic or Aquic Hapludents and Orthic or Udic Haplaquents. This subdivision cuts across the texture subdivision between the families but follows the drainage phases given for each family.

Summarizing the conclusions given above, the idealized correlations between the major soil groups in this report and the great groups of the 7th Approximation can be presented as in Table 8. Apparent discrepancies in this table, but more particularly in the more detailed correlations discussed above, are mainly due to the following factors:

(1) Less emphasis on topsoil characteristics in the classification in this report than in the 7th Approximation.

(2) Insufficient information and less emphasis on differences in base saturation and pH when the classification for this report was prepared.

(3) Neglect of the argillic horizon as a criterion in the classification in this report, except when it is strongly expressed.

(4) Insufficient appreciation of the differences between gley mottling and plinthite mottling. It is felt that this distinction still presents a problem.

(5) Greater emphasis in the classification in this report on differences in depth, colour, texture, and consistence in the wide range of Hapludolls and Argudolls occurring in the area.

(6) Difference in emphasis on texture and gleying in the young alluvial soils.

III. Description of Major Soil Groups and Families

(a) *Soil Morphology*

The following soil descriptions are based on the terminology outlined in the Soil Survey Manual of the United States Department of Agriculture (1951) and on Munsell soil colour notations. They refer to moist soils unless stated otherwise. Soil families for which analytical data are available on request have been marked with an asterisk.

Soil structure is mentioned only rarely in the descriptions. This is because they are almost entirely based upon soil auger samples, which are unsuitable for the observation of soil structure. This disadvantage is not serious, as experience has shown that soil structure is not of great value in the classification of New Guinea soils because it is mostly poorly expressed and varies rather haphazardly though within narrow limits. Poorly drained subsoils are massive, and even well-drained subsoils of mature soils are commonly structureless or have weak subangular or angular blocky structure, in many cases compound coarse and fine. This structure is not visually observable, but is revealed only when the soil material is disturbed. Structure is more pronounced in A_1 horizons, especially in the upper part. It can be stated generally that crumb and granular structures predominate in well-developed and/or coarse-textured A_1 horizons, subangular and angular blocky structures in more poorly developed and/or fine-textured A_1 horizons. In many A_1 horizons both types of structure occur combined, or a crumb structure merges into a blocky structure with depth. The impression was gained that in many profiles the structure was influenced by the activities of wild pigs, rodents, earthworms, and burrowing insects, and by the root density. Granular structure may also be associated with rather dry soils under frequently burned grassland.

(i) *Podzolic Red and Yellow Earths*.—These soils have developed in sandy and somewhat quartz-gravelly Pleistocene sediments on top of gentle rises and on gentle slopes below small slump scarps. Locally they occur on colluvial deposits of old colluvial toes, and on moderately steep lower slopes. The vegetation consists of poor *Themeda–Arundinella* grassland, rarely garden regrowth and forest.

The soils have an $A_1/A_2/B$ profile in which the A horizons are coarse and the B horizon finer-textured. Textures range from loamy sand over sandy loam in Kumbi family, to sandy loam over sandy clay in Komburaga and Ravendagum families, to sandy clay and gravelly clay over sandy heavy clay to heavy clay in Rabiawa family. The texture change occurs between $1\frac{1}{2}$ and 2 ft depth. The A_2 and B horizons especially are massive, and the consistence ranges from loose to very friable in the A horizons to firm in the B horizon. A tendency to brittleness is common. The A_1 horizon is very dark grey-brown in colour, the A_2 horizon brownish or grey and brown mottled, and the B_2 horizon yellow-brown to red, commonly with some white streaks. Lateritic iron concretions can occur in the A_2 horizon. The soils are more than 4 ft deep and the C horizon, where observed, consists of purplish or yellow-brown sandy clay, retaining signs of the original stratification of the sediments.

Kumbi Family (1 observation)

A_1: 9 in. of very dark grey-brown (10YR3/2) very friable sandy loam, merging gradually into

A_2: 21 in. of dark grey-brown and with depth brown (10YR4/2 into 5/3) loose loamy sand, merging gradually into

AB: 12 in. of yellow-brown (10YR5/4) with faint strong brown mottles loose to very soft loamy sand, merging diffusely into

B_2: extending beyond 48 in. depth; yellow-brown (10YR5/6) loose sandy loam with below 45 in. depth some grey-brown more clayey bands and some white mottles.

**Komburaga Family* (2 observations)

A_1: 3–9 in. of very dark grey-brown (10YR3/2) moist or wet loose clayey sand to very friable sandy clay loam. Merges clearly into

A_2: 9–11 in. of dark grey-brown plus dark yellow-brown (10YR4/2+4/3), or brown plus grey-brown (10YR5/3+5/2), moist or wet loose clayey sand or very friable sandy loam. Merges clearly into

A_{2g}: 3–5 in. of distinctly medium-sized red-brown, very light brown-grey or strong brown and grey mottled, moist compact and brittle sandy clay loam; or wet slightly sticky and non-plastic clayey sand. Merges clearly between 15 and 25 in. depth into

B_1: 4 in. of prominently medium-sized red, strong brown and grey mottled sandy clay or sandy clay loam merging into sandy clay; moist firm and compact, wet slightly plastic and sticky. Merges clearly into

B_2: extending beyond 4 ft depth; red (2.5YR4/6) with few to common prominent light grey to white mottles; sandy clay to sandy heavy clay; the red soil is firm to friable, with some brittle harder fragments. The light grey material, which may occur in veins, is plastic.

Ravendagum Family (2 observations)

A_1: 3–8 in. of very dark brown (10YR3/2) very friable sandy loam or coarse sandy loam, merging clearly into

A_2: 15–16 in. of dark brown to dark yellow-brown (10YR3/3, 3/4) very friable to brittle and compact sandy loam or coarse sandy loam. May contain increasing amounts of concretions. Merges gradually between 18 and 24 in. depth into

B_1: 5–7 in. of patchy brown and dark red-brown (5YR3/4) friable coarse sandy clay or gravelly sandy clay. The gravel consists of concretions and quartz. Merges gradually between 25 and 29 in. depth into

B_2: extending beyond 4 ft depth; red-brown (5YR4/4) with dark brown patches, firm to very firm coarse sandy clay or coarse sandy heavy clay, with a low and decreasing amount of concretions and an increasing amount of quartz gravel.

**Rabiawa Family* (4 observations)

A_1: 15–16 in. of very dark brown to very dark grey-brown (10YR2/2, 3/2, 7.5YR3/2) friable to very friable light clay, sandy clay, or clay, with a moderate amount of quartz gravel or concretions. Merges gradually into

A_2: 6–19 in. of dark brown (10YR3/3, 4/3, 7.5YR3/4) gravelly clay or clayey gravel. Gravel is quartz and/or concretions. Merges gradually between 21 and 22 in. depth into

B_2: extending beyond 3–4 ft depth; red-brown to yellow-red (5YR4/4, 4/6) with more or less dark brown or brown patches (7.5YR4/4); firm to very firm sandy heavy clay, coarse sandy heavy clay or heavy clay, which may contain low amounts of quartz gravel or concretions.

(ii) *Uniform Red and Yellow Clays*.—These soils occur mostly on rounded or broad level crests and benches or on gentle foot slopes, but are locally also found on very steep mountain slopes. The strongly weathered parent rocks include volcanic and igneous rocks, weakly to moderately consolidated sedimentary rocks, and coral limestone (Muschu family). Vegetation is mostly forest and regrowth, locally *Ophiuros–Imperata* and *Themeda–Arundinella* grassland.

The soils have A_1/B_2 profiles. Soil texture is fine throughout with only a slight tendency to be coarser in the A_1 horizon. This horizon is mostly less than 1 ft thick, various shades of brown in colour, and friable to firm in consistence. It is very poorly developed in Turu family. The B_2 horizon is a reddish, or red and brown mottled, firm to very firm heavy clay, or a bright brown friable clay. Notwithstanding the fine texture, there is only limited tendency towards plasticity. The soils appear to be largely structureless, although they crack into irregular, compound coarse and fine nutty fragments upon drying. The soils are mostly more than 4 ft deep, but truncated profiles of 2–3 ft depth are not uncommon. Where observed, the C horizon differed from the B horizon mainly in stronger mottling and more silty texture, except in Muschu family, which is abruptly underlain by broken coral limestone.

Turu Family (5 observations)

A_1: 2–4 in. of dark brown (10YR4/3) moist or wet very friable silty clay loam to light clay. Merges clearly into

B_2: 24 to more than 48 in. of yellow-brown to strong brown (10YR5/4, 5/6, 7.5YR4/6, 5/6) and in the upper part commonly dark yellow-brown to brown (10–7.5YR4/4) wet or moist friable clay, with only a slight tendency to plasticity when wet. Contains varying amounts of yellow-brown firm weathered rock fragments, increasing with depth.

BC (absent in 2 profiles): red-brown, yellow-brown, strong brown, or dark grey-brown mottled, moist or wet friable silty clay or clay, with increasing amounts of harder weathered rock fragments.

**Aricone Family* (7 observations)

A_1: 6–11 in. of very dark grey-brown to dark brown (10YR3/2, 7.5YR2/2, 3/2) and, in lower part in some cases, dark red-brown (5YR3/3) friable light clay to clay, in lower part commonly firm clay to heavy clay. Merges clearly into

B_2: 23 to more than 46 in. of red (2.5YR4/6, 10R4/4) to yellow-red, red-brown, or dark red (5YR4/4, 4/6, 2.5YR3/6), the latter mainly in the upper part of the horizon; firm to very firm structureless heavy clay with a tendency to plasticity. Merges gradually between 36 and 60 in. depth into

C_1: red or yellow-red silty or sandy clay, or red, yellow-brown, and in some cases white, black, and purple mottled silty heavy clay to heavy clay, which breaks up rather strongly into small angular fragments. The mottles represent completely weathered rock fragments, and harder rock fragments may also be present.

**Muschu Family* (5 observations)

A_1: 3–9 in. of dark brown (10YR3/3, 3/4, 7.5YR3/2) friable to firm clay to heavy clay. Merges clearly into

B_{21}: 5–12 in. of dark red-brown to dark yellow-brown (5–7.5YR3/4, 10YR4/4) firm plastic heavy clay. Merges gradually between 13 and 18 in. depth into

B_{22}: 24 to more than 33 in. of yellow-red to strong brown (5YR4/4, 7.5YR4/6, 5/6) firm heavy clay, commonly with a strong tendency to become very plastic, when lightly kneaded. Merges abruptly at depths below 38 in. into

C_2: Rapidly increasing broken coral limestone, mixed with decreasing amounts of reddish soil.

**Numarin Family* (3 observations)

A_1: 4–10 in. of very dark brown to dark yellow-brown (10YR2/2, 3/2, 3/4) friable light clay to clay, which may exhibit a weak medium-sized angular blocky structure. Merges abruptly or clearly into

$B_{2(g)}$: extending beyond 40 in. depth; with depth increasingly mottled red, red-brown, strong brown, and yellow-brown, firm to very firm structureless heavy clay.

**Boen Family* (11 observations)

A_1: 5–16 in. of very dark grey-brown (10YR3/2) or dark grey-brown to dark yellow-brown (10YR4/2, 4/3, 3/4) moist to moderately dry friable sandy clay, silty clay, or clay, and in a few cases firm to very firm heavy clay. May contain low amounts of black concretions, ferruginous weathered rock fragments, and/or quartz gravel. Merges clearly or gradually into

B_2: 9–26 in. of yellow-brown, dark yellow-brown, or brown (10YR4/4, 4/6, 5/3, 5/4, 5/6, 7.5YR4/4, 5/6), commonly patchy, firm or very firm to plastic or very plastic heavy clay, and more rarely friable to firm silty to sandy clay. The texture normally becomes finer with depth. Commonly contains low amounts of small hard to firm black and/or red concretions. Merges gradually or diffusely between 14 and 32 in. depth into

BC_g: extending beyond 4 ft depth; rather variably mottled red, red-brown, strong brown, yellow-brown, olive-brown, grey-brown, and, with depth, increasingly light grey-brown, light grey, and white; firm or very firm to plastic or very plastic heavy clay, silty or sandy heavy clay. With depth texture may become slightly coarser. May contain very low amounts of red concretions. With depth there is commonly a tendency towards angular breaking up of the soil or brittleness, with increases in smooth firmer fragments, representing completely weathered rock fragments.

(iii) *Gleyed Red and Yellow Earths*.—Developed on strongly weathered Pleistocene sediments, or colluvium thereof, mudstone, and volcanic rock, these soils are found on very gentle to moderate slopes in rolling plains with a vegetation of *Themeda–Arundinella* grassland, rarely poor forest or garden regrowth.

The soils have essentially $A_1/B_2/BC$ profiles, although an A_2 horizon is present in some profiles of Tring family. There is a marked texture contrast between the sandy loam or clay loam to clay A_1 horizon and the sandy heavy clay or heavy clay B_2 horizon. The degree of texture contrast is related to the amount of sand available in the parent rock. The A_1 horizon is about 1 ft thick, black to very dark grey-brown in colour and very friable to firm in consistence. It commonly becomes lighter in colour and finer in texture with depth. The B_2 horizon is red and yellow-brown mottled or predominantly brown with brighter brown and red mottles. The consistence is firm or very firm to plastic or very plastic, and the horizon is apparently structureless, although it cracks into nutty fragments upon drying. Low to very high amounts of iron concretions occur in the lower A and upper B horizons. The BC_g horizon, beginning at a depth of 20–40 in., is prominently white, red, and brown mottled, and apparently structureless, although it cracks strongly into small nutty fragments upon drying. The soils are at least 3 ft but commonly more than 4 ft deep. The C horizon, where observed, is similar to the BC_g horizon, but with more subdued mottling, more silty texture, and stronger nutty fragmentation.

**Tring Family* (4 observations)

$A_{1(cn)}$: 8–9 in. of dark red-brown, very dark grey-brown, or very dark brown (5YR2/2, 10YR2/2, 3/2) very friable coarse sandy loam to loamy gravel. Gravel consists of hard red or black concretions 10–30 mm in size, but may be partly quartz.

B_{1cn}: 13–20 in. of dark red-brown to dark yellow-red (5YR3/4, 4/4) gravelly sandy clay loam to gravelly clay. Gravel consists mainly of red and black concretions 5–20 mm in size, but may also be partly quartz. The upper or the lower part of the horizon may contain fewer concretions and have a texture of very friable coarse sandy clay loam to friable clay. This horizon merges between 22 and 29 in. depth into

B_{2cn}: 4–11 in. of dark yellow-red (5YR4/4), yellow-brown mottled, plastic or very plastic to firm or very firm coarse sandy heavy clay or silty heavy clay. Contains a large amount of concretions and in some cases also fine quartz gravel. Merges gradually between 26 and 40 in. depth into

BC_g: extending beyond 4 ft depth; light grey to white, pale brown, red or purple mottled, very plastic heavy clay. Contains moderate amounts of firm to hard purple to red concretions 5–25 mm in size, commonly embedded in red mottles.

Wawat Family (5 observations)

A_{11}: 5–7 in. of black, very dark brown, or very dark grey-brown (10YR2/1, 2/2, 3/2) friable clay loam to clay.

A_{12}: 3–7 in. of dark brown to dark grey-brown (10YR4/2, 3/3, 3/4) friable to firm light clay or clay. Merges gradually or clearly between 10 and 13 in. depth into

B_2: 14–21 in. of distinctly mottled red (5–2.5YR4/6) and yellow-brown, very plastic heavy clay. Merges gradually between 21 and 34 in. depth into

BC_g: extending beyond 3–4 ft depth: prominently mottled light grey to white (5Y7/1, 8/2) and red or purple (up to 7.5R3/8), and commonly also yellow-brown and strong brown; very plastic heavy clay, which in some cases makes a friable impression because it breaks up into very small smooth-faced nutty fragments that are not visible *in situ*. With depth this horizon may gradually come to look like a C_{1g} horizon.

Giri Family (6 observations)

A_{11}: 5–9 in. of very dark brown, very dark grey-brown, or very dark grey (10YR2/2, 3/2, 3/1, 2.5Y3/2), moist friable to firm, wet plastic clay, with a moderately developed fine to very fine angular blocky structure. Merges clearly or gradually into

A_{12}: 3–6 in. of dark grey-brown to very dark grey (10YR4/2, 3/1, 2.5Y3/2) and moderately grey-brown, yellow-brown, or dark red-brown mottled, firm to very firm clay to heavy clay, containing a low to high amount of round or irregular black, brown, and red concretions. Merges clearly or gradually between 9 and 15 in. depth into

B_2: 10–19 in. of predominantly grey-brown, brown, or olive-brown (10YR5/2, 5/3, 2.5Y4/4), but strongly red, strong brown, and yellow-brown (and in some cases also grey or light grey) mottled heavy clay, moist firm or very firm to plastic or very plastic, wet very plastic and slightly sticky. May contain low amounts of small round dark red-brown to purple-red concretions. Merges between 19 and 30 in. depth into

BC_g: extending to 3–4 ft depth; prominently mottled light grey and red to purple, and with depth commonly more light grey and yellow-brown, moist very plastic, wet very plastic and very sticky heavy clay.

(iv) *Meadow Podzolic Soils*.—Developed mostly on weathered Pleistocene sediments, but Parua and Yambi families also on mudstone and Solai family also on volcanic rock, these soils occur on broad rises, very gentle slopes, and locally in slight depressions of undulating plains with grassland of the *Themeda–Ischaemum* complex. Very rarely they are found under poor forest. A hole or trench microrelief is commonly associated with these soils. Stone stripes are locally found with Teringi family (Haantjens 1965).

The profiles have various horizon sequences, which reflect differences in degree and nature of the texture contrast between upper and lower soil layers, in depth of organic matter, and in depth at which gleying begins. The most common sequences are $A_1/A_2/B_{1g}/B_{2g}$ in soils with strongest texture contrast (Teringi and Kworo families), A_1/A_{3g}–B_{1g}/B_{2g} in intermediate soils (Minjim, Parua), and A_1/B_{2g} in the soils with least texture contrast (Solai family). Texture contrast is abrupt in Teringi family (very gravelly upper layers overlying heavy clay at 9–18 in. depth), but gradual in the other series. The degree of texture contrast appears to be related to the amount of coarse particles present in the parent material, and, apart from Teringi family, ranges from $1\frac{1}{2}$ ft of sandy loam merging into sandy clay or sandy heavy clay (Kworo family) to 1 ft of clay loam or clay merging into heavy clay (Solai family).

The A_1 horizon is mostly less than 1 ft thick and black to very dark grey-brown in colour. A less dark finer-textured A_3 horizon is present in several families. Gleying mostly begins immediately below the A_1 horizon. The A_3 and B_1 horizons are dull dark grey and brown mottled, the B_2 horizon bright light grey, red and yellow-brown mottled, or almost purely very light grey in colour. Iron concretions are common in the A_2, A_3, and B_1 horizons, especially in the gravelly soils, and mostly seem to merge into the reddish mottles of the subsoil. Apart from the rather crumbly A_1 horizon, the soils are massive. There is a tendency to brittleness in the otherwise friable sandy layers, whilst the clayey subsoils are very plastic. The C horizon, commonly found at $4\frac{1}{2}$–5 ft depth, differs only from the B_2 horizon in having a more silty texture, paler brown mottling (it may be predominantly brown), and a somewhat nutty structure.

Teringi Family (7 observations)

$A_{1(cn)}$: 5–11 in. of wet, moist, or moderately dry, black or very dark grey-brown (10YR2/1, 3/2) gravelly sandy loam to clayey gravel. The dark colour arises from the black organic coating of the gravel, which consists either of quartz 5–40 mm in size, rounded black to very dark brown concretions 4–15 mm in size, or red irregular lateritic concretions 4–25 mm in size. Merges clearly into

A_{12cn}–A_{2cn}: 4–7 in. of wet dark brown (10YR3/3), dark grey-brown (10YR4/2), or brown to pale brown (10YR5/3, 6/3) gravelly sandy loam to clayey gravel. Gravel consists mainly of concretions, commonly mixed with quartz, and in one case pure quartz. Merges abruptly between 9 and 18 in. depth into

B_{2g}: extending beyond 4 ft depth; light grey (10YR6/1, 7/2, 5Y6/1, 7/2, N6/0, 7/0) very plastic heavy clay, with very few to very many prominent medium-sized red, strong brown, and yellow-brown mottles. Contains moderate amounts of firm to hard brown, red, or purple concretions 3–15 mm in size. May contain low amounts of quartz gravel.

**Kworo Family* (3 observations)

A_1: 12–14 in. of black, very dark grey, or very dark grey-brown (10YR2/1, 3/1, 3/2), moist very friable, wet slightly sticky but non-plastic sandy loam.

A_{2g}: 4–6 in. of dark grey (10YR4/1) or brown (10YR5/3) with grey mottles, wet sticky but non-plastic sandy loam. Merges between 16 and 18 in. depth into

B_{1g}: 6–9 in. of light grey to light brown-grey (10YR6/1, 6/2), more or less yellow-brown mottled, moist firm to plastic, wet slightly plastic to plastic and very sticky sandy clay loam to sandy clay, with a low to moderate amount of red concretions. Merges between 24 and 28 in. depth into

B_{2g}: extending beyond 4 ft depth; light grey (5Y6/1, N7/0), plastic to very plastic, sandy or silty heavy clay, in some cases with a few red and brown mottles. Contains a low to moderate amount of brown to red concretions, which become softer with depth.

**Minjim Family* (8 observations)

A_1: 11–16 in. of black, very dark brown, very dark grey, or very dark grey-brown (10YR2/1, 2/2, 3/1, 3/2), moist to wet, very friable sandy clay loam, which may contain some fine quartz gravel. Merges clearly into

A_{3g}–B_{1g}: 6–13 in. of dark grey to grey (10YR4/1, 5/1) moist firm, wet plastic and sticky sandy clay, slightly to strongly brown or red mottled. Commonly contains a moderate amount of black or red concretions and/or quartz gravel. Merges clearly or gradually between 17 and 28 in. depth into

B_{2g}: extending to a depth of 3 ft or more; very strongly grey (10YR5/1), and below 22–28 in. depth light grey (10YR6/1, 7/1) or even white, red or purple and yellow mottled, plastic to very plastic sandy heavy clay. With depth the red and brown colours may dominate over the grey and white. Commonly contains a low amount of hard to firm red concretions and/or quartz gravel or grit.

C_{1g}: found in four cases at about 3 ft depth; brown (strong brown to olive-brown) with few or moderate white or pink mottles, firm to friable silty clay to silty heavy clay.

Parua Family (5 observations)

A_1: 6–12 in. of very dark grey or very dark grey-brown (10YR3/1, 3/2), moist friable, wet friable to slightly plastic sandy clay or coarse sandy clay (may be sandy clay loam in the upper part). Commonly contains a moderate amount of small quartz gravel.

A_{3g}–B_{1g}: 7–11 in. of dark grey to dark brown (10YR4/1, 3/3) and moderately yellow-brown and grey mottled, firm (brittle) to very plastic coarse sandy clay to sandy heavy clay. Commonly contains a low to high amount of fine quartz gravel and in some cases firm to hard brown to red concretions. Merges between 13 and 21 in. depth into

B_{2g}: extending beyond 4 ft depth; very strongly light grey (10YR6/1, 7/1), red and yellow-brown mottled plastic sandy heavy clay or very plastic heavy clay.

**Yambi Family* (19 observations)

A_1: 6–11 in. of black, very dark brown, very dark grey, or very dark grey-brown (10YR2/1, 2/2, 3/1, 3/2), moist friable to very friable, wet slightly speckled and sticky clay loam to light clay.

A_{2g} or A_{3g} or B_{1g}: 8–13 in. thick. This horizon has been named A_{2g} if the texture is silty clay loam to clay, independently of the colour being mainly grey (10YR5/1), dark grey (10YR4/1), or grey-brown (2.5Y5/2). When the texture is heavy clay it has been named A_{3g} if the colour is dark grey (10YR4/1), and B_{1g} if the colour is grey (10YR5/1) or grey-brown or pale brown (2.5Y5/2, 10YR6/3). The horizon is strongly brown or red-brown mottled. The consistence for A_{2g} is moist friable to firm, wet plastic and sticky; for A_{3g} and B_{1g}, moist plastic to very plastic, wet plastic and very sticky. Many profiles contain a low to moderate amount of small round black to red-brown concretions. Merges between 13 and 24 in. depth into

B_{2g}: extending to 4 ft depth or more; light grey (10YR6/1, 7/1, N6/0, 7/0, rarely 8/0), strongly red or purple-red and yellow-brown mottled, moist very plastic to extremely plastic, wet very plastic and very sticky heavy clay. Commonly contains a low to moderate amount of red concretions, which are in some cases embedded in red mottles.

$C_{1(g)}$: found in four profiles at depths between 54 and 66 in.; olive-brown to yellow-brown, more or less light grey mottled silty clay to heavy clay.

**Solai Family* (2 observations)

A_{11}: 6 in. of black to very dark brown (10YR2/1, 2/2), moist friable, wet friable to slightly plastic clay to clay loam.

A_{12}: 4 in. of very dark grey to very dark grey-brown (10YR3/1, 3/2), friable to firm clay to fine sandy clay, containing a low to high amount of black, yellow-brown, or red-brown hard round concretions. Merges clearly or abruptly into

B_{2g}: extending beyond 4 ft depth; light grey (10YR6/1, 2.5Y6/2, 7/2, 5Y6/1, 7/2, N6/0, 7/0) extremely plastic heavy clay, with a low to moderate amount of brown to red-brown hard, but with depth softer, concretions. Few to very few prominent strong brown to red mottles.

BC_g: found in one profile at 50 in. depth; light olive clay, containing an increasing amount of brown to strong brown more powdery fragments. With depth, less brown material and more grey fragments, which are like completely weathered sediment.

(v) *Dull Meadow Podzolic Soils.*—These soils occur on level to slightly undulating plains (locally in shallow depressions) of more or less quartz-sandy Pleistocene sediments, rarely siltstone. Strong to moderate hole and trench microrelief is common. The vegetation consists of *Themeda–Ischaemum* and *Themeda–Arundinella* grassland, but also of forest and garden regrowth.

These soils are essentially similar to those of group (iv), the horizon sequences being $A_1/A_{2g}/BC_g$ in the soils with strongest texture contrast (Kiniambu family), $A_1/B_{1g}/BC_g$–B_{2g} in intermediate soils (Soandagum and Urimo families), and A_1/B_{2g} in the soils with least texture contrast (Naupi family). The principal morphological differences are that these soils are coarser-textured than their counterparts in group (iv), and that the subsoils are dull grey and brown mottled instead of light grey and red, and commonly resemble C horizons. The texture ranges from 2–3 ft of sandy loam and sandy clay loam merging into sandy clay or sandy heavy clay (Kiniambu family) to about 1 ft of sandy clay loam and gravelly loam overlying sandy heavy clay. Again, texture contrast is abrupt in the gravelly and gradual in the sandy soils. Streaks of bleached sand are a common feature in the A horizons of Kiniambu and Soandagum families. Iron concretions occur in varying amounts in most profiles, particularly in the lower A and in the B_1 horizons, especially in the gravelly soils. The soils are massive, except the upper part of the A_1 horizon. There is a tendency to brittleness in the otherwise loose to very friable sandy layers, whilst the clayey subsoils are plastic to very plastic. Unmistakable C horizons were rarely observed and appear to consist of brownish silty clay.

**Kiniambu Family* (5 observations)

A_1: 7–12 in. of very dark grey-brown to very dark brown (10YR3/2, 2/2) very friable sandy loam to sandy clay loam, which may be faintly brown mottled. Merges gradually or clearly into

A_{21g}: 10–20 in. of dark grey, dark grey-brown, dark brown, or grey-brown (10YR3/3, 4/2, 4/1, 5/2), moderately brown mottled, moist very friable, wet slightly sticky and non-plastic loamy sand to sandy loam. Commonly has streaks of bleached fine sand. Merges gradually between 18 and 32 in. depth into

A_{22g}: 7–10 in. of dark grey, grey, or brown-grey (10YR4/1, 5/1, 5/2), moderately yellow-brown mottled, moist friable to very friable, wet slightly plastic and sticky sandy clay loam. May have streaks of bleached fine sand and commonly contains small amounts of fine quartz gravel or concretions. Merges gradually between 25 and 39 in. depth into

BC_g: extending beyond 4 ft depth; distinctly mottled brown, yellow-brown, grey-brown, and grey, and with depth more light grey, moist friable to plastic, wet plastic and sticky sandy clay or moist plastic to very plastic sandy heavy clay. Very dark grey veins of topsoil commonly penetrate this horizon, which normally contains some fine quartz or concretions.

**Soandagum Family* (6 observations)

A_1: 20–22 in. of dark brown, dark yellow-brown, or olive-brown (10YR3/3, 3/4, 2.5Y4/4), moist very friable to brittle, dry slightly hard, wet friable to slightly plastic and sticky, compact sandy loam to sandy clay loam, which may be more or less yellow-brown, brown-grey, and grey mottled, especially in its lower part. Commonly contains red-brown concretions and/or quartz gravel, increasing with depth. May exhibit streaks of bleached fine sand.

$B_{1(g)}$: 5–11 in. of more or less brown and grey mottled, moist firm to friable, dry hard, wet plastic sandy or coarse sandy clay, with a low amount of concretions. Merges between 27 and 33 in. depth into

BC_g: extending beyond 4 ft depth; strongly grey, light grey, brown, strong brown, yellow-brown, and light grey-brown mottled, very firm to very plastic sandy heavy clay or clay. In some profiles the matrix colour is brown, in others grey.

**Urimo Family* (8 observations)

A_{11}: 5–11 in. of very dark brown to very dark grey-brown (10YR2/2, 3/2), moist very friable, wet sticky and not or slightly plastic sandy clay loam to sandy loam, commonly with dark brown mottles around roots. Merges clearly or gradually into

A_{12g}: 5–9 in. of very dark grey, dark grey, or dark grey-brown (10YR3/1, 4/1, 4/2), little to strongly brown mottled, moist friable, wet slightly plastic and sticky sandy clay loam. May contain some fine quartz gravel and/or concretions. Merges clearly between 11 and 18 in. depth into

B_{1g}: 8–15 in. of grey or dark grey (10YR4/1, 5/1, 5YR5/1), moderately to strongly yellow-brown mottled, moist firm, wet plastic and sticky to very sticky sandy clay, which may contain a low to moderate amount of black to brown concretions. Merges gradually between 22 and 26 in. depth into

B_{2g}: extending beyond 4 ft depth; grey to light grey (10YR5/1, 6/1, 7/1, N6/0, 7/0), moderately to strongly yellow-brown to strong brown mottled, moist very plastic, wet plastic to very plastic and very sticky sandy heavy clay or heavy clay. Dark grey veins of topsoil commonly penetrate this horizon, which may contain a low amount of concretions and/or fine quartz gravel.

**Naupi Family* (4 observations)

A_{11}: 4–8 in. of black to dark grey-brown (10YR2/1, 3/2, 4/2), very friable sandy loam to sandy clay loam, merging gradually or clearly into

A_{12cn}: 4–5 in. of very dark brown to dark grey-brown (10YR2/2, 4/1, 4/2), somewhat brittle gravelly loam to gravelly sandy clay. Gravel consists of black rounded concretions of various sizes, but may also be mainly quartz. Merges abruptly between 9 and 12 in. depth into

B_{2g}: extending to 3 ft depth or more; grey to dark grey (10YR4/1, 5/1, 5Y4/1, 5/1), and with depth grey to light grey, moderately to strongly brown mottled, moist very plastic, rather dry very firm to extremely firm sandy heavy clay. Contains normally a small amount of firm to hard black, brown, and red concretions. This horizon is penetrated by black to very dark grey veins of topsoil. With depth the colour becomes more brown and less grey.

(vi) *Meadow Soils*.—These soils occur mostly on level plains or in slight depressions, but also on undulating land, broad crests, and gentle slopes. Locally there is slight to moderate microrelief. They are found mainly on fine-textured Pleistocene sediments, but also on mudstone and Recent alluvial and colluvial deposits. Roma family occurs very locally on volcanic rock. The vegetation consists of *Themeda–Ischaemum* grassland with much *Ischaemum* and sedges in depressions, rarely of poor forest or garden regrowth.

The soils have A_1(A_0 in Mindumo family)/A_{3g}/B_{2g} profiles. They are essentially uniform heavy clays, although there is significant texture contrast in the Yari family with clay loam to silty clay in the A_1, and silty clay to clay in the A_3, horizon.

The A_1 horizon is commonly less than 1 ft thick, friable to very firm, and black to very dark grey in colour, whilst the A_0 horizon in Mindumo family is 1 ft thick and black and peaty. The A_3 horizon is of similar dimension, dark grey in colour, more brown mottled, finer-textured, and much more plastic than the A_1 horizon. It commonly has streaks of bleached silt in Yari family, and iron concretions in Roma family, rarely in Yari family. The B_2 horizon is grey, with few to many brown mottles. It is very plastic in consistence. In Yari and Roma families very dark veins of topsoil material commonly penetrate this horizon to a depth of 3 ft and more. Apart from a tendency to crumb structure in the A_1 horizon, the soils are structureless. Although most profiles are more than 4 ft deep, C horizon material was found in several soils at about 3 ft depth. This is more silty in texture, more brown in colour but still mottled, and contains harder and rather powdery fragments.

* *Yari Family* (7 observations)

A_1: 10–13 in. of black, very dark grey, or very dark grey-brown (10YR2/1, 3/1, 3/2), in some cases slightly brown mottled, moist friable to firm, wet plastic to slightly plastic clay loam to silty clay. Commonly shows small patches and streaks of bleached silt or fine sand. Merges gradually into

A_{3g}: 5–13 in. of dark grey (10YR4/1), brown mottled, friable to firm and even plastic in lower part, silty clay to clay. Shows small patches of bleached silt in some cases. Merges gradually or diffusely between 15 and 20 in. depth into

B_{2g}: extending to 4 ft depth or more; grey (10YR5/1, N5/0), moderately to strongly brown mottled, very plastic heavy clay. The colour becomes light grey (10YR6/1) with depth in some cases. Commonly dark grey veins of topsoil penetrate to some depth.

**Roma Family* (24 observations)

A_1: 6–12 in. of black, very dark grey, or very dark grey-brown (10YR2/1, 3/1, 3/2), in many cases somewhat brown mottled, dry hard to very hard, moist firm and with depth very firm to very plastic, wet plastic and sticky (in upper part sometimes sticky and non-plastic), heavy clay, but commonly clay in uppermost 4–6 in. Contains in many cases a low to moderate amount of small round black concretions, especially in the lower part. Merges gradually into

A_{3g}: 6–12 in. of dark grey (10YR4/1, 5Y4/1, N4/0), moderately to strongly brown mottled, moist very plastic, wet plastic and extremely sticky heavy clay. May contain some very dark grey streaks of topsoil and some grey mottles of subsoil. Normally contains a low to moderate amount of small round brown concretions. Merges gradually between 14 and 24 in. depth into

B_{2g}: extending beyond 4 ft depth; grey (10YR5/1, 5Y5/1, N5/0), and below 20–36 in. depth light grey (10YR6/1, 7/1, 5Y6/1, 6/2, 7/1, N6/0, 7/0), moderately to strongly brown mottled, very plastic heavy clay. Contains in some cases decreasing amounts of concretions with depth. Dark grey veins of topsoil may penetrate this horizon to about 3 ft depth.

**Mindumo Family* (2 observations)

A_0: 11–12 in. of black (N2/0) peaty clay, wet friable to slightly plastic and very sticky. May exhibit strong, very fine granular structure. Merges clearly into

A_{3g}: 6–18 in. of very dark grey to dark grey (N3/0, 10YR4/1), wet plastic and very sticky heavy clay, which is somewhat brown mottled. Contains in one case a moderate amount of small round red-brown to yellow-brown concretions. Merges clearly between 17 and 20 in. depth into

B_{2g}: extending beyond 4 ft depth; strongly grey, red-brown, and yellow-brown mottled, moist very plastic, wet plastic and very sticky heavy clay. Contains in one case a moderate amount of very small concretions.

(vii) *Gleyed Forest Soils*.—Developed in Pleistocene or sub-Recent sediments, mudstone, and more rarely volcanic rock, these soils occur on terrace benches, almost level ridge tops, and also on gentle to rather steep slopes, under lowland hill forest and garden regrowth. Strong microrelief occurs locally on level surfaces.

The soils have an $A_1/B_2/B_{2g}$–BC_g profile in which the A_1 horizon is thin and only slightly darker than the B_2 horizon, or may be entirely lacking. The texture is essentially heavy clay (which may be very silty) and slightly coarser in the A_1 horizon. The B_2 horizon is brown, the B_{2g} or BC_g horizon brown and grey mottled. Both B horizons may contain a few iron concretions or ferruginous weathered rock fragments. The soils appear to be virtually structureless and are commonly very compact. Plasticity increases with depth. The deeper subsoil commonly exhibits the angular fragmentation characteristic of C horizon material developed from mudstone, but no unmistakable C horizon was found above 4 ft depth.

**Witibi Family* (15 observations)

A_1 (absent in one-third of the observations): 2–9 in. of very dark grey-brown to dark grey-brown (10YR3/2, 4/2, 3/3, 2.5Y3/2, 4/2), moist to moderately dry friable to very firm clay to heavy clay. Merges clearly into

B_2: 10–18 in. of olive-brown or brown (2.5Y4/3, 4/4, 5/4, 10YR4/3, 5/3), commonly patchy or finely mottled, or with clearer grey, yellow-brown, or dark grey and dark grey-brown mottles, moist very plastic to very firm, dry hard heavy clay or silty heavy clay, or less commonly firm to plastic clay to silty clay. May contain a low amount of black concretions or ferruginous weathered rock fragments, and may break up into angular fragments. Merges gradually between 16 and 24 in. depth into

B_{2g} or BC: extending beyond 4 ft depth; strongly grey and brown mottled (in upper part commonly more dark grey and dark grey-brown, in lower part more light grey, grey-brown, yellow-brown, and strong brown), compact, moist very plastic, moderately dry very firm heavy clay to silty heavy clay. The colour may be dominantly grey or dominantly brownish. May contain a low amount of black to red-brown concretions and firm weathered mudstone fragments. Commonly breaks up into angular fragments, and becomes more like weathered sediment or mudstone with depth.

(viii) *Brown Forest Soils.*—These soils occur on irregular mountain and hill slopes and crests, mostly moderate to very steep. They have developed from commonly more or less calcareous sedimentary rocks (mudstone, siltstone, sandstone, conglomerate), volcanic rocks, and shales. Differences between families are largely related to differences in parent rock. The vegetation is forest or garden regrowth, rarely *Ophiuros–Imperata* or *Themeda–Arundinella* grassland.

The soil horizon sequence ranges from $A_1/B_2/C$ (Nagapam family) to A_1/C (Kaboibis family), with intermediate stages of $A_1/AB/C$, $A_1/BC/C$, and $A_1/AC/C$. The soils are shallow, ranging in depth from 3–4 ft in Nagapam to $\frac{1}{2}$–1 ft in Kaboibis family. They are mostly firm brown clay soils with slightly coarser-textured friable A_1 horizons, although much coarser-textured soils occur and are grouped in Kamesal family. The A_1 horizons are very variable, but generally become more prominent as the soil depth decreases. There is a gradual transition to the C horizon, which is more compact, commonly harder and strongly fragmented (especially in the soils on slates and volcanic rock), or may show texture stratification and some mottling.

**Nagapam Family* (27 observations)

A_{11} (absent in two-fifths of the observations): 3–12 in. of very dark grey-brown (10YR–2.5Y3/2), moist firm to very firm, dry hard to very hard clay to heavy clay, which may have a weakly to moderately developed fine to coarse angular blocky structure. Merges clearly or gradually into

A_{12}: 5–15 in. of dark grey-brown (10YR–2.5Y4/2, 4/3), moist firm to very firm, dry slightly hard to very hard clay to heavy clay, structureless or with a weakly developed angular blocky structure. Merges gradually between 6 and 18 in. depth into

B_2: 15–35 in. of olive-brown, light olive-brown, brown, or yellow-brown (2.5Y4/3, 4/4, 5/4, 10YR4/4, 5/3, 5/4), commonly somewhat patchy or somewhat grey, strong brown, yellow-brown, or dark grey-brown mottled, very firm to very plastic, structureless heavy clay or sandy heavy clay. Dark veins of topsoil commonly penetrate this horizon, which commonly contains soft yellow-brown weathered rock fragments or a very low amount of black concretions. Merges gradually to diffusely between 27 and 45 in. depth into

C_1 (absent in many observations): light olive-brown, brown, yellow-brown, commonly patchy, or with brown-grey, strong brown, and black mottles, compact silty to sandy clay.

C_2: Either yellow-brown to grey-brown, angularly broken, firm to hard mudstone, siltstone, or sandstone, commonly mixed with soil in the upper part, or dark brown to light olive-brown, unconsolidated, compact, moderately to very sandy sediments, commonly somewhat mottled. May also consist of stratified sand and clay layers or gravel beds.

**Abauge Family* (4 observations)

A_1: 8–17 in. of very dark grey-brown (10YR3/2), moist firm to friable, dry slightly hard clay.

AB: 8–15 in. of dark grey-brown to olive-brown (10YR4/2, 4/3, 2.5Y4/4, 5/4), moist firm to very firm, dry hard clay to silty heavy clay, which may be slightly brown-grey and brown mottled. Merges between 22 and 25 in. depth into

C_2: yellow-brown to pale brown, weathered soft to firm fine sandstone or siltstone, with decreasing pockets and veins of dark grey-brown clay, and with increasing amounts of harder lumps of weathered rock.

**Kamesal Family* (12 observations)

A_{11}: 6–15 in. of very dark grey-brown (10YR3/2), friable to very friable, sandy clay loam or gravelly clay. Gravel is mainly quartz, but may also comprise pebbles of other rock types. Low to moderate amounts of quartz gravel may be present in the sandy clay loam soils.

A_{12}: 5–8 in. of dark grey-brown (10YR–2.5Y4/2), firm (in some cases brittle and compact) sandy clay loam, sandy clay, or gravelly clay. Gravel is commonly quartz, but may be of other types of rock. Low to moderate amounts of gravel may be present in the sandy clay loam to sandy clay soils. Merges between 11 and 20 in. depth into

BC: 8–23 in. of dark grey-brown, dark brown, brown, or yellow-brown (10YR4/2, 3/4, 4/3, 4/4, 5/3, 5/6), firm clay with very many weathered rock fragments, or friable gravelly sandy clay loam to gravelly sandy clay, or sandy clay to sandy clay loam, or very friable coarse sandy clay loam to sandy loam. Gravel is mainly quartz, and there may be so much that augering is almost impossible. Other profiles have little or no gravel but are very sandy. Merges between 19 and 26 in. depth into

C_2: brown (10YR4/4), and in some cases also light yellow-brown, firm to soft weathered sandstone or siltstone, or soft compact very sandy sediments with a sandy clay loam to sand texture.

**Yaugiba Family* (8 observations)

AB: 12–24 in. of dark yellow-brown, dark brown, or brown (10YR3/4, 4/3, 7.5YR3/3, 3/4, 4/4), and in the uppermost few inches commonly dark brown (10YR3/3, 7.5YR3/2), firm clay (may be light clay in upper part). Contains a low to moderate amount of weathered rock fragments, either completely weathered and soft or rather fresh and hard, increasing with depth.

B_2 (observed in only two deep profiles, but considered typical for this family): 11–13 in. of yellow-brown to strong brown (10YR5/4, 5/6, 7.5YR5/6), firm to very firm clay to silty heavy clay. With depth, increasing amount of soft to firm, completely weathered rock fragments. Merges clearly or gradually between 15 and 25 in. depth into

C_2: brownish, and with depth commonly more olive-brown, soft to firm, completely weathered volcanic rock, which is commonly broken up, with veins of brown soil or grey plastic clay, and also harder rock fragments.

**Ambekanya Family* (4 observations)

A_1: 9–14 in. of very dark grey-brown to very dark grey (2.5Y3/2, 5Y3/1), moist friable to firm, dry slightly hard silty clay, which may have a strongly developed fine subangular blocky structure. May be slightly brown mottled in the lower part. Contains a low to moderate amount of weathered rock fragments. Merges gradually into

AC: 6–10 in. of dark grey-brown to dark grey (2.5Y4/2–5Y4/1), and usually dark brown mottled, moist friable, dry hard, compact silty clay loam. Contains a moderate to high amount of angular weathered rock fragments. Merges between 16 and 20 in. depth into

C_2: grey-brown, weathered, broken shale, with veins or pockets of grey or brown silty clay loam to clay.

Kaboibis Family (2 observations)

A_1: 6–14 in. of black to very dark grey-brown (5YR2/1, 2.5Y3/2), moist firm, dry hard clay, with moderately to well developed angular or subangular blocky structure. With depth, increasing amounts of hard weathered rock fragments. Merges gradually into

C_2: brownish weathered sandstone or volcanic rock, which may contain veins of clay.

(ix) *Shallow Black Earths*.—These soils have developed from calcareous siltstone and mudstone, marl, or mixtures of such rocks and coral debris. They occur on crestal surfaces, gentle to moderate slopes, and more rarely on steep slopes, under a vegetation of *Ophiuros–Imperata* grassland, lowland hill forest, or garden regrowth, and appear to be restricted to drier parts of the hill zone.

The soils have A_1/C or A_1/BC/C profiles. The A_1 horizon is 1½–2 ft thick, black or very dark grey, heavy clay, which has a strongly developed fine angular blocky structure when dry and may be granular at the surface. When moist, this horizon is very firm to very plastic. Some lime concretions or coral fragments may be present in the lower part in Tonembe family. The C horizon consists of soft to firm, commonly strongly fractured, compact, weathered mudstone or siltstone, containing, in Tonembe family, varying amounts of limestone fragments or streaks and soft concretions of lime. In Tonembe family a brown, firm to very plastic, silty clay to heavy clay BC horizon of variable thickness and containing coral gravel or lime concretions occurs between the A_1 and C horizons.

**Pagoma Family* (14 observations)

A_1: 15–25 in. of black, very dark brown, or very dark grey (N2/0, 10YR2/1, 2/2, 3/1) (commonly darkest in the upper part), moist very firm to very plastic, dry hard to very hard clay. When moist, the soil commonly has a weakly developed coarse angular blocky structure; when dry, commonly a strongly developed fine angular blocky structure, whilst the dry surface soil may be strongly granular. The lower part of this horizon may be somewhat brown mottled and/or contain brown weathered rock fragments. Merges gradually or clearly into

C_2: yellow-brown, olive-brown, or pale brown, soft to firm weathered mudstone or siltstone, commonly strongly fractured, and containing veins and pockets of dark soil, decreasing with depth, and harder rock fragments.

**Tonembe Family* (6 observations)

A_{11}: 10–18 in. of black to very dark grey-brown (10YR2/1, 2/2, 3/1, 3/2), firm to very firm and in the lower part commonly very firm to very plastic clay to heavy clay, which may have a moderately developed, fine to medium angular blocky structure. May contain some black concretions and/or lime concretions, especially in the lower part. Merges clearly or gradually into

A_{12}: 6–10 in. of normally patchy dark grey-brown, dark brown, very dark grey-brown, and olive-brown, firm or very firm to plastic or very plastic heavy clay, which may contain some lime concretions, coral gravel, and/or black concretions. Merges gradually between 16 and 28 in. depth into

BC: 7–20 in. of olive-brown to yellow-brown (2.5Y4/4, 5/4, 10YR5/4, 5/6), firm to very plastic silty clay to heavy clay. Normally contains coral gravel or lime concretions. Merges gradually between 20 and 43 in. depth into

C_2: soft weathered mudstone, sandstone, or siltstone (may be stratified), with low to very high amounts of coral limestone, or streaks of lime and soft lime concretions.

(x) *Rendzinas*.—Occurring both on very steep to gentle hill slopes inland and on coral reefs along the coast, these soils have developed from coral limestone, coral debris, or shell grit over coral. The vegetation consists of forest, *Ophiuros–Imperata* grassland, garden regrowth, or coconut plantation.

The soils have A_1/C or A_1/A_3/C profiles in which the black to very dark brown A horizon is 1–2 ft thick and directly overlies whitish limestone or coral sand. The texture of the A horizon is friable to very firm clay to heavy clay in Passam family, loose to very friable sandy loam to sandy clay loam in Rempi family. The structure is subangular blocky or crumbly. Small limestone fragments are scattered throughout the A horizon, increasing with depth.

**Passam Family* (9 observations)

A_1: 6–24 in. of black, very dark brown, or very dark grey-brown (N2/0, 10YR2/1, 2/2, 3/2, 5YR2/1, 7.5YR3/2), moist very firm to friable, dry hard to very hard heavy clay or clay, which commonly contains some coral gravel. May show a weak to moderate subangular blocky structure. Merges clearly and irregularly into

C_2: broken coral limestone with black soil in cracks and holes, or yellow-white rather soft coral debris.

Rempi Family (2 observations)

A_0: 2–4 in. of dark red-brown (5YR2/2) root mat or peaty clay.

A_1: 4 in. of very dark brown to dark red-brown (10–5YR2/2), moist very friable sandy loam or wet slightly plastic and sticky clay loam. May have a crumbly structure, be somewhat white-speckled, and contain few pieces of coral.

A_3: 6–10 in. of dark grey-brown, moist loose sandy loam, wet slightly plastic and sticky coarse sandy clay loam, speckled white, and with depth containing increasing pieces of coral. Merges between 12 and 18 in. depth into

C_2: extending beyond 30 in. depth: light grey-brown to yellow-white clayey coral sand or larger coral fragments.

(xi) *Dark Colluvial Soils*.—Developed in colluvial deposits derived from mudstone, sandstone, and Pleistocene sediments, these soils are found on gentle to moderate slopes of valley heads, colluvial toes, and aprons, and in narrow valleys in hilly to undulating land. The vegetation consists of garden regrowth or grassland. These soils have A_1/AB, and in Kwaliangu family A_1/BC, horizon profiles. They are dark coloured to a depth of at least 2½ ft, rather patchy or mottled, and very compact below the A_1 horizon. The texture varies from heavy clay to sandy clay loam. Concretions and ferruginous weathered rock fragments occur irregularly or in layers in most profiles. The profile depth is 4 ft or more.

Winge Family (11 observations)

A_1: 6–14 in. of very dark grey-brown to very dark grey (10YR3/2, 3/1), moist firm to very firm, wet plastic clay to heavy clay. Merges gradually or diffusely into

AB: extending beyond 30–36 in. depth; patchy very dark grey, dark grey, very dark grey-brown, and dark grey-brown, with varying degrees of yellow-brown, strong brown, red-brown, and/or grey mottling, moist to rather wet very plastic compact heavy clay or sandy heavy clay. May contain a low amount of ferruginous weathered mudstone fragments, quartz gravel, or black concretions.

Sima Family (4 observations)

A_1: 7–9 in. of very dark grey to dark grey-brown (10YR3/1, 2/2, 4/2), moist very friable, dry almost loose sandy clay loam. Merges gradually into

AB: extending beyond 30 in. depth; patchy, very dark grey, dark grey, or dark grey-brown, and moderately to strongly mottled yellow-brown, dark brown, or red-brown, firm sandy clay and, with depth, commonly very firm sandy heavy clay. Very compact and commonly brittle.

**Kwaliangu Family* (6 observations)

A_{11}: 7–15 in. of very dark grey-brown to very dark grey (10YR3/2, 3/1), moist, wet, or rather dry firm to friable or plastic sandy clay, clay, or heavy clay. May be brown-mottled and may contain a high amount of black concretions in the lower part. Merges clearly into

A_{12}: 7–18 in. of patchy dark grey and dark grey-brown (10YR4/1, 4/2, 2.5Y4/2), with slight to strong yellow-brown, grey, red, and very dark grey to very dark brown mottling, very plastic to very firm heavy clay or sandy heavy clay. Contains a low to high amount of black concretions or ferruginous weathered rock fragments. Merges gradually between 15 and 22 in. depth into

BC_g: extending beyond 4 ft depth; moderately to strongly mottled olive-brown, light olive-brown, yellow-brown, brown-grey, and commonly also grey, dark grey, or black, very plastic to firm silty heavy clay to heavy clay, which is compact, but commonly breaks up easily into small angular fragments. With depth it becomes more and more like weathered clayey sediment.

(xii) *Alluvial Black Clays.*—These soils occur on poorly drained alluvial clay plains and depressions, locally on high terraces under a vegetation of grass swamp, *Scleria*-sedge swamp, locally *Themeda–Ischaemum* grassland, and rarely sago woodland or low forest. The horizon sequence is A_1/A_3 or A_1/C_g. The soils are very plastic heavy clays, black or very dark grey to at least 1 ft depth, but to 3 ft depth or more in Kasamp family. The upper part of the A_1 horizon may be somewhat peaty. The deeper subsoil is (dark) grey or blue-grey and moderately to little brown-mottled. In Tumunum family the subsoil becomes increasingly sandy with depth.

Kasamp Family (3 observations)

A_1: 12–20 in. of black (10YR2/1), moist very plastic, wet plastic and very sticky heavy clay, which may be somewhat peaty, especially in the upper part. Merges gradually into

A_3: extending to 40 in. depth or more; very dark grey (10YR3/1), wet plastic to very plastic and sticky to extremely sticky heavy clay, which may be moderately mottled olive-brown and light yellow-brown.

**Mungin Family* (14 observations)

A_1: 10–20 in. of very dark grey to black (10YR3/1, 2/1, N3/0), moist very firm to very plastic, wet very sticky to extremely sticky heavy clay, which is commonly somewhat peaty and less plastic in the upper part. May be moderately brown-mottled in the lower part. Merges clearly or gradually into

C_{1g}: extending to 4 ft depth or more; dark grey (10YR4/1, N4/0), and with depth commonly grey (10YR5/1, N5/0), or more blue-grey, little to moderately brown-mottled heavy clay, wet plastic to very plastic, moist very plastic. May have very dark grey patches in the upper part.

Tumunum Family (1 observation)

A_{11}: 5 in. of black (10YR2/1), wet plastic clay.

A_{12}: 8 in. of very dark grey (10YR3/1), with brown patches, very plastic heavy clay.

C: 13 in. of dark grey (10YR4/1) very plastic heavy clay, mixed with (probably stratified) dark brown (10YR3/3) plastic silty clay loam.

D: dark brown (10YR3/3) wet slightly plastic and sticky fine sandy clay loam and, with depth, fine sandy loam, with some thin bands of yellow-brown and grey mottled plastic clay.

(xiii) *Organic Soils.*—These soils have developed in flood-plain and tidal swamps from accumulated residues of grass, herbaceous, and woody vegetation. The vegetation consists of various freshwater swamp communities and mangroves.

The soils consist either of poorly decomposed, brown, open-textured peats or well-decomposed, commonly friable and granular, black clayey peat and peaty clay, or of very soft, water-saturated mixtures of alluvial clay and organic matter. The well-decomposed black peaty soils can overlie alluvial clay at shallow depth (1–2 ft) or be buried by clay to a depth of $1\frac{1}{2}$–$2\frac{1}{2}$ ft.

Raw Mangrove Peat (4 observations)

A_{00}: brown root mass with little-decomposed peaty material. Many hard thicker roots make auger penetration very difficult. In one case this layer was underlain at 32 in. depth by

AD: very dark grey and very dark brown, wet plastic and very sticky heavy clay, with many roots and decomposed plant remains. Merges into black to dark red-brown, wet very plastic and very sticky heavy clay. In one case the A_{00} horizon extended beyond 42 in. depth.

Raw Peat (5 observations)

A_{00}: 25–40 in. of very dark brown, spongy and sloppy, open-textured and little-decomposed, water-saturated peat. Merges abruptly or clearly into

D: blue-grey, saturated, heavy clay or very dark grey sandy clay loam (in a profile near the coast).

**Black Peat Soils* (*Deep*) (4 observations)

A_0: 40–83 in. of black, wet non-plastic to slightly plastic and very sticky, well-decomposed peat or clayey peat, which may have a granular structure. Overlies

D: blue-grey or grey-brown plastic and very sticky heavy clay.

**Black Peat Soils* (*Topsoil*) (7 observations)

A_0: 12–34 in. of black to rarely very dark brown, wet slightly plastic and very sticky peaty clay, or more rarely clayey peat. May be somewhat granular. Merges clearly into

AD: 20–28 in. of black to very dark grey (10YR2/1, 3/1, N2/0, 3/0), and in some cases dark blue-grey, wet plastic to very plastic and very to extremely sticky heavy clay. The upper part of this horizon may be somewhat peaty.

A_{0b} or D: the deeper subsoil, below 34–46 in. depth, commonly consists of black, well-decomposed peaty clay or peat (A_{0b} horizon), or dark olive (5Y3/2) or very dark grey-brown (10YR3/2), sloppy heavy clay, rich in organic matter (D horizon).

**Black Peat Soils* (*Subsoil*) (3 observations)

D_g: 18–28 in. of blue-grey, dark blue-grey, or dark grey, wet slightly plastic to plastic and very to extremely sticky heavy clay. Commonly contains half-decomposed plant remains. May be partly brown mottled. Merges clearly into

A_{0b}: extending to 48 in. depth or more; black, well to moderately decomposed peat, wet friable to slightly plastic and sticky to very sticky.

Organic Muds (9 observations)

AD: extending beyond 4 ft depth; very dark grey, dark grey, or dark blue-grey, wet sloppy heavy clay, with many half-decomposed plant remains. Over-saturated with water, in some cases it is not more than a thick mud suspension in water. Very many organic remains in the topsoil, and locally in layers of the subsoil. Commonly too soft to be augered. In one case the deeper subsoil is black.

(xiv) *Old Alluvial Soils*.—These soils occur on alluvial deposits of stable alluvial plains, fans, terraces, and valley fills, as well as on marine deposits of stable beach ridges and swales. The vegetation consists of *Ophiuros–Imperata* grassland and garden regrowth.

The soils have A_1/C or A_1/D profiles. The A_1 horizon is 1–2 ft thick and very dark coloured. The C and D horizons are brown, or mottled when poorly drained. The texture varies from firm clay to very friable sandy (clay) loam overlying sand or gravel.

**Dumpu Family* (5 observations)

A_1: 14–25 in. of very dark grey-brown to very dark brown (10YR2/2, 3/2, 2.5Y3/2), firm clay, merging gradually into

C_1: extending beyond 4 ft depth; olive-brown (2.5Y4/4), and commonly patchy dark grey-brown (2.5Y4/2), firm clay or silty clay. In some imperfectly drained profiles this horizon is distinctly grey and yellow-brown mottled in the lower part.

Bembi Family (1 observation)

A_1: 16 in. of very dark grey-brown (10YR3/2), friable sandy clay, merging gradually into

D: extending beyond 4 ft depth; olive-brown (2.5Y4/4), very friable sandy clay loam.

Nubia Family (4 observations)

A_{11}: 5–12 in. of black to very dark brown (10YR2/1, 2/2) loose loamy sand to friable sandy clay loam.

A_{12}: 5–13 in. of very dark brown to very dark grey-brown (10YR2/2, 3/2, 2.5Y2/2) loose sand or very friable sandy loam to loamy sand. Merges gradually between 13 and 25 in. depth into

C: extending beyond 4 ft depth; dark brown to dark olive speckled loose sand. In imperfectly to poorly drained profiles this horizon is mottled or grey and can have a high water-table.

Ouarara Family (1 observation)

A_1: 9 in. of very dark brown (10YR2/2) very friable sandy clay loam, merging gradually into

D: dark brown (10YR3/3) very friable sandy loam, with rapidly increasing amount of river gravel, which prevents augering below 13 in. depth.

(xv) *Young Alluvial Soils*.—These soils are found on alluvial deposits of aggrading swamps and active flood-plains, levees, terraces, and scrolls, and on marine deposits of young beach ridges and swales. The vegetation comprises various types of alluvium forest, sago palm communities, and grass swamp and includes small areas of *Ophiuros–Imperata* grassland.

The soils consist of more or less stratified alluvial deposits, without or with poorly developed A_1 horizons. The texture ranges from very plastic heavy clay to loose sand in some subsoils. The colour of well-drained profiles is olive-brown, but becomes increasingly grey and brown-mottled, or even blue-grey, as the drainage status deteriorates.

**Plastic Heavy Clay Alluvial Soils*

Well Drained (2 observations)

A_1: 4 in. of dark brown (10YR3/3) friable clay that merges clearly into

C_1: 22–44+ in. of dark yellow-brown, olive-brown, or yellow-brown (10YR4/4, 5/4, 2.5Y4/4), very plastic heavy clay.

**Imperfectly Drained* (4 observations)

A_1: 3 in. of very dark grey to very dark grey-brown (10YR3/1, 3/2, 2.5Y3/2), firm to very firm clay to heavy clay, which merges clearly into

D_1: 19–30 in. of dark grey-brown, grey-brown, or dark brown (10YR4/2, 4/3, 2.5Y4/2, 5/2), firm or very firm to very plastic, heavy clay or silty heavy clay. Merges gradually between 22 and 34 in. depth into

D_{2g}: extending beyond 4 ft depth; dark grey to grey-brown, and brown and grey mottled, very firm to very plastic heavy clay or silty heavy clay.

**Poorly Drained* (9 observations)

A_1: 2–8 in. of dark grey, dark grey-brown, very dark grey, or very dark grey-brown (10YR3/2, 4/2, 3/1, 2.5Y3/2, 4/2), firm to friable clay. Merges clearly into

D_1: 6–15 in. of olive-brown (2.5Y4/4) and commonly patchy dark grey, brown, grey-brown, firm or very firm to plastic or very plastic silty heavy clay or heavy clay. Merges between 9 and 17 in. depth into

D_{2g}: extending beyond 4 ft depth; strongly grey and/or dark grey, brown, olive-brown, or yellow-brown mottled, very firm to very plastic heavy clay or silty heavy clay.

Very Poorly Drained (19 observations)

A_1: 2–6 in. of dark grey-brown (2.5Y4/2), or dark grey, dark brown, and brown mottled, or very dark grey, dark grey, and grey mottled, moist friable to plastic, wet slightly plastic and sticky, silty clay to heavy clay. Merges clearly or abruptly into

D_g: extending beyond 4 ft depth; strongly mottled dark grey or grey and brown, olive-brown, or brown-grey, moist very plastic, wet plastic and sticky to very sticky, heavy clay or silty heavy clay.

Swampy (9 observations)

D_g: extending beyond 4 ft depth; dark grey to grey (N4/0, 5/0, 5Y4/1) and commonly yellow-brown mottled, or blue-grey and normally not mottled, wet plastic to very plastic and very to extremely sticky heavy clay. The topsoil may be darker-coloured, because of admixtures of half-decomposed plant remains or more decomposed peaty material (A_0 horizon).

Medium-textured Alluvial Soils

Well Drained (23 observations)

A_1 (absent in two-fifths of profiles): 3–7 in. of dark grey-brown, very dark grey-brown, or dark brown (2.5Y3/2, 4/2, 10YR3/3, 4/2), very friable to firm sandy clay loam to clay.

D_1: extending beyond 4 ft depth; olive-brown, brown, dark yellow-brown, or dark grey-brown (2.5Y4/3, 4/4, 10YR4/2, 4/3, 4/4), very friable to firm sandy clay loam to clay, commonly strongly stratified.

Imperfectly Drained (12 observations)

A_1: 4–8 in. of dark grey-brown (10YR–2.5Y4/2) and, in upper part, commonly very dark grey-brown or dark brown (2.5Y3/2, 10YR3/3), moist firm to friable, wet plastic clay to silty clay.

D_1: 15–30 in. of olive-brown to brown (2.5Y4/3, 4/4, 10YR3/4, 4/3), stratified, alluvial material, ranging from very friable to firm sandy clay loam or silty clay loam to silty clay or clay, with a tendency to plasticity in the most fine-textured layers. Merges between 22 and 32 in. depth into

D_{2g}: extending beyond 4 ft depth; grey, brown, olive-brown mottled, but otherwise similar to the D_1 horizon.

Poorly Drained (9 observations)

A_1: absent in almost half the profiles; 2–6 in. of very dark grey to very dark grey-brown (10YR3/1, 3/2), moist friable to firm, wet plastic silty clay to clay.

D_1: 10–20 in. of dark brown-grey to olive-brown (10YR4/2, 2.5Y4/2, 4/3), commonly slightly mottled or patchy, moist friable to firm, wet plastic silty clay to clay. Merges between 12 and 20 in. depth into

D_{2g}: extending beyond 4 ft depth; strongly grey and brown mottled, and in some cases blue-grey with depth, clay, silty clay, or sandy clay.

Very Poorly Drained (11 observations)

D_g: extending beyond 4 ft depth; dark grey, grey, olive-grey, olive, or dark grey-brown, and with depth in several cases blue-grey, strongly brown and grey mottled, stratified, alluvial material, ranging from very friable fine sandy loam to firm clay, with, in several profiles, layers of plastic silty heavy clay. Texture commonly very silty.

Coarse-textured Alluvial Soils

Excessively to Well Drained (2 observations)

A_1 (in one case): 3 in. of dark grey-brown (2.5Y4/2) friable fine sandy clay loam.

D_1: extending beyond 4 ft depth; olive-brown (2.5Y4/4), moist very friable, dry loose sandy loam to loamy sand. In one case this merges into very gravelly alluvial material, and in the other case into very friable fine sandy clay loam.

Poorly Drained (2 observations)

A_1: 5–6 in. of very dark brown, wet very friable to slightly plastic and sticky sandy loam to sandy clay loam.

D_1: 9–12 in. of dark yellow-brown to dark grey-brown, moist or wet loose sand. Slightly speckled. Merges between 14 and 18 in. depth into

D_{2g}: extending beyond 4 ft depth; very dark grey and somewhat brown mottled, speckled, wet loose to non-plastic and slightly sticky sand.

(*b*) *Analytical Data and Soil Fertility*

The average values of the granulometric composition and chemical properties of the major soil groups are presented in Table 9, separately for topsoil and subsoil. The large number of figures available for the young alluvial soils allowed a separate presentation for the plastic heavy clay and medium-textured alluvial soils, in order to bring out some characteristic differences between these important soil families.

Although Table 9 is useful for outlining the analytical differences between the soil groups, it should be used with caution. The average values are based on strongly differing numbers of observations. This tends to make especially speculative all figures marked by an asterisk, which are single determinations only. The values of most properties range widely within each soil group.* This tends to make the average values less significant. In calculating the averages, a few extremely and unilaterally deviating values have been omitted.

(i) *Texture Properties*.—A comparison of the field texture with laboratory data shows that in 112 samples the field texture was assessed as (commonly much) finer than the laboratory texture, in 27 samples there is good correlation, and in only 3 samples was the field texture assessed as coarser than the laboratory texture. The correlation between field and laboratory texture of the sandiness of the samples is good, and the textural trends as observed in the field are also properly reflected in the laboratory textures.

Since the laboratory clay contents commonly appear much too low to account for the cation exchange capacities, and since the field textures appear to correspond best with the observed soil consistencies, it seems likely that in many cases there has been incomplete dispersion. Similar experiences have been common with soils in other parts of New Guinea (Haantjens 1964; Rutherford and Haantjens 1965). The undispersed clay appears mostly in the fine silt fraction, in some cases also in the coarse silt fraction. Dispersion difficulties tend to vary erratically, with the result that in some profiles the laboratory clay and silt contents vary greatly, and in opposite directions,

* Analytical data of individual profiles are available upon request.

although no large textural differences are apparent in the field. There is, however, no suggestion that nearly all the silt, as determined in the laboratory, is in reality clay. Many soils have a distinctly silty feel and the possibility cannot be excluded that the fine silt fraction of several soils contains much material approaching clay in size and contributing materially to the exchange capacity of the soil.

(ii) *Chemical Properties and Clay Mineralogy.*—The only column heading requiring explanation is that of C.E.C./100 g "clay". These figures were arrived at in the following way. The influence of organic matter was arbitrarily but reasonably eliminated by subtracting 3 m-equiv. per cent from the C.E.C. value for each 1% of organic carbon present. This procedure is based on the assumption that the organic matter : organic carbon ratio is 1·7 and the C.E.C. of 100 g organic matter is 180 m-equiv. These assumptions fit reasonably well with the C.E.C. value of 350 m-equiv. per 100 g organic carbon found by Pratt (1961). The remaining C.E.C. values were generally impossibly high in relation to laboratory clay content. Since there is evidence of incomplete dispersion of the fine earth and/or chemical activity of very fine silt, the C.E.C./100 g "clay" figures were based on laboratory clay plus fine and coarse silt, or clay plus fine silt, or clay alone, whichever corresponded best with the field texture.

(1) *Pedological Considerations.*—From a pedological point of view the following properties are generally considered to be most important and will be briefly discussed: C : N ratio, C.E.C./100 g "clay", pH, percentage saturation, total P, and clay minerals. With the exception of C : N ratios the values of these properties are markedly lower for the mature soils than for the semi-mature and immature soils, and are accompanied by distinct differences in clay minerals. There are two main exceptions to this trend. The uniform red and yellow clays have high total P contents. This is not unusual for latosolic soils in New Guinea and is probably due to retention of P by iron–aluminium compounds. The dull meadow podzolic soils have distinctly higher pH and base saturation than the other major groups of the mature soils. Since illite and smectite are also more common in these soils, it seems reasonable to suggest that this major group is transitional to the semi-mature soils. There are no systematic differences between semi-mature and immature soils, although total P contents tend to be higher in the latter. Apparently, although morphologically distinct pedogenesis has taken place in the semi-mature soils, leaching and chemical weathering have not yet reached an advanced stage.

It is interesting to note that C : N ratios are markedly higher in the mature soils than in the others. They are rather strongly, but inversely, correlated with the C.E.C./100 g "clay", which points to N fixation in the soils with the most active clay minerals, and to leaching of such nitrogen in the most mature soils. Nitrogen fixation is also indicated by the general lowering of the C : N ratio in the subsoils. There is also a weaker tendency for high C : N ratio to be associated with low C content and vice versa, which could point to different humus composition in the mature and in the other soils. The major exceptions to this trend are the organic soils with very high C contents and correspondingly high C : N ratios and some young alluvial soils with very low C contents and very low C : N ratios, probably due to strong N fixation.

TABLE
ANALYTICAL DATA FOR

Major Soil Group	Horizon	Granulometric Composition: Coarse Sand (2000–200μ) (%)	Fine Sand (200–50μ) (%)	Coarse Silt (50–20μ) (%)	Fine Silt (20–2μ) (%)	Clay (<2μ) (%)	C (%)	N (%)	C:N Ratio
Mature soils									
Podzolic red and	A	35	31	10	9	14	1·4	0·10	13
yellow earths	B	27	17	12	14	33	0·2	0·02	10
Uniform red and	A	8	9	13	34	36	2·6	0·27	10
yellow clays	B	4	6	14	19	58	0·7	0·08	8
Gleyed red and	A†	47	26	18	1	8	1·3	0·11	12
yellow earths	B	35	19	8	8	29	0·3	0·05	6
Meadow	A	14	30	19	19	18	1·5	0·11	13
podzolic soils	B	16	18	8	14	43	0·3	0·04	9
Dull meadow	A	19	42	20	10	9	0·9	0·09	10
podzolic soils	B	15	31	14	14	26	0·2	0·03	8
Semi-mature soils									
Meadow soils	A	12	13	16	18	41	3·7	0·36	10
	B	7	5	12	24	54	0·6	0·07	10
Gleyed forest	A†	9	28	25	19	19	1·6	0·15	11
soils	B†	12	24	16	14	34	0·2	0·04	5
Brown forest	A	8	21	17	26	29	1·7	0·19	9
soils	B	5	15	10	30	40	0·6	0·09	7
Shallow black	A	1	10	15	28	46	2·1	0·24	9
earths	C†	1	1	22	55	21	0·3	0·04	8
Rendzinas	A	10	8	27	35	19	3·2	0·43	7
Immature soils									
Dark colluvial	A†	10	25	29	10	26	1·1	0·12	9
soils	B	3	18	24	22	33	0·5	0·06	7
Alluvial black	A	2	8	17	33	40	3·0	0·32	10
clays	C	2	5	7	20	66	0·6	0·10	9
Organic soils	Peaty	No data	No data	No data	No data	No data	16·8	1·17	15
	Mineral	1	2	10	40	47	3·2	0·26	12
Old alluvial	A†	1	29	32	16	22	1·3	0·15	9
soils	C†	2	36	27	16	19	0·4	0·03	13
Young alluvial soils									
Plastic heavy clay	Topsoil	1	5	18	41	35	0·9	0·14	8
	Subsoil	1	4	14	46	35	0·3	0·05	7
Medium-textured	Topsoil	5	15	25	30	25	1·7	0·24	8
	Subsoil	8	26	23	28	15	0·4	0·07	7

* Data are nearly always for subsoils only. Ka, kaolin; Me, metahalloysite; Sm, smectite; Il, illite.

† These figures, or all figures in these rows, represent only a single determination.

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MAJOR SOIL GROUPS

P_2O_5 (p.p.m.) Truog	P_2O_5 (p.p.m.) 25% HCl	pH H_2O	Cation Exchange Properties: Saturation (%)	Ca (m-equiv. %)	Mg (m-equiv. %)	Na (m-equiv. %)	K (m-equiv. %)	C.E.C./100 g clay (m-equiv. %)	Clay Minerals*
8	70†	6·3	43	3·1	1·7	0·2	0·3	31	Ka in A, Me in B;
25	60	5·9	39	4·0	3·5	0·2	0·2	36	locally Sm, Il in B
4	1090	5·9	29	6·2	3·0	0·3	0·3	35	Ka. Locally Sm in B
37	658	5·7	20	4·3	2·2	0·4	0·2	36	
0	240	6·1	35	2·0	1·0	0·2	0·1	20	Me
0	155	5·8	29	1·7	1·0	0·2	0·3	25	
4	246	5·6	35	1·9	1·2	0·7	0·1	20	Me or Ka. Locally Sm
2	127	5·5	36	3·1	4·0	0·8	0·1	30	in B
25	160†	6·1	44	1·8	1·6	0·2	0·1	25	Sm, Il observed in
5	10†	6·4	56	4·9	5·8	0·4	0·1	38	one profile
4	450†	5·7	39	4·4	6·2	1·2	0·5	36	Sm, Il
2	150†	6·1	48	6·5	13·2	0·9	0·1	52	
0	450	6·8	55	8·1	1·6	1·5	0·1	39	Sm, Il
0	80	6·6	56	6·2	3·4	1·4	0·1	40	
20	880	6·2	54	9·5	5·5	0·7	0·3	45	Sm, Il. Rarely Ka in B
30	292	6·3	53	9·8	8·7	0·7	0·2	56	
10	730†	6·2	53	16·5	6·0	1·8	0·3	54	Sm, Il
10	950	8·0	83	35·5	3·7	0·7	0·1	62	
110	1990†	7·3	81	45·5	1·9	0·9	0·3	98	Sm, Il
10	No	6·3	19	3·3	0·5	0·3	0·2	54	No data
0	data	6·9	74	10·4	16·9	0·5	0·2	56	
0	560†	5·7	37	5·7	5·3	0·3	0·3	30	Sm, Il
0	150†	5·8	56	9·3	12·0	2·3	0·3	52	
20	2690	4·8	39	19·2	12·0	2·7	0·6	No data	No data
10	755	5·7	47	15·3	12·0	2·3	0·8	62	
0	No	5·9	50	3·8	1·6	1·8	0·1	29	No data
0	data	6·8	62	5·1	2·1	1·6	0·1	37	
64	130†	6·6	55	13·7	10·9	0·5	0·5	56	Sm, Il
100	840†	7·0	53	12·4	12·8	0·6	0·3	56	
148	1360	6·5	59	14·2	5·0	0·8	0·6	66	Sm, Il
134	1000	6·8	66	11·9	4·2	0·7	0·2	68	

The low C.E.C./100 g "clay" of the mature soils is related to the presence of kaolin and metahalloysite as dominant clay minerals, instead of illite and smectite. In some subsoils of mature profiles on sedimentary rock, illite and/or smectite are dominant, probably as relicts of the original sediments, and raise the C.E.C. of these soil materials. In the dull meadow podzolic soils, which are clearly transitionary between the mature and the semi-mature soils, the average C.E.C./100 g "clay" is too low for the illite–smectite combination found in one profile. It is likely that a proportion of the profiles of this group is dominated by metahalloysite. The variations in C.E.C./100 g "clay" of the semi-mature and immature soils are too large for the uniform distribution of illite and smectite, as shown in the clay mineral column. It is possible that the actual minerals of the smectite group vary in different soil groups, e.g. consist of pure montmorillonite in the rendzinas, and do not include montmorillonite at all in the old alluvial soils. Also, the proportion of illite and smectite may vary more than can be deduced from the D.T.A. analysis. In any case, the almost complete absence of kaolin and metahalloysite in the semi-mature and immature soils is quite significant. Kaolin was observed only once, in a profile of Yaugiba family which is transitional to Nagapam family. Goethite and hydrargillite are present in varying amounts in all soil groups, but less in the mature than in the semi-mature and immature soils, although the only profiles in which these minerals were not observed belong to the young alluvial soils.

Although pH differences are small and irregular, it is noteworthy that the only genuine very low pH (the low pH of the organic soils appears to be largely due to oxidation processes upon drying) is found in the meadow podzolic soils of the mature soils. Also, high pH is not found at all in the mature soils and most frequently not in the immature soils. In many soils pH is higher than would be expected from the percentage saturation, but in the shallow black earths it is lower.

Saturation is generally low in the mature soils, but when the soils are sandy and have a very low C.E.C. it may be moderate. The combination of low C.E.C. and low to moderate saturation leads to very low amounts of exchangeable cations in the mature soils, in comparison with the semi-mature and immature soils, where saturation is invariably high to medium. It is interesting to note that only in the first three groups of the mature soils does the saturation of the topsoil exceed that of the subsoil; in all other soils it is lower than or equal to that of the subsoil. A similar but less consistent pattern can be seen in the pH values. These features point to the advanced stage of leaching of podzolic red and yellow earths, uniform red and yellow clays, and gleyed red and yellow earths, and the retention of bases in the topsoil of these profiles by the vegetation. It is not found in the meadow podzolic and dull meadow podzolic soils, perhaps because of the impervious nature of the subsoil, which is poorly rooted and forms an obstacle to leaching. If this is so, it follows that the very poor chemical characteristics of these soils are primarily due not to leaching but to inherent poverty of the parent material sediments. This is confirmed by the large amounts of quartz in these sediments, and by their heavy mineral composition (see Section IV(*b*)(*ii*)). Within the semi-mature and immature soil categories, the shallow black earths, rendzinas, organic soils, and young alluvial soils stand out as the least leached and weathered soils of the area. It is rather surprising that this group does not include the dark colluvial and old alluvial soils. The figures of the latter are based on only one profile each and may not be representative. Also, these two profiles have developed in very locally transported material, which may well have been rather leached to begin with.

(2) *Soil Fertility*.—From the point of view of soil fertility it is most useful to consider the following chemical properties: percentage saturation, pH, total and available P, N, and K, and Ca : Mg ratio. The first three have already been discussed in (1) above. The other properties are less strongly related to the soil groups than were the pedologically important characteristics.

Available P (P—Truog) is low to very low in most soils. The only groups in which the level appears to be adequate are the rendzinas and young alluvial soils. From a comparison with total P figures (P—HCl), P fixation appears to be particularly strong in the uniform red and yellow clays and organic soils. However, it may be expected that sufficient amounts of P will be released from the peaty material should this be exposed to drying and oxidation.

Nitrogen varies consistently with the organic matter content and is therefore low in many mature and immature soils. The semi-mature soils have the most consistent N levels. The organic soils have by far the highest N content, followed by the uniform red and yellow clays, meadow soils, rendzinas, and alluvial black clays. In all other soil groups the levels are rather low.

Low amounts of potash are one of the most characteristic properties of the soils of this area. There is little correlation with soil type, although contents tend to be lowest in the mature and highest in the immature soils. The only soil groups with adequate K supply are the organic and young alluvial soils. If expressed as percentage of C.E.C., the position is even worse: no soil group reaches the commonly accepted minimum 2%. Percentage K is generally higher in the topsoil than in the subsoil, because of leaching and retention by the vegetation. However, it tends to be equal in topsoil and subsoil of the immature soils, which provides one of the few chemical differences between the semi-mature and immature soils. A feature of the soils of this area is that exchangeable Na is commonly much higher than exchangeable K, which may accentuate the deficiency of the latter. Sodium has a tendency to remain constant in topsoil and subsoil, and is apparently not subject to selective retention by the vegetation.

Rather characteristic differences exist in the exchangeable Ca : Mg ratio of the soil groups, although these are not related to the maturity of the soils. The ratios tend to be higher for well-drained and calcareous soils (uniform red and yellow clays, brown forest soils, shallow black earths, rendzinas, old alluvial soils, and medium-textured young alluvial soils) and lower for poorly drained soils (mainly in meadow podzolic and dull meadow podzolic soils, meadow soils, alluvial black clays, less in podzolic red and yellow earths, gleyed red and yellow earths, dark colluvial soils, organic soils, plastic heavy clay alluvial soils). The percentage magnesium in the latter category increases in the subsoil. It is thought that these high percentages of magnesium contribute to the poor physical conditions of these soils, although remarkable differences exist in individual profiles with similar characteristics. Apart from this influence on the physical nature of the soil, the high Mg values are likely to upset the general nutrient balance in many soils of the area.

Summarizing, it can be said that soil fertility is undoubtedly highest in the shallow black earths, rendzinas, organic soils, and young alluvial soils, but it is unlikely that permanent agriculture can be pursued even on these soils without the application of fertilizers. Response to P is most likely in the shallow black earths, to K in the shallow black earths and rendzinas, and to N in the young alluvial soils. Moderately infertile are the uniform red and yellow clays, meadow soils, gleyed forest soils, brown forest soils, and alluvial black clays and possibly also the dark colluvial and old alluvial soils. All these soils are likely to need P and K, and commonly also N. Very infertile are the podzolic red and yellow earths, gleyed red and yellow earths, meadow podzolic and dull meadow podzolic soils, the meadow podzolic soils (which predominate at Yambi Experimental Station) being the worst. In addition to severe N, P, and K deficiencies, there is evidence from field experiments at Yambi Experimental Station that these soils also suffer from many trace element deficiencies. Strong fixation of P, K, and possibly also N is likely on these soils.

IV. Soil Formation and Distribution

(*a*) *Soil Sequences*

Although the survey area embraces many kinds of soil with widely differing characteristics, it was found that at the same time there is a remarkable continuity in morphological soil properties both between the major soil groups and between the soil families within a group. These relationships are illustrated in Figure 8, in which the dashed lines mark the transitions from one soil family to another, and simultaneously show the relationships between the major soil groups in the boxes. From the mass of interrelationships some of the most important sequences may be briefly discussed.

(i) *Sequence* 1.—Podzolic red and yellow earths–uniform red and yellow clays–gleyed red and yellow earths–meadow podzolic soils–dull meadow podzolic soils–meadow soils–alluvial black clays. In this sequence the principal factors controlling the succession are maturity (age), drainage, and parent material. Maturity decreases in the order given, especially from the meadow podzolic soils onwards. Parent material (decreasing amounts of quartz sand and gravel) is responsible for differences between podzolic red and yellow earths and uniform red and yellow clays and between dull meadow podzolic soils and meadow soils. Drainage status, reflecting differences in slope and permeability of parent material, deteriorates generally in the order given.

(ii) *Sequence* 2.—Meadow soils–gleyed forest soils–brown forest soils–shallow black earths–rendzinas. Improvement of the drainage status, due to steepening of slope and increasing permeability of parent material, largely accounts for the succession meadow soils–gleyed forest soils–brown forest soils. The succession brown forest soils–shallow black earths–rendzinas is determined by increasing carbonate content in the parent material. There would seem to be little difference in maturity (age) within this sequence.

(iii) *Sequence* 3.—(*a*) Brown forest soils–uniform red and yellow clays; (*b*) gleyed forest soils–gleyed red and yellow earths. Transitions between these major soil groups appear to be mostly due to increase in maturity (age) as a function of site stability.

(iv) *Sequence* 4.—(*a*) Dark colluvial soils–alluvial black clays–organic soils; (*b*) rendzinas–old alluvial soils–young alluvial soils–organic soils. Both sequences are restricted to immature soils, except the semi-mature rendzinas in sequence (*b*). Both are characterized by slight decreases in profile development and by increases in waterlogging. Decrease in carbonate content is further important in sequence (*b*).

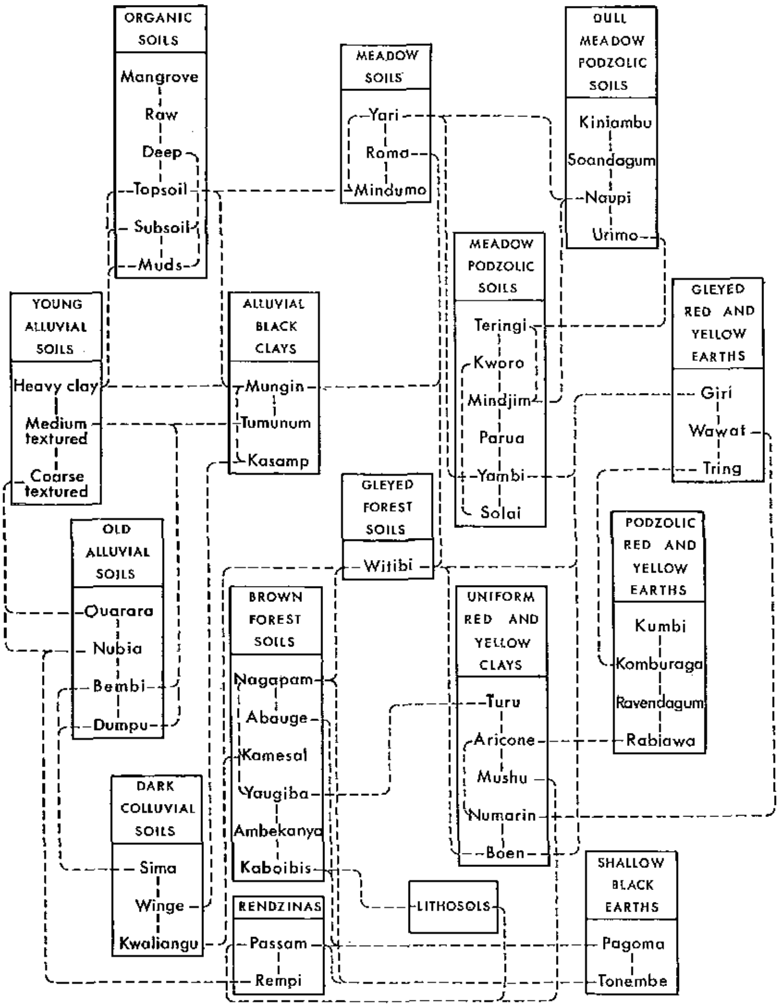

Fig. 8.—Relationships between major soil groups (in boxes) and their component soil families. Broken lines indicate the existence of transitional profiles.

(*b*) *Major Soil Groups and Land Systems*

(i) *Distribution.*—Table 10 presents the distribution of the major soil groups over the land systems. The mountain land systems are characterized by a very simple soil pattern, consisting mainly of semi-mature well-drained brown forest soils. The indication of uniform red and yellow clays in Turu and Nagapam land systems refers

TABLE 10

DISTRIBUTION OF MAJOR SOIL GROUPS IN LAND SYSTEMS

Occurrence of soil families is indicated as D (dominant, >50% of land system area), S (subdominant, 50–20%), or m (minor, <20%)

Major Soil Group	Mountains				Steep Hills					Hills with Remnant Upland Surfaces				Inactive Depositional Surfaces					Active Depositional Surfaces: Flood-plains			Active Depositional Surfaces: Swamps					
	Turu	Nagapam	Imbia	Numoiken	Kaboibis	Yangoru	Wonginara	Kumbusaki	Winge	Senambila	Passoram	Muschu	Kworo	Yambi	Bosman	Madang	Nubia	But	Nagam	Misinki	Palimbai	Pandago	Kabuk	Sanai	Pora	Kobar	Murik
Mature soils																											
Podzolic red and yellow earths										m			m														
Uniform red and yellow clays	S	m							m	S	m	S		m													
Gleyed red and yellow earths									m	S	m		m														
Meadow podzolic soils									m	m	S		S	D	m												
Dull meadow podzolic soils									m		m		S	m													
Semi-mature soils																											
Poorly drained:																											
Meadow soils									m	m	S		m?	S	D				m								
Gleyed forest soils				m			S?			m	m	m	m	m	m												
Well drained:																											
Brown forest soils	D	D	D	D	D	D	D	D	S	D	D	m	m	m	m												
Shallow black earths				m	S				S	m	m?																
Rendzinas					m						S	S				S											
Immature soils																											
Dark colluvial soils					S?				S?		m		m	m													
Alluvial black clays									m				m	m	m				m	m				S			
Organic soils																				m		S	S	D?	D	D	D
Old alluvial soils									m			m				S?	S	S	m								
Young alluvial soils					m	m		m	m	m	m	m	m	m	m	S	S	D	D	D	D	D	S	S			

to relatively immature yellow mountain soils on more stable slopes at higher altitudes, largely on volcanic rocks, and to small stable patches of red soils, mainly on shoulders. There is also a slight increase in gleyed forest soils and shallow black earths on probably finer-textured and more calcareous sedimentary rocks in the low mountainous Numoiken land system. All these soils are mainly covered with forest vegetation.

There are no fundamental differences between the soil patterns of the steep hills and the mountains. The dominance of brown forest soils remains, except on the lowest hills in Winge land system. The increase in shallow black earths in Kaboibis and Winge land systems may be due to a variety of factors—lower rainfall (see Part III, data for Bainyik), more calcareous sediments, inherently shallow soil cover on less weathered parent material. Uniform red and yellow clays do not occur, except very locally on gentle slopes in Winge land system. This indicates the virtual absence of stable surfaces. Lithosols, not incorporated in Table 9, are most common in the steep hilly land systems. The instability of Kaboibis and Winge land systems, at least in the near past, is further reflected in the common occurrence of dark colluvial soils in valley heads and on colluvial toes. Winge land system forms topographically a transition to the next group and this is reflected in the appearance of many more mature soils, typical of stable land surfaces. The first appearance of the young alluvial soils in this group of land systems is a reflection of the slight widening of river valleys in the hills, as compared with the mountains. The vegetation in this group is essentially forest, but secondary grassland, largely of the *Ophiuros–Imperata* type, becomes more and more dominant with decreasing relief.

The hills with remnant upland surfaces are characterized by complicated soil patterns, in which mature soils and poorly drained semi-mature soils attain increasing importance. In Senambila and Passoram land systems, which are still largely dissected and forested, brown forest soils retain a narrow dominance, but these soils become minor in Muschu and Kworo land systems. The rolling to undulating surfaces at rather high elevation on volcanic rocks in Senambila land system display the most varied array of mature soils in the area, whereas the pattern of poorly drained soils on the undulating mudstone areas of Passoram land system rather resembles that of the undulating Pleistocene sediments of Kworo land system, although coarse-textured soils are far more common on the latter. Although not fully correlated, there is a strong relationship between the occurrence of gentle topography, mature soils, and well-established secondary grassland vegetation, mostly of the *Themeda–Ischaemum* type (Haantjens, Mabbutt, and Pullen 1965). The mature soils are commonly podzolic in character and mostly strongly gleyed, which is due partly to the low base status of the quartz-rich parent material and partly to impeded drainage on gentle slopes and impermeable rock. It is noteworthy that the podzolic red and yellow earths, considered to be the most mature soils in the survey area, are confined to those land systems of this group where stable conditions have locally prevailed longer than anywhere else. In Muschu land system the predominance of uniform coral limestone, with the absence of podzolic soils, has led to a more simple soil pattern consisting mainly of uniform red and yellow clays and shallow rendzinas. The latter occur also on rather large areas of limestone in Passoram land system. Forest is the dominant vegetation type on these soils and is only locally replaced by secondary grassland.

TABLE 11

HEAVY MINERAL COMPOSITION* OF SOME SELECTED B HORIZONS

Sample No.†	Soil Family	Land System	Apparent Parent Rock	Tourmaline	Zircon	Garnet	Rutile	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Epidote	Zoisite	Saussurite	Hornblende	Actinolite	Glaucophane	Augite	Hypersthene	Chromite	Mineral Association
59011 (P5)	Medium-textured alluvial soils	Nagam	Coastal recent alluvium			4				1				50	1	11	20			7	3		Epidote–hornblende–pyroxene
59019 (P9)	Nagapam	Numoiken	Siltstone			1								39	2	2	52			3	1		Hornblende–epidote
59031 (P15)	Solai	Senambila	Volcanics		1	1	4					1		34	2		11			14	31	1	Pyroxene–hornblende–epidote
59033 (P16)	Boen	Senambila	Volcanics	3	4	3	14	2		16	2			4	1		1		1	18	31		Pyroxene–staurolite–rutile
59050 (P23)	Nagapam	Kworo	Pleistocene sediments			2	1			1			1	66	24		1	2		1	1		Epidote–zoisite
59055 (P26)	Roma	Kworo	Pleistocene sediments	1		2	2							64	31								Epidote–zoisite
59056 (P26)	Roma	Kworo	Pleistocene sediments		1	1	6		1	1				60	30								Epidote–zoisite
59080 (P38)	Kworo	Kworo	Pleistocene sediments	9	16		51	4		9	5	3		1						2			Rutile–zircon–staurolite
59092 (P44)	Witibi	Kworo	Old valley fill in Pleistocene sediments	4	2	10	4				5			52	17		5					1	Epidote–zoisite–garnet

* Data represent percentages of non-opaque and non-altered sand grains. The percentages of opaques (variable, but commonly very high) and alterites (low) have been omitted. Determinations by Mr. H. Kiel, Royal Tropical Institute, Amsterdam.

† Location of sites in parentheses is shown in Figure 2.

There is no significant change in the occurrence of immature soils in this group, as compared with the previous group of steep hilly land systems. These soils are restricted to local stream valleys and colluvial slopes.

In the land systems of the inactive depositional surfaces two groups can be clearly recognized: Yambi and Bosman land systems with predominantly meadow podzolic and meadow soils on poorly drained fine-textured sediments; and Madang, Nubia, and But land systems with predominantly old and young alluvial soils on better-drained, younger, and commonly more coarse-textured sediments. This subdivision is supported by vegetation differences: largely grassland in Yambi and Bosman land systems, and largely forest and regrowth in Madang, Nubia, and But land systems. Thus the first two land systems have a strong affinity to those of the previous group, the last three to those of the next group.

The distribution of the gleyed forest soils, a group of widespread but always minor occurrence, ends in the inactive depositional surfaces. This distribution indicates that these soils will develop under very locally occurring conditions of poor drainage and limited slope stability, which may be fulfilled on a rather wide range of rock types and general topographic conditions. There is evidence that such conditions are brought about by minor rock displacements and unconformities and by local ground-water seepage. The common occurrence of rendzinas in Madang land system coincides with the presence of slightly raised coral reefs.

The active depositional surfaces consisting mainly of flood-plains have an almost complete dominance of young alluvial soils. Minor other types of soil are related to stable higher terraces, whilst organic soils occur locally in swampy depressions of Misinki land system. The vegetation is predominantly forest.

In the swamps, comprising the lowest parts of the flood-plains, the young alluvial soils are mostly heavy clays and are always very poorly drained. With increased swampiness of the land systems, organic soils become more and more dominant. The vegetation includes many types of typical swamp communities.

(ii) *Heavy Mineral Composition*.—The heavy mineral composition of a small number of selected B horizons is presented in Table 11. The following provisional conclusions may be drawn from this material and from a comparison with the results of a petrological examination of rock specimens* collected during the survey by the geomorphologist.

Similar soils can develop on mineralogically very different parent materials. For example, meadow podzolic soils, which are mostly found on Pleistocene sediments (sample 59080, with much rutile, zircon, tourmaline, and staurolite), can also develop in predominantly volcanic rock (sample 59031, with much hypersthene, augite, and hornblende). However, because of the scarcity of quartz sand in the latter, very little texture contrast will develop in meadow podzolic soils on such more basic parent material. The major chemical indications of the difference in parent material between these two profiles are much lower P, Ca, Mg, and C.E.C. values in the soil on Pleistocene sediments compared with that on volcanic rock. A second example is provided

* Baker, G. (1960).—Mineragraphic Report No. 817. Mineragraphic Section, CSIRO, Melbourne. (Unpublished report.)

by two profiles of Nagapam family, one of which is developed in siltstone (sample 59019, with much hornblende and epidote) and one in Pleistocene sediments (sample 59050, with very much epidote and much zoisite). The position here is reversed in so far as brown forest soils are rare on Pleistocene sediments and very common on siltstone and volcanic rock. The chemical data show markedly higher P, K, and C.E.C. values for the soil on siltstone compared with that on Pleistocene sediments. In both examples the chemical differences are consistent with the mineralogical differences, which point to the originally advanced stage of weathering of the Pleistocene sediments. The conclusion from these observations is that such factors as slope, slope stability, and permeability of parent rock have a more decisive effect on the type of soil development than the mineralogical composition of the rock. The very different frequency with which certain profile types are found on certain types of rock is likely to be related to the frequency with which certain slope forms are associated with certain rock types.

The mineralogical make-up of samples 59031 and 59033 is not in accordance with parent material of a purely volcanic nature. Even though volcanic and igneous rock samples, collected in Senambila land system in the vicinity of these soils, contain traces of epidote and zoisite, their mineralogical composition cannot be reconciled with that of the soil samples. This is particularly true for sample 59033. It is also surprising to find such high amounts of augite and hypersthene, minerals which are scarcely mentioned for the rock samples. These observations confirm the theory, already evolved from field evidence, that the volcanic area of Senambila land system was originally covered with a thin blanket of sedimentary and extrusive rocks of which it has been largely stripped but which is still reflected in the mineralogical composition of the soils. There appear to be large differences in mineralogical composition of this blanket between the western part of the area (characterized by epidote and hornblende, which is in agreement with sample 59019, collected in sediments further west) and the eastern part (characterized by rutile and a number of stress minerals, the possible origin of which is unknown).

The mineralogical composition of sample 59019 is sufficiently different from a metamorphosed dolerite rock sample collected in its vicinity but lower in the rock sequence, to confirm the field evidence that the surface rock in the Numoiken land system is of a sedimentary nature and that the basement rock occurs at greater depth, with local intrusions of dykes into the sediments.

The strong similarity between samples 59019 from Numoiken land system and 59011 from the coastal plain (Nagam land system) a few miles further to the west indicates that the coastal plain deposits are derived primarily and recently from the sedimentary rocks of Numoiken land system, during a cycle of rapid erosion, with little selective weathering and accumulation of minerals. Other rock types, partly of volcanic origin, have contributed to these alluvial deposits, as can be seen from the high amounts of pyroxenes and saussurite. This is likely to become more marked towards the west.

No types of consolidated rock were found with a mineralogical composition approaching that of the Pleistocene sediments (samples 59050, 59055, 59056, 59080, 59092). Yet the minerals in the latter do occur in small quantities in the rock samples collected from the mountains. The conclusion is that a strong selective accumulation of resistant minerals is evident in the Pleistocene sediments, and this is confirmed by their very high quartz content. As this accumulation can hardly be attributed to selection by grain size, the reason has to be sought in weathering processes that could have been caused either by several cycles of erosion and deposition or by weathering *in situ* of the Pleistocene sediments. Actual soil weathering may have contributed to the selective composition of these samples, but that this could not have been of great significance is shown by the essentially similar composition in soils with such varying degree and type of weathering as meadow podzolic, meadow, gleyed forest, and brown forest soils.

There are at least two very different sources of the Pleistocene sediments. One, characterized by epidote and zoisite (samples 59050, 59056, 59092), is presumably derived mainly from Tertiary sediments, schists, and intrusive rocks, as found in Turu, Nagapam, and Numoiken land systems. Another, characterized by rutile, zircon, tourmaline, and staurolite (sample 59080), is presumably derived from gneissic basement rocks, as found in Nagapam land system north of Maprik. As the latter rocks are found north of the present water divide, these data indicate a strong shift of this divide to the south since early Pleistocene times. Such a shift seems also probable on purely physical grounds. It is hard to imagine that the extensive Pleistocene sediments of Kworo and Yambi land systems could have been derived from the extremely small southern mountain catchments, as they exist today, whilst deposition from the west by the Sepik River is equally unlikely in view of the marked north–south orientation of the land surface features and gradients.

It is interesting to draw attention to the similarity of the mineralogical composition of samples 59033 and 59080, collected in widely separated parts of the survey area. It would seem to indicate that the former cover of Tertiary sediments over the eastern part of Senambila land system was derived from a source of metamorphic rocks similar to that from which the Pleistocene sediments in the western part of Kworo land system were derived, but there are no indications of the existence of such a source in the east at present. This observation, and the general cyclic relationship between the mineralogical composition of the Tertiary sediments and the underlying basement rocks, points to the derivation of the former from a land mass consisting essentially of the same rock types as the basement rocks of the present coastal range. Thus a southward shift of both the sedimentary trough and the basement rock anticline, similar to that assumed in the region of the Adelbert Mountains,* is indicated.

Sample 59092 provides evidence of the similarity in mineralogical composition of the old valley fills, found locally as a lining along the river valleys in the Pleistocene sediments of Kworo and Yambi land systems, and that of these sediments themselves. This probably indicates that the valley fill consists largely of only locally reworked Pleistocene sediments, during a period of interruption in the process of dissection of the plains. It should be noted that the high percentage of garnet in this sample points to the original derivation of this material from the southern mountain fringe near Mt. Turu, where this mineral is a common component of the rocks.

* Corbett, D. W. P.—Geological reconnaissance in the Ramu valley and adjacent areas, New Guinea. Unpublished records 1962/32. Bureau of Mineral Resources, Geology and Geophysics, Canberra.

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PART VI. VEGETATION OF THE WEWAK–LOWER SEPIK AREA

By R. G. ROBBINS*

I. CLASSIFICATION

The vegetation types recognized in the area and listed in Table 12 are grouped to indicate their regional and environmental relationships or their successional status. Secondary forest phases and garden regrowth have not been classified as separate communities but are described in Section III with their corresponding climax categories. The forest types are closely correlated with those described in Part VII. The forest resources map will also be useful to the reader of this Part.

TABLE 12

CLASSIFICATION OF VEGETATION COMMUNITIES

Broad Habitat or Vegetation Status	Vegetation Communities
Higher mountains	Lower montane rain forest
	Lower ranges forest
Lower mountains and hills	Lowland hill forest
Alluvial plains and fans	Well-drained alluvium forest
	Mixed flood-plain forest
	Levee forest
Swamps	Swamp forest
	Swamp woodland
	Campnosperma–sago palm forest
	Sago palm forest
	Sago palm swamp
	Sago palm–*Phragmites* swamp
	Sedge–fern swamp
	Scleria sedge swamp
	Phragmites swamp
	Mixed grass swamp
	Herbaceous swamp
	Aquatic vegetation
Coastal zone	Strand woodland
	Mangrove woodland
Successional vegetation	River scroll succession
	River terrace succession
	Coastal plain succession
Disclimax vegetation	*Polytoca–Sorghum* grassland
	Ophiuros–Imperata grassland
	Mixed association grassland
	Themeda–Arundinella grassland
	Themeda–Ischaemum complex
	Ischaemum–Apluda grassland

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II. General Description and Ecology

(a) *Forest Vegetation*

For the most part the forests of the lower Sepik valley are typical lowland tropical rain forests with three strata of trees. The canopy is composed of tall flange-buttressed trees and the strata include palms and large woody lianes.

The most extensive forest type is that covering the coastal range and the hilly uplands, and it accounts for some 1500 sq miles or almost one-third of the total survey area. On Mt. Turu, one of the few peaks in the area that rise above 3000 ft, the occurrence of lower montane rain forest makes an interesting record. Covering only a few square miles of the summit area, this forest may be distinguished from the surrounding forest by differences in structure, physiognomy, and floristic composition.

Generally the range and hill forests show considerable variation in structure, species composition, and timber resources. Regionally they present two aspects, the first of which covers 500 sq miles of higher and wetter slopes of the main range and is here called "lower ranges forest". Such a moist forest aspect contrasts with the lowland hill forest proper which covers some 1000 sq miles of the range foothills and the adjoining but less elevated hilly uplands. Here, floristic and physiognomic differences reflect the generally drier forest habitat.

Forest on alluvium is not extensive in the lower Sepik area, accounting for only 300 sq miles. Small patches occur along the coastal plain, notably at the mouth of the Sowam and Hawain Rivers. Inland, alluvium forest becomes mappable along the lower reaches of the small northern tributaries to the Sepik River (see Nagam land system). The greater part of the alluvium forest falls into the well-drained aspect, and there are smaller areas of mixed flood-plain forest in which the high incidence of palms indicates periodic inundation of the site.

Levee forest assumes most importance along the banks of the Sepik River and the southern tributaries, which for the most part flow through low-lying swamp grassland.

(b) *Swamp Vegetation*

Swamp land is characteristic of the Sepik flood-plain, and about 1350 sq miles of the survey area fall into this category. All these communities are controlled by periodic flooding of the Sepik River and the sequences are fluctuating rather than definable into seasonal and permanent aspects. Some may experience a deep, swiftly flowing inundation of short duration, whereas others may be flooded by shallow water but nevertheless maintain a high water-table throughout the year. In the more fluctuating aspects various sago palm communities may occur. Under more permanent swamp conditions and where deep flooding is the rule, mixed swamp forest, *Phragmites*, grass, and herbaceous swamp are to be found. Extensive lily pads and floating aquatic plants line waterways and extend over the shallow lakes.

(c) *Coastal Vegetation*

At Terebu the main range extends to the coast to form steep cliffs. For the rest, the coastline consists of a narrow coastal plain fronted by curving sandy beaches or small coral headlands. Along these beaches a zone of pioneer sand-binding plants is followed by a littoral hedge of salt-tolerant shrubs and a narrow beach ridge line of strand woodland composed of typical tropical strand tree species. Inland to the beach ridges are low-lying swampy swales often occupied by sago palms. Brackish tidal estuaries are lined with mangrove woodland which is most extensive in the Murik lagoons.

(*d*) *Successional Vegetation*

Natural successions are found along the river flood-plains and fall into two major categories—scrolls and terraces. Scroll banks are a feature of the inner curves of the Sepik River and take the form of a series of parallel successive levee ridges and intervening furrows which represent the past activity of the river. The vegetation is correlated to this pattern and exhibits a sequence of seral communities from pioneer water grasses in the hollows to woody vegetation along the ridges.

The flood-plain terraces throughout constitute a site for successional communities dominated by tall *Saccharum* cane grass.

Coastal plain succession is a vegetation complex showing aspects of both man's interference and the limiting conditions of the site. It includes secondary growth, grasslands, and swamp communities.

(*e*) *Grassland Vegetation*

This accounts for some 1300 sq miles of the survey area and ranks among the most extensive in the Territory of New Guinea. Along the inland foothills of the coastal ranges, with their dense population, the grasslands are dominated by tall cane grass species. Here, too, are found the *Imperata cylindrica* (kunai) grasslands and a broad zone of mixed short grassland in which many species are co-dominant.

Further south are the middle Sepik grasslands covering an area of poor soils subject to alternate waterlogging and drying out. *Themeda australis* (kangaroo grass) dominates on dry stony sites while *Ischaemum* grass and numerous sedges occupy wetter hollows and drainage courses. For the greater part the grassland is a complex of these two aspects, the dry tolerant *Themeda* in association with the moisture-seeking *Ischaemum* and sedge species. The Sepik plains grassland therefore represents a unique association complex of dry and wet grassland, which is only a reflection of the peculiar conditions prevailing. This complex only segregates to show its true nature where there are clear contrasts in topography.

All the grasslands are here considered to be disclimax in nature, that is, to have been initiated by shifting cultivation over previously forested areas and subsequently entrenched by their periodic burning. The process may have occupied some hundreds of years and the sites have now become so far degraded that, even given the opportunity, tree growth would be extremely slow to reoccupy the area. No direct evidence now remains of a past forest vegetation over the middle Sepik plains. The present population is sparse and lives along the narrow strips of forest bordering the river gullies. The Maprik peoples, who constitute the greatest population concentration to the north, show by their language affinities (Laycock 1965*) that they migrated northwards across the grasslands from the Sepik River. Such past migration, considered with the apparently marginal conditions of the original forest and the increased efficacy of wind-driven fires along the continuous north–south corridors of the plains, may well explain the rapid conversion of the area to grassland. The forest remnants, except for limited terrace forest, are to be classed with lowland hill forest, and thus represent a now remnant pattern of a once more extensive forest that has been driven to the shelter of the incised river courses by extensive fires which still sweep along the grassland tracts. They cannot be regarded as merely ecotonal tongues of gallery or riverine forest protruding into a climax grassland.

III. Description of the Plant Communities†

(a) *Forest Vegetation*‡

(i) *Lower Montane Rain Forest.*—While an incipient development of the lower montane rain forest is evident on some of the higher points of the Prince Alexander Mountains and on Kairiru Island, a true ecological expression of such forest formation is to be found only on the summit slopes of Mt. Turu and Mt. Wesagunimi (Turu land system). These mountain peaks do not quite attain 4000 ft above sea level, with the lower montane forest commencing only at about 3500 ft. Hence the total extent of such forest is limited to about 2 sq miles.

Such limited occurrence, however, is not without interest. At 3500 ft the forest structure becomes simplified from three tree layers to two. The canopy, lowered to about 80–90 ft, is without emergents and is closely followed by a subcanopy of tall slender trees reaching 60 ft or more. The *Pometia* and *Terminalia* trees of the lowland forest are replaced by lower montane species and lowland physiognomic features such as plank buttressing, abundance of palms, and woody lianes become less apparent. Tree ferns increase while filmy ferns, epiphytes, and bryophytes become more abundant.

The canopy trees include many Cunoniaceae such as *Schizomeria* and *Opocunonia*, while other genera are *Adinandra*, *Castanopsis* (oaks), *Cryptocarya*, *Elaeocarpus*, *Engelhardia*, *Euodia*, *Gmelina*, *Gonocaryum*, *Galbulimima belgraveana*, *Litsea*, *Podocarpus neriifolius*, *Siphonodon*, and several *Syzygium* species.

In the subcanopy are *Archidendron*, *Cinnamomum*, *Ehretia*, *Pittosporum pullifolium*, and *Planchonella*.

The presence, among the smaller trees and shrubs, of *Amaracarpus*, *Bubbia*, *Chloranthus*, *Eurya*, and *Trimenia*, together with an increased representation of Melastomataceae and Gesneriaceae such as *Medinilla*, *Memecylon*, and *Cyrtandra*, gives further indication of the montane habitat. Also to be mentioned here are *Euodia*, *Homalanthus*, Myrsinaceae, *Paratrophis glabra*, *Rhodomyrtus novoguineensis*, and various Rubiaceae and Rutaceae.

* Laycock, D. C. (1965).—The Ndu language family, Sepik District, New Guinea. Linguistic Circle of Canberra Publications. Ser. C, No. 1. 250 pp.

† Vernacular names used in this report are in the Amele language (Madang District).

‡ See also forest resources map.

Terrestrial herbs, ferns, and bryophytes are abundant and include Araceae, *Argostemma*, *Begonia*, *Dianella*, Marantaceae, Orchidaceae, and *Selaginella*. Common ferns are many Hymenophyllaceae, *Asplenium*, *Adiantum*, *Athyrium cordifolium*, and *Marattia*.

Climbers include Apocynaceae, *Dichrotrichum*, *Maesa*, *Piper*, and Urticaceae.

Scattered individuals of the hoop pine, *Araucaria cunninghamii*, have been reported from some of the high peaks on the coastal flanks of the range.

(ii) *Lower Ranges Forest*.—The hill forest covering the lower parts of the Prince Alexander Mountains shows physiognomic and floristic differences that reflect generally greater relief and higher rainfall over this region. The relief varies with a range of 1500 ft, while altitudes frequently attain 3000 ft above sea level. This forest type is to be found in Turu, Nagapam, Imbia, and Kumbusaki land systems and is about 500 sq miles in extent.

There are three tree layers with a dense uniform canopy at a mean height of 100 ft. Emergent trees are very infrequent. Canopy trees are: *Adinandra*, *Albizia falcata*, *Alstonia scholaris*, *Alphitonia incana*, *Artocarpus altilis*, *Cananga odorata*, *Canarium* sp., *Casearia*, *Castanopsis acuminatissima* (infrequent), *Celtis* (at least three species), *Chisocheton*, *Chrysophyllum*, *Cryptocarya* sp., *Dillenia*, *Dracontomelum mangiferum*, *Dysoxylum* spp., *Elaeocarpus*, *Euodia*, *Ficus* sp., *Garcinia*, *Gmelina*, *Homalium foetidum*, *Intsia bijuga*, *Litsea* sp., *Mangifera*, *Maniltoa*, *Myristica*, *Octomeles sumatrana*, *Pangium edule*, *Parartocarpus venenosus*, *Parinari*, *Planchonella*, *Planchonia papuana*, *Podocarpus neriifolius*, *Pometia pinnata*, *Prainea papuana*, *Prunus*, *Pterocarpus indicus*, *Pterocymbium beccarii*, *Sloanea* spp., *Sterculia*, *Syzygium*, *Terminalia* spp., and *Tristiropsis*.

The second tree layer is between 50 and 70 ft and includes the following trees: *Aglaia*, *Archidendron*, *Boerlagiodendron*, *Chisocheton*, *Cinnamomum*, *Dillenia castaneifolia*, *Diospyros*, *Endospermum*, *Engelhardia*, *Ficus* spp., *Harpullia*, *Homonoia javensis*, *Horsfieldia*, *Linociera*, *Macaranga*, Melastomataceae, Meliaceae, *Microcos*, Monimiaceae, *Myristica* spp., Myrsinaceae, *Octamyrtus behrmannii*, *Pimeleodendron amboinicum*, *Pittosporum pullifolium*, *Prunus*, *Syzygium* spp.

In the third layer at about 30 ft small trees such as *Astronia*, *Cerbera floribunda*, *Dichroa febrifuga*, *Jagera*, *Ryporosa*, and *Decaspermum* are to be found.

The shrub layer is usually well represented by Annonaceae, *Antiaropsis decipiens*, *Archidendron*, Apocynaceae, *Bubbia*, *Callicarpa*, *Clerodendrum*, *Cyrtandra*, *Donax canniformis*, *Ervatamia*, *Euodia*, *Harpullia*, *Heliconia indica*, *Gardenia*, *Medusanthera*, Meliaceae, *Micromelum minutum*, Monimiaceae, Myrsinaceae, Myrtaceae, palms and rattans, *Psychotria*, Sapindaceae, *Saurauia*, *Schefflera*, *Schuurmansia henningsii*, and *Cyathea* and *Marattia* tree ferns.

Terrestrial vegetation is of low *Alpinia*, Liliaceae, *Begonia*, the grass *Centotheca*, *Elatostema*, *Lycopodium*, Orchidaceae, *Pilea*, *Piper*, *Selaginella*, and Zingiberaceae, together with terrestrial ferns, bryophytes, and tree seedlings.

Among the climbing and epiphytic plants are aroids and ferns such as *Vittaria* as well as Loranthaceae, *Freycinetia*, and *Poikilospermum*.

As the area is only sparsely populated, gardens and regrowth phases are negligible, but occur along the inland fringes of the main range where the Maprik and Yangoru peoples are already gardening on the mountain slopes (Plate 6, Fig. 2).

(iii) *Lowland Hill Forest* (Plate 5, Fig. 1; Plate 7, Fig. 1).—In the Wewak–Lower Sepik area this forest covers some 1000 sq miles over the foothills to the coastal range and across the extensive hilly uplands that form a south-eastern extension as far as Angoram on the Sepik River (Numoiken, Kaboibis, Yangoru, Wonginara, Winge, Senambila, Passoram, Muschu, Kworo, Yambi, Bosman, and But land systems). The general order of relief is 600 ft, while altitudes seldom exceed 1000 ft above sea level.

The forest habitat differs from that of the lower ranges forest in being drier in aspect and more diverse in soils, and having a generally lower altitude associated with a lesser and more uniform relief. Such differences in site conditions are related to small physiognomic and floristic changes in the forest. Lowland hill forest includes the gully remnants that border the rivers flowing southward across the middle Sepik grassland plain (Plate 8, Fig. 2).

The forest shows a well-developed structure of three tree layers with a canopy height of 100–120 ft. A few emergent trees may attain greater heights. The second layer finds a mean height of 80 ft and may be fairly dense. The third layer may be defined at between 30 and 45 ft.

Floristically, lowland hill forest is of very mixed composition. More than 60 tree species are recorded for the canopy layer alone. Locally, *Intsia bijuga* (kwila) may be regarded as a diagnostic species. Over much of the area this forest can be typed from the aerial photos and separated from alluvium forest by the presence of light-coloured emergent tree crowns. However, it was found difficult to identify these with individual species during the ground traverses. Apparently a number of deciduous trees are included, among which are *Flindersia*, *Sterculia*, and *Terminalia*.

Trees belonging to the canopy are: *Aglaia*, *Alstonia scholaris*, Apocynaceae, *Artocarpus altilis*, *Barringtonia*, *Bombax ceiba*, *Buchanania*, *Campnosperma*, *Canarium* ("asisiv", "enal"), *Casuarina*, *Cedrela*, *Celtis philippensis*, *Celtis*, *Chisocheton*, *Chrysophyllum*, *Crudia*, *Dracontomelum mangiferum*, *Dracontomelum* sp., *Dysoxylum*, *Elaeocarpus*, *Endospermum*, *Euodia bonwickii*, *Ficus* spp., *Firmiana papuana*, *Flindersia* spp., *Garuga floribunda*, *Hernandia ovigera*, *Homalium* sp., *Horsfieldia*, *Intsia bijuga*, *Litsea*, *Kingiodendron*, *Macaranga*, *Maniltoa*, *Mangifera*, *Myristica*, *Neonauclea* (infrequent), *Octomeles sumatrana*, *Palaquium*, *Pangium edule*, *Parartocarpus venenosus*, *Parinari*, *Planchonella*, *Planchonia papuana*, *Pometia pinnata*, *Pterocarpus indicus*, *Pterocymbium beccarii*, *Pterygota horsfieldii*, *Rhodamnia*, Sapindaceae, *Semecarpus*, *Serianthes dilmyi*, *Sloanea*, *Spondias dulcis*, *Sterculia*, *Syzygium*, *Terminalia* ("o" and "samanak"), *Terminalia kaernbachii*, *Thespesia*, *Tristiropsis* (frequent), *Vitex cofassus*, *Xanthophyllum papuanum*, and *Xylopia*.

The second layer includes *Adenanthera*, *Boerlagiodendron*, *Buchanania*, *Dillenia*, *Diospyros*, *Dracontomelum mangiferum*, *Dysoxylum*, *Garcinia*, *Myristica*, *Palaquium supfianum*, *Pandanus* and palms, *Pangium edule*, *Pimeleodendron amboinicum*, *Polyalthia*, Rubiaceae, and Rutaceae.

A third and lowermost tree layer has *Aceratium*, *Aglaia*, *Barringtonia*, *Jagera*, *Linociera*, *Litsea*, *Maniltoa*, *Microcos*, *Phyllanthus*, *Pisonia*, Rubiaceae, *Semecarpus*, and *Syzygium*.

Among the shrubs are Annonaceae, *Aglaia*, *Antidesma*, *Aphania cuspidata*, *Antiaropsis decipiens*, *Archidendron*, *Calyacanthus magnusianus*, *Casearia*, *Cerbera floribunda*, *Clerodendrum*, *Euodia*, *Ervatamia*, *Gardenia*, *Gnetum*, *Ixora*, *Phaleria*, *Pleomele angustifolia*, *Psychotria*, *Semecarpus*, and *Syzygium*.

The ground cover is often sparse and includes terrestrial ferns and herbs such as *Pilea*, *Selaginella*, and small fan palms. Climbers are more numerous with Apocynaceae, Araceae, *Dischidia*, *Freycinetia*, *Gnetum*, *Luffa*, *Mucuna*, Menispermaceae, *Petraeovitex multiflora*, *Quisqualis indica*, *Solanum*, *Uncaria*, and Vitaceae. Among the epiphytes are a woody *Schefflera* and the large fern *Asplenium nidus*.

Population of the Wewak–Lower Sepik area is at present centred in the hilly uplands and as a consequence many phases of garden regrowth and advanced secondary forest may be seen throughout the lowland hill forest (Plate 6, Fig. 1). In some localities an extensive bamboo brake is found, composed of a small broad-leaf species of bamboo.

In the second or third year after clearing, gardens are strongly invaded by weeds. *Imperata* grass dominates together with such weeds as Acanthaceae, *Ageratum conyzoides*, *Amaranthus*, *Cyathula prostrata*, *Cyclosorus* fern, *Cyperus*, *Drymaria cordata*, *Emilia*, *Lepionurus*, *Ludwigia*, *Selaginella*, *Sida*, *Synedrella nodiflora*, *Peperomia*, *Pteris*, and Zingiberaceae. Common grasses are *Chrysopogon aciculatus*, *Cymbopogon*, *Eleusine indica*, *Saccharum spontaneum*, *Sorghum halepense*, *Panicum sarmentosum*, *Paspalum*, *Pennisetum macrostachyum*, and *Polytoca macrophylla*.

Climbers and scramblers become frequent and include *Aristolochia*, *Cardiospermum halicacabum*, *Combretum*, *Dioscorea*, *Lygodium*, *Passiflora foetida*, *Phaseolus*, and Vitaceae.

When abandoned the garden plot is rapidly taken over by many small shrubby regrowth trees which enter the sequence to form a dense thicket including the following species: *Aglaia*, *Allophylus cobbe*, *Althoffia*, *Antidesma*, *Artocarpus altilis*, *Astronia*, bamboo, *Barringtonia*, *Bixa orellana*, *Breynia*, *Callicarpa*, *Carica papaya*, *Casuarina*, *Colona*, *Commersonia bartramia*, *Cordia dichotoma*, *Crotalaria*, *Dillenia castaneifolia*, *Geunsia*, *Glochidion*, *Fagraea*, *Ficus* spp., *Kleinhovia hospita*, *Leea indica*, *Macaranga*, *Mallotus ricinoides*, *Mangifera*, *Melanolepis multiglandulosa*, *Micromelum minutum*, *Musa*, *Myristica*, *Nauclea*, *Octomeles sumatrana*, *Osbeckia*, *Pandanus* and palms, *Pipturus*, *Premna*, *Ricinus officinalis*, *Sarcopteryx*, *Timonius*, and *Tournefortia*.

(iv) *Well-drained Alluvium Forest*.—Well-drained alluvium forest is distinguished by habitat, structure, and floristic composition. It finds only limited expression in the present survey area. Along the coast small areas of alluvium forest occur at the river mouths. Inland, small occurrences of alluvium forest are found in the hill valleys, but larger areas occur only in the lower reaches of the northern tributaries of the Sepik River (Nagam land system).

Well-drained alluvium forest is a tall three-tree-layered forest with a canopy over 100 ft high and occasional emergent individuals reaching to 140 ft.

These canopy trees are *Aleurites moluccana, Alstonia scholaris, Artocarpus altilis, Buchanania, Cananga odorata, Canarium* spp., *Celtis* spp., *Chisocheton, Chrysophyllum* (frequent), *Cinnamomum, Dracontomelum mangiferum, Dracontomelum* sp., *Dysoxylum, Elaeocarpus, Ficus* spp. (including a common strangler fig), *Hernandia ovigera, Homalium foetidum, Mangifera, Mastixiodendron pachyclados, Nauclea, Octomeles sumatrana, Parartocarpus venenosus, Planchonella, Planchonia papuana, Polyalthia, Pometia pinnata* (frequent), *Pterocarpus indicus, Pterocymbium beccarii, Semecarpus, Spondias dulcis, Syzygium, Terminalia kaernbachii, Terminalia* ("o"), *Teysmanniodendron bogoriense, Tristiropsis,* and *Vitex cofassus.*

The second storey of trees is between 60 and 70 ft and the following belong to it: Araliaceae, *Barringtonia, Boerlagiodendron, Casearia, Chisocheton, Chrysophyllum, Dillenia castaneifolia, Endospermum, Erythrospermum candidum, Ficus* sp., *Garcinia, Homalium foetidum, Inocarpus edulis, Laportea, Lophopetalum, Maniltoa, Microcos, Myristica, Neonauclea* and *Nauclea, Neuburgia, Pandanus* and palms, *Pangium edule, Pisonia, Pometia pinnata,* and *Vatica papuana.*

The third storey is at 30–35 ft and includes *Antiaropsis decipiens, Archidendron, Cerbera floribunda, Diospyros, Glochidion, Fagraea racemosa,* sago palms and *Licuala* palms, *Myristica, Medusanthera, Pandanus, Sloanea, Syzygium, Timonius, Vavaea,* and *Voacanga papuana.*

Among the shrubs are Anacardiaceae, Annonaceae, *Aphania cuspidata, Cerbera floribunda, Ervatamia,* Euphorbiaceae, *Ficus, Micromelum minutum, Microcos, Pleomele angustifolia,* Rubiaceae, fan palms, *Phaleria,* and *Piper.*

Frequent, as herbs on the forest floor, are Acanthaceae, *Cyathula prostrata, Pilea,* Rubiaceae, *Selaginella,* and Zingiberaceae, as well as small palms, seedlings, and ferns. Climbers include many ferns and aroids with *Aristolochia, Calamus, Faradaya, Flagellaria, Freycinetia, Gouania,* Menispermaceae, *Mucuna* (d'Albertis vine), and *Poikilospermum.*

Following cultivation, grass weeds such as *Digitaria, Eulalia, Leptaspis banksii,* and *Panicum* appear with sedges and the hard fern *Asplenium. Lygodium, Mucunia,* and *Tournefortia* are common scramblers. With further time woody regrowth is asserted and includes *Abroma, Artocarpus altilis, Althoffia pleiostigma, Casuarina, Cerbera floribunda, Cordia dichotoma, Costus speciosus, Desmodium, Dillenia castaneifolia, Donax vittiformis, Dracontomelum mangiferum, Endospermum, Ervatamia, Fagraea racemosa, Ficus pungens* and other small species, *Kleinhovia hospita, Leea indica, Macaranga aleuritoides,* Marantaceae, *Nauclea, Psychotria, Tabernaemontana aurantiaca, Timonius, Urena lobata,* and Zingiberaceae.

(v) *Mixed Flood-plain Forest* (Plate 10, Fig. 1).—In this category are placed all the seasonally inundated aspects of the alluvium forests. While ranging through mixed types to palm-dominated flood-plain forests, they are nowhere very extensive in the area (Passoram, Kworo, Yambi, But, Nagam, and Misinki land systems).

Mixed flood-plain forests usually occur as small pockets and are typically poor in quality. Stature is reduced to about 60 ft with only two tree layers. Floristic composition becomes simpler and resolves into species more tolerant of wet conditions.

In places the canopy may be irregular and broken with abundant rattan growth. On wet sites more palms enter and may comprise up to 50% of the canopy.

Trees are *Artocarpus*, *Buchanania* (often abundant), *Celtis*, *Cerbera*, *Dracontomelum mangiferum*, *Ficus* spp., *Maniltoa*, *Mallotus*, *Nauclea*, Polygalaceae, *Pometia pinnata*, *Pterocarpus indicus*, *Spondias dulcis*, *Terminalia* sp., and *Teysmanniodendron bogoriense*.

Garcinia subtilininervis, several *Myristica* species, and *Pandanus* all produce prop roots. Sago and other palms are frequent and the swamp liane fern, *Stenochlaena palustris*, may become rampant.

(vi) *Levee Forest* (Plate 10, Fig. 2).—A well-defined levee forest is found as a border along much of the Sepik River bank and is typical of the southern tributaries, namely Korosameri, Yuat, and Keram Rivers and Pora Pora Creek (Misinki and Palimbai land systems). The levees are typically narrow, being a few chains in width and about 10 ft high. Development of levee forest on these banks is related to the height, width, and age of the levee, and a seral pattern from pioneer scroll ridge communities can be readily traced. Behind the levees the terrain slopes down to extensive mixed grass swamps and thus the levee forest often stands out as a striking feature of the flat landscape. Old courses of the rivers are revealed crossing the swampy lowland by the double strips of trees marking the old levee banks.

Ficus species, of which there are about six represented, are common along the levees, and a small-leaved species reaches 100 ft. For the most part, however, the trees are 50 to 60 ft high. Very frequent are *Octomeles sumatrana*, *Artocarpus altilis*, *Chisocheton*, *Dysoxylum*. *Dracontomelum*, *Maniltoa*, several *Terminalia* species, and *Syzygium*.

Smaller associate trees include Annonaceae, *Barringtonia*, *Bischofia javanica*, *Baccaurea*, *Didymocheton amooroides*, *Dillenia castaneifolia*, Euphorbiaceae, *Inocarpus edulis*, *Nauclea orientalis*, *Myristica*, *Pandanus*, *Premna*, *Sapium indicum*, *Semecarpus*, and sparse shrubs including *Piper*, Anacardiaceae, and Zingiberaceae.

Lianes include *Cissus*, *Dioscorea*, *Flagellaria indica*, *Gnetum*, and *Pothos*.

Where the levee broadens out into a high terrace taller trees may be included such as *Alstonia scholaris*, *Bischofia javanica*, *Calophyllum*, *Diospyros*, *Intsia bijuga*, *Litsea*, *Octomeles sumatrana*, *Planchonia papuana*, *Pterocarpus indicus*, *Spondias dulcis*, and *Vitex cofassus*. On these sites the forest approaches an alluvium forest.

(*b*) *Swamp Vegetation*

(i) *Swamp Forest*.—Mixed swamp forest is confined to Kobar land system which forms a hinterzone to the mangrove woodland of Murik land system. It is covered with a vegetation complex where swamp forest merges into transitions with sago and nypa palm groves and mangrove woodland on the one hand and swamp woodland, sedge–fern swamp, and herbaceous swamp on the other. The whole area is within the tidal influence of the Murik lagoons and the Sepik River. Owing to the difficulty of access to the area many of the transitional communities could not be adequately studied on the ground.

Swamp forest is composed of tall trees up to 80 ft high, growing closely grouped together and developing either prop roots or a sprawling exposed root system. Pools of water accumulate over the muddy floor. In open sites sago and nypa palms form small groves, and progress through the swamp forest is slow and uncomfortable.

Among the taller trees are *Calophyllum, Homalium foetidum, Intsia bijuga,* and the inland mangroves *Heritiera littoralis* and *Sonneratia caseolaris.* Smaller trees present are *Barringtonia, Garcinia* sp., *Brownlowia argentata, Dolichandrone spathacea, Inocarpus edulis, Myristica* sp., *Planchonella, Teysmanniodendron hollrungii,* and *Urandra umbellata.*

(ii) *Swamp Woodland.*—Over much of the swampy Kobar and Pora land systems and locally in Bosman land system the woody vegetation is reduced to a swamp woodland of slender trees 30–40 ft high. This varies in floristic composition and density. Tree species are *Buchanania* sp., *Dillenia castaneifolia, Fragraea racemosa, Ilex* sp., Myrsinaceae, and *Timonius.* Typically the trees form a dense grove together with an abundance of *Pandanus* (screw palms).

A terrestrial layer is of low sprawling *Pandanus* and *Freycinetia* species, the fleshy monocot *Hanguana malayana,* massed *Gleichenia* fern, and in more open glades *Stenochlaena* and *Acrostichum* ferns with *Phragmites* and tall Cyperaceae. In the southern part of Pora land system swamp woodland merges into an almost pure stand of a small swamp *Pandanus* sp.

(iii) Campnosperma *Sago Palm Forest.*—This swamp forest type which is confined to Pora land system has a close affinity with sago palm forest. Here, however, the tree canopy is dominated by the large-leaved *Campnosperma brevipetiolata.* Often occurring in pure stands, the trees form a close evenly massed canopy at 60–70 ft over the sago palms, and such forest is easily identified on the aerial photos. Over much of Pora land system, however, the *Campnosperma* trees form a scattered and somewhat open canopy of variable height above the substorey sago palms. The denser stands are shown on the forest resources map.

(iv) *Sago Palm Forest.*—Occurring in Senambila, Bosman, Nagam, Pandago, and Pora land systems, this is a more seasonal aspect of swamp community and is composed of several tree species and sago palm (*Metroxylon sagu*). A considerable variation in the ratio of palms to trees exists, also in the proportion of mature palms in the grove. While reflecting minor differences in the water relations of the site such variation requires more detailed study to establish precise correlations.

Within the sago palm forest palms may constitute up to 60% of the community forming a dense lower tier of spreading fronds 30 ft high, with here and there a group of mature individuals elevated by the development of the starch-producing trunk.

The associated trees are usually scattered throughout with small crowns emerging above the palms to reach 50–60 ft. Mostly they are species tolerant of wet conditions, such as *Alstonia scholaris, Campnosperma brevipetiolata, Dolichandrone spathacea, Erythrina* sp., *Ficus* spp., *Garcinia subtilininervis, Gynotroches axillaris, Litsea, Myristica, Nauclea, Pandanus, Polyalthia, Sapium indicum, Semecarpus, Sterculia, Syzygium buettnerianum, Terminalia* ("samanak"), and the two climbers *Combretum* and *Stenochlaena.*

(v) *Sago Palm Swamp*.—This is a widespread community (Passoram, Kworo, Yambi, Bosman, Madang, Nubia, But, Nagam, Pandago, Kabuk, and Kobar land systems) consisting solely of dense stands of sago palms. The interior is gloomy with low fronds overarching the bare muddy floor. The majority of the palms are young individuals branching from the base at ground level, but after a few years and preparatory to flowering, individuals produce a trunked form elevating the crown 30 ft or more in height. Within the grove, spacing of palms may average 15–20 ft, but after flowering side suckers are produced and thus small grouped stools are formed. Site conditions range over a considerable water gradient and this may have a relationship with the proportion of mature palms present in any one grove. Some stands on the Sepik flood-plain are apparently permanently stunted. Both smooth and spiny varieties of sago palms occur intermingled throughout the area.

(vi) *Sago Palm*–Phragmites *Swamp*.—As site conditions become more permanently wet coupled with greater depth of seasonal flooding (Kabuk and Pora land systems), an edaphic ecotone occurs between palm and grass swamp. Sago palm–*Phragmites* swamp is a mixed community of low sago palms characteristically growing in scattered circular groves up to 300 ft in diameter and set in a dense stand of *Phragmites karka*. Its main occurrence in the Wewak–Lower Sepik area is in the east at the mouth of the Sepik River, where it links up with similar communities of Kabuk land system described for the Lower Ramu–Atitau area.*

(vii) *Sedge–Fern Swamp*.—This is a community of quite limited extent found in Kobar land system. Small circular or oval areas surrounded by swamp and mangrove woodland form a low open community in which a fern, *Blechnum indicum*, and a sedge, *Eleocharis* sp., are co-dominant.

(viii) Scleria *Sedge Swamp* (Plate 9, Fig. 2).—In depressions and drainage courses with a standing water-table above the ground surface a large *Scleria* species dominates. Such swamp usually takes the pattern of narrow strips following the shallow folds and inconspicuously shelving valley heads throughout the middle Sepik grassland plain (Kworo and Yambi land systems). The large bulrush-like *Scleria* forms dense stands with lesser associated sedges such as *Fimbristylis globulosa* and *Eleocharis*. Wet habituating grasses such as *Leersia*, *Isachne*, and *Apluda*, together with water plants, e.g. *Nymphoides*, may also be present.

(ix) Phragmites *Swamp*.—*Phragmites karka* swamp made up of pure stands up to 20 ft high and with rare associated plants is to be found mainly near the coast (Bosman and Nubia land systems) and in the eastern parts of the Sepik flood-plains (Misinki and Sanai land systems), where there is less seasonality in flood-water levels than there is further upstream.

(x) *Mixed Grass Swamp* (Plate 11).—On the low-lying scrolls and flood-plains of the Sepik River (Sanai land system) occur extensive swamp grasslands which are covered with water up to 10 ft deep during the flood season. The vegetation is dense lush broad-leaved grasses with long trailing culms often floating along the water surface.

* Lands of the Lower Ramu–Atitau area, New Guinea. CSIRO Aust. Div. Land Res. Reg. Surv. divl Rep. 59/1 (unpublished).

Dominant grasses are *Hymenachne pseudointerrupta*, *Echinochloa stagnina*, the robust swamp grass *Ischaemum polystachyum*, and a *Panicum* sp. Also present are the water grasses *Isachne*, *Leersia hexandra*, and *Oryza* sp. Waterways through these grass swamps may be lined with taller grasses such as *Phragmites karka*, *Saccharum robustum*, *Coix gigantea*, Cyperaceae, and trailing *Polygonum*.

On slightly higher marginal areas *Panicum paludosum* is a common grass, together with *Apluda mutica*, *Eragrostis*, and *Paspalum* species. Here are also the herbs *Aeschynomene indica*, a semi-woody Composite, Convolvulaceae, *Corchorus capsularis*, *Heliotropium indicum*, *Melochia concatenata*, *Nasturtium indicum*, and Scrophulariaceae.

(xi) *Herbaceous Swamp* (Plate 12, Fig. 1).—A mixed herbaceous swamp community is of minor importance in the Lower Sepik area as most of the swamp land is dominated by water grasses. Where it occurs in Sanai and Kobar land systems, herbaceous swamp is a mass of fleshy monocotyledonous plants such as *Hanguana malayana* and *Monochoria hastata* together with *Phragmites*, *Stenochlaena* and *Acrostichum* ferns, and Cyperaceae.

(xii) *Aquatic Vegetation* (Plate 12, Fig. 2).—Along the margins of waterways and cut-off meanders, as well as the extensive shallow lakes of Sanai land system, a dense growth of floating and semi-submerged and trailing water plants is found. Among these are the aquatic *Hydrocharis dubia*, *Limnocharis*, *Limnophila*, *Ludwigia repens*, *Ipomoea aquatica* (the water "kau kau"), *Myriophyllum*, *Nymphoides indica*, *Pistia stratiodes*, and *Utricularia*. Dominant in still water are water-lily pads composed of several species of *Nymphaea* and the large pink-flowered *Nelumbium nelumbo*.

(*c*) *Coastal Vegetation*

(i) *Strand Woodland*.—Where a sandy beach has developed as in Madang and Nubia land systems, a narrow fringe of strand woodland some 150 ft wide fronts the sea. As the beach rises up to the first beach ridge, sand-binding plants may form a pioneer littoral zone. In this are small sea beach grasses, *Ischaemum muticum* and *Thuarea involuta* with the sedge *Cyperus pedunculatus*. Sprawling over the sand are the leguminous trailers *Canavalia maritima* and *Vigna marina*, accompanied by the pan-tropical convolvulus *Ipomoea pes-caprae*.

Immediately landward is a low fronting zone of shrubs or littoral hedge protecting the strand woodland. Included here are *Scaevola sericea*, *Derris trifoliata*, *Lumnitzera racemosa*, the spider lily *Crinum asiaticum*, *Morinda citrifolia*, and a small maritime *Pandanus*. The parasitic *Cassytha filiformis* is frequent on plants in this zone.

Immediately following is the true strand woodland of salt-spray-tolerant trees 30–50 ft high. The following are frequent species here: *Barringtonia asiatica*, *Calophyllum inophyllum*, *Cerbera manghas*, *Heritiera littoralis*, *Hibiscus tiliaceus*, *Inocarpus edulis*, *Mallotus philippensis*, *Pandanus*, *Premna*, *Pittosporum ferrugineum*, *Sophora tomentosa*, *Terminalia catappa*, *Thespesia populnea*, *Timonius*, and *Xylocarpus*.

(ii) *Mangrove Woodland*.—Mangrove woodland finds extensive expression in Murik land system and occurs locally in Madang land system. Mangrove woodland of commercial value has been mapped on the forest resources map.

Low-lying mud islands up to an acre or so in extent may be entirely covered with a dense stand of mangrove trees. On larger islands and estuary banks this mangrove woodland forms a fringing zone about a chain in depth. The dominant mangrove is *Bruguiera gymnorrhiza*, this species occupying the mid and high tidal range zone. *Bruguiera* is best developed in the mid tidal range where the rise and fall is about 1 ft. Here it forms almost pure stands reaching 60–70 ft high. The canopy is dense and uniform with a sparse subcanopy of small trees of the same species. Trunks are smooth and tall, the largest being about 2 ft in diameter and spaced 10–15 ft apart. The floor is of silty mud overlying a peat built up by the mangroves. Progress is over a mass of arching strut roots, the main groups of which come out from the trunk at levels up to 3 ft. Several larger struts may come off at anything up to 10 ft. Very few mangrove seedlings are to be found on the muddy floor but there is abundant population of crabs and a large bivalve, the so-called mud oyster, *Mactra eximia*.

The mangrove trees on the shelving fringe of the mud flats grow in the zone of maximum tidal fluctuation, the rise and fall here being some 2 ft. These trees which front the open lagoons are lower in overall height and bushy and compact, thus closing off the exposed edge of the woodland. Such fronting trees have also a denser mass of fine stilt roots at the base of the trunk whilst branches that overhang the water often produce roots that may grow down from 20 ft to trail in the water. *Aegiceras corniculatum* is a frequent species in this edge zone.

Avicennia eucalyptifolia becomes more abundant on sandy spits and higher ground while *Sonneratia caseolaris*, often a large tree 80 ft or more high, dominates the upper reaches of the lagoons and tidal estuaries. *Rhizophora*, *Nypa fruticans*, *Brownlowia argentata*, and other members of the swamp woodland may also be present in the ecotonal zones.

(*d*) *Successional Vegetation*

(i) *River Scroll Succession* (Plate 10, Fig. 2).—While many of the scrolls of the Sepik River are deeply flooded and support only swamp grassland, older and higher scrolls may show a succession of plant communities (Palimbai and Sanai land systems).

The scroll pattern is essentially one of a series of small parallel levees 4–6 ft high and interspaced by hollows 20–30 ft across. In these troughs there is a dense stand of *Saccharum robustum* or, in very low-lying swales, *Phragmites karka*.

The vegetation on the levee ridges is a pioneer growth of small trees leading to levee forest. The species are *Althoffia*, *Ardisia*, *Campnosperma*, *Cerbera floribunda*, *Commersonia bartramia*, *Cordia dichotoma*, *Endospermum*, *Ficus* spp., *Harpullia*, *Kleinhovia hospita*, *Laportea*, *Macaranga*, *Mallotus*, *Micromelum minutum*, *Morinda*, *Octomeles sumatrana*, *Pandanus*, and small palms and rattans.

Terrestrial ferns such as *Lygodium* and *Helminthostachys zeylanica* are frequent.

(ii) *River Terrace Succession* (Plate 5, Fig. 2).—Terraces and flood-plains of the smaller rivers are of alluvial silts and gravels occupied by a dense cover of *Saccharum spontaneum* growing up to 15 ft high. On higher and more stable terraces patches of *Imperata* grass with woody herbs and shrubs are found.

Among the herbs are *Asclepias*, *Ageratum conyzoides*, *Amaranthus*, *Borreria*, *Clitoria ternatea*, *Cyclosorus* fern, *Desmodium*, *Euphorbia*, *Moghania strobilifera*, and Zingiberaceae. Grasses are *Chrysopogon aciculatus*, *Eleusine indica*, *Paspalum conjugatum*, *Pogonatherum paniceum*, *Sporobolus*, and *Setaria*. Shrubs and small trees include *Artocarpus*, *Breynia*, *Cerbera*, *Commersonia*, *Crotalaria*, *Ficus*, *Macaranga*, *Mussaenda*, *Nauclea*, and *Timonius*.

Where higher terraces develop along the low-lying southern tributaries of the Sepik River a similar vegetation may be found, with *Saccharum* and *Phragmites* forming a dense cover on wetter sites and groves of quick-growing softwood tree species entering on higher ground. These groves are often almost pure stands of *Artocarpus* or *Octomeles*.

(iii) *Coastal Plain Succession*.—The narrow coastal plain, particularly that part made up of successive beach ridges and swales and small deltas (Madang, Nubia, and But land systems), is occupied by a mixed coastal vegetation, usually secondary in nature, of littoral and lowland hill forest species. Mixed remnants of strand, alluvium, and lowland hill forests may be present. In the more low-lying swales a swampy vegetation may range through sedge–fern swamp to sago palm communities. Where villages occur, mixed grass and woody regrowth communities are found.

Common grasses are *Cenchrus*, *Echinochloa colonum*, *Chrysopogon aciculatus*, *Dactyloctenium aegyptium*, *Eragrostis*, *Eleusine indica*, *Imperata cylindrica*, *Ischaemum barbatum*, *Ophiuros exaltatus*, *Oplismenus*, *Paspalum* spp., and *Setaria*. Taller grasses are *Pennisetum macrostachyum*, *Saccharum spontaneum*, and *Sorghum halepense*.

Herbs are Acanthaceae, *Alpinia*, *Borreria*, *Centrosema pubescens*, *Hyptis*, *Mollugo*, *Mimosa pudica*, *Moghania strobilifera*, *Sida*, *Stachytarpheta*, and *Synedrella nodiflora*. These are followed by the shrubs *Cassia alata*, *Crotalaria*, *Dodonaea*, and *Morinda* with the small trees *Albizia procera*, *Antidesma ghaesembilla*, *Commersonia bartramia*, *Dillenia*, *Nauclea orientalis*, *Premna*, *Timonius*, *Syzygium*, and small *Areca* and *Caryota* palms.

Along the estuaries of small tidal creeks are nypa and sago palms with a small holly-like shrub (*Acanthus*) and also *Dolichandrone spathacea*.

(*e*) *Disclimax Vegetation*

(i) Polytoca–Sorghum *Grassland*.—This is a mixed tall cane grass community representative of the populated foothills in the Maprik and Yangoru areas (Kaboibis, Yangoru, Winge, and Passoram land systems). Nowhere does this grassland become extensive but it is typical of roadsides and on slopes and valley edges throughout the actively gardened hills.

A dense cover, up to 6 ft high, is made up of *Polytoca macrophylla*, *Sorghum halepense*, and *Saccharum*. *Pennisetum macrostachyum*, *Croix lacryma-jobi*, and *Coelorachis rottboellioides* are less frequent members. All observations suggest that these tall grasslands are early phases of regrowth after conversion of the forest to gardens and that with continued and repeated interference they will slowly pass into mixed short grass vegetation.

(ii) Ophiuros–Imperata *Grassland* (Plate 7, Fig. 2).—Small tracts of this community are found throughout the survey area (Kaboibis, Yangoru, Winge, Passoram, Muschu, Kworo, and Bosman land systems).

Imperata cylindrica (kunai grass) forms a dense cover some 4 ft high, throughout which are dispersed tussocks of the taller *Ophiuros exaltatus*. Minor associates which occupy the more open sites are the short grasses *Arundinella*, *Alloteropsis semialata*, *Capillipedium*, *Paspalum*, *Sorghum nitidum*, and *Ischaemum*.

Herbs are *Crotalaria*, Convolvulaceae, *Cuscuta*, *Eriocaulon*, Euphorbiaceae, *Nepenthes*, *Scleria*, and Scrophulariaceae.

Regrowth is active with many small trees and shrubs. These are *Ervatamia*, Euphorbiaceae, *Fagraea racemosa*, many small *Ficus* species, Leguminosae, *Macaranga*, Meliaceae, Melastomataceae, Urticaceae, and climbers from the Compositae and Leguminosae, e.g. *Phylacium*.

(iii) *Mixed Association Grassland*.—In the Wewak–Lower Sepik area a zone of mixed short grasses forms an ecotone between the tall grassland on the inland foothills and the short *Themeda* and *Ischaemum* grasslands of the middle Sepik plains. In this zone (Kaboibis, Yangoru, Winge, Senambila, Passoram, and Kworo land systems) many species of short grasses may be co-dominant. Considerable variation occurs from location to location but no one species composition dominates over any extent. Short grass species recorded for this mixed association are *Alloteropsis semialata*, *Apluda mutica*, *Arundinella setosa*, *Capillipedium parviflorum*, *Digitaria*, *Dimeria*, *Eleusine indica*, *Eragrostis*, *Eremochloa*, *Eulalia*, *Hakelochloa granularis*, *Imperata cylindrica*, *Ischaemum barbatum*, *Ischaemum fragile*, *Ischaemum polystachyum*, *Ophiuros exaltatus*, *Panicum*, *Paspalum conjugatum*, *Paspalum* spp., *Sacciolepis indica*, *Setaria* spp., *Sorghum nitidum*, and *Themeda australis*.

Some of the numerous herbs found are *Passiflora foetida*, *Ipomoea*, *Eriocaulon*, *Cyclosorus* fern, *Rhynchospora rubra*, *Fimbrystylis monostachya*, *Nepenthes mirabilis*, *Lycopodium cernuum*, *Pteridium esculentum*, *Hibiscus abelmoschus*, *Stackhousia intermedia*, and *Pimelea*. Woody shrubs include *Acacia*, Melastomataceae, *Massaenda*, and *Crotalaria*.

(iv) Themeda–Arundinella *Grassland* (Plate 6, Fig. 1; Plate 9, Fig. 1).—This is a short grass community that occurs on drier slopes and crests in Kaboibis, Yangoru, Senambila, Passoram, and Kworo land systems. The dominant species is *Themeda australis* (kangaroo grass) which often attains single dominance. Mostly, however, it is co-dominant with *Arundinella setosa*. Only small and local patches of this grassland occur, mainly in the middle Sepik plain.

(v) Themeda–Ischaemum *Grassland Complex* (Plate 8; Plate 9, Fig. 2).—The grasslands of the middle Sepik plains are among the most extensive in New Guinea. Within the survey area they are to be found occupying a general rectangle some 60 miles long and 20 miles wide in Winge, Senambila, Passoram, Kworo, and Yambi land systems. The greater part of the grasslands is in the form of long continuous tracts several miles wide and running north to south, and separated by narrow strips of forest bordering the river gullies.

In the north, where the grasslands join the foothills of the coastal ranges, there is a floristic transition zone with *Ophiuros–Imperata* grassland. Here, species composition is richest and the grasslands more mixed. Also in this zone small regrowth shrubs such as *Antidesma ghaesembilla*, *Cassia mimosoides*, *Crotalaria*, *Cordia dichotoma*, Euphorbiaceae, *Glochidion*, *Fagraea racemosa*, *Indigofera*, *Mussaenda*, and *Pandanus* are more frequent.

The main grassland, extending south to the Sepik River flood-plain, is found over uniformly poor soils subject to distinct seasonal alternation of wet and dry phases. This is reflected by the species composition, which is a complex of *Themeda australis* and its associate *Arundinella setosa*, on the one hand, and *Ischaemum barbatum* with several common sedges on the other. Such a community appears to be unique for New Guinea and ecologically represents an ecotone of the dry *Themeda–Arundinella* community and wet *Ischaemum–Apluda* grasslands. In fact, where the relief is sufficiently developed the first-named group segregates out to occupy the drier hill crowns while *Ischaemum* dominates the shallow valleys and depression folds. Where co-dominant, the *Themeda* grass forms small surface-rooted tufts while the *Ischaemum* has a root system penetrating into the wet subsoil.

All the grasslands are subject to regular or periodic firing and, apart from its role in initiating and maintaining the grasslands, this factor has a relationship to the population of associated broad-leaf herbs present in the grasslands.

Many occasional grasses, sedges, and herbs are found only beside tracks while others appear to flower only during the brief open aspect that follows a burn.

Themeda australis and *Ischaemum* are the dominants throughout, but associate grasses also present are *Alloteropsis semialata*, *Capillipedium parviflorum*, *Centotheca lappacea*, *Dimeria*, *Eragrostis*, *Eremochloa*, *Imperata cylindrica*, *Ischaemum fragile* (a small species hitherto known only from the Fly River and Queensland), *Ophiuros exaltatus*, *Paspalum*, *Sorghum nitidum*, *Sacciolepis indica*, and *S. myosuroides*.

Sedges are common, among which are *Cyperus*, *Eleocharis*, *Fimbristylis*, *Fuirena umbellata*, *Rhynchospora*, *Scleria*, and *Thoracostachyum sumatranum*.

A list of herbs recorded includes *Buchnera*, *Commelina*, *Desmodium*, *Dianella*, *Eriocaulon*, *Heliotropium indicum*, *Hibiscus abelmoschus*, *Ipomoea*, *Lindernia*, *Nepenthes mirabilis*, *Phyllanthus*, *Pimelea*, *Polygala*, *Portulaca*, *Pycnospora lutescens*, *Salvia*, *Stackhousia intermedia*, and *Osbeckia*.

(vi) Ischaemum–Apluda *Grassland*.—Wetter depressions within the grassland in Winge, Kworo, Yambi, and Bosman land systems are often dominated by *Ischaemum barbatum* and associated moist site grasses such as *Apluda mutica*, *Leersia hexandra*, and *Isachne papuana* and sedges. They are usually small local patches which stand out in the landscape because of their lush green colour.

IV. Acknowledgments

Many botanical names in this report have been provided by the herbarium of the Division of Land Research in Canberra. Identifications of wood samples were provided by the Division of Forest Products, CSIRO, Melbourne. This helpful assistance is gratefully acknowledged. Plant specimens were collected in the field by the author and by Mr. R. Pullen.

PART VII. FOREST RESOURCES OF THE WEWAK–LOWER SEPIK AREA

By J. C. SAUNDERS*

I. INTRODUCTION

Productive forest covers only 35% of the survey area—1210 sq miles of hill forests and 390 sq miles of alluvium forests. This relatively low figure for forest cover in lowland New Guinea is explained by the large areas still being actively cleared by the population on the inland foothills of the Prince Alexander Mountains and more especially by the extensive areas constituting the middle Sepik grass plain and the flood-plain swamp lands.

The bulk of future timber resources undoubtedly lies in the forests of the lower ranges and hills. As can be seen from the forest resources map, these form a wide belt over the Prince Alexander Mountains and extend south-eastwards towards Angoram.

Generally the forests are fairly accessible. The present coastal road extending from Terebu to But could serve for the exploitation of the coastal slopes of the ranges but many short access roads would be necessary. The inland slopes accessible from the Mandi–Maprik road now offer little in timber resources. A road link from Mambe–Tring to Angoram would pass through the centre of the Angoram lowland hill forest and could play an important part in the exploitation of this forest tract.

II. METHODS

Base camps, taking into consideration factors of transport and facilities of access, were chosen to investigate interesting vegetation patterns selected during a preliminary air-photo interpretation. These base camps were situated at But, Hawain River, Tring, Minjim River, Yangoru, Numoikum, and Angoram. From But and Hawain River the alluvium forests on the coastal plain and the lower ranges forest were investigated. At Tring, in lowland hill forest, traverses were made to the south and to the coastal village Samap. The base camp on the Minjim River, one of the northern tributaries of the Sepik River, allowed access to the alluvium forest of the upper and middle parts of the river and also to lowland hill forest. From Yangoru, a traverse via Waramuru on the eastern slopes of Mt. Turu to the coastal plain at Hawain River gave access to lower montane rain forest, lower ranges forest, and some lowland hill forest near the coast. At Numoikum and Angoram the wetter and drier aspects of the lowland hill forest were investigated. Information on the swampy forest types was obtained from the plant ecologist.

The sampling method consisted of line transects 1 chain wide and at least 5 acres in area. Where necessary, e.g. in lowland hill forest, the transects were aligned

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to cut across land of varying relief. Only "commercial size timber trees", i.e. trees 5 ft or more in girth at breast height, were recorded. For each tree recorded, data on girth, bole length and form, and total height were recorded together with the local name (in the Amele dialect, Madang District), and a wood sample was collected. Where time permitted, records were supported by the collection of plant specimens for the CSIRO herbarium in Canberra. Duplicates of these specimens have been lodged in the herbarium of the Department of Forests, Lae, and, where sufficient material was available, distributed to selected overseas herbaria, notably Leiden. The Division of Forest Products, CSIRO, gave valuable assistance in determining difficult wood samples.

The average number of trees per acre for individual species and for all species, and estimated timber volumes, were all obtained by analysis of the data for each forest type. Timber volumes were based on a form factor of 0·5 and, being accepted or rejected on external characteristics, did not include any allowance for internal defects. An average volume figure for all species that were recorded only once in a forest type was used in estimating the timber volume per acre of these species.

Data recorded in respect of each forest type sampled were extrapolated using air-photo interpretation, and the areas quoted were measured on the dot grid system using the forest resources map as a base.

III. Classification

(a) Broad Grouping

For forestry purposes the area has been subdivided into three broad groups: productive forest on gentle topography; productive forest on steep or rugged topography; and other areas.

(i) *Productive Forest on Gentle Topography.*—This group comprises forest that has a minimum stocking rate of 3000 super ft per ac of commercial size timber and is situated on flat or gently undulating land where the general slope is not greater than 30% and dissection is only slight to moderate. The total area of forest, including mangrove, in this group is approximately 980 sq miles.

(ii) *Productive Forest on Steep or Rugged Topography.*—Forest in this group has a minimum stocking rate of 3000 super ft per ac of commercial size timber but is situated on areas with general slope of more than 30% or on severely dissected terrain. This group covers an area of approximately 620 sq miles.

(iii) *Other Areas.*—These include all areas of forested and unforested land not included in groups (i) and (ii). This group covers an area of approximately 3000 sq miles. The unforested areas comprise young regrowth stages, grassland, and various swamp communities.

(b) Forest Types

The productive forests have been classified into forest types. These are listed in Table 13 together with their topographic conditions, areal extent, and estimated timber volume, and are shown on the forest resources map. There is a close relationship between these forest types and the forest communities described in Part VI. Since forest mapping has been guided largely by timber volume, the areas of the forest types are generally smaller than those covered by the corresponding forest vegetation communities, which include secondary vegetation and poor stands of no commercial value.

TABLE 13

FOREST TYPES OF THE WEWAK–LOWER SEPIK AREA

Forest Type	Topography	Area (sq miles)	Volume (super ft/ac)
Lower montane rain forest	Steep, rugged	2	4000
Lower ranges forest	Steep, rugged	410	14,000
Lowland hill forest	Steep or rugged	210	5000
Lowland hill forest	Gentle	590	5000
Well-drained alluvium forest	Gentle	80	12,000
Mixed flood-plain forest	Gentle	170	3500
Dense *Campnosperma* forest	Gentle	10	8500
Open *Campnosperma* forest	Gentle	40	3500
Mangrove	Gentle	90	n.d.

IV. Description of Forest Types

In the following descriptions tree species names are only occasionally mentioned. The distribution over the forest types of all tree species recorded that attain a girth at breast height of 5 ft or more is shown in alphabetical order in Table 14. In cases where species names are unknown the local name in Amele language (Madang District) is bracketed beside the generic name.

TABLE 14

TREES RECORDED AND THEIR FREQUENCY OF OCCURRENCE IN EACH FOREST TYPE

D, dominant, 50% or more; LD, locally dominant; C, common, 10–15%; O, occasional, 5–10%; R, rare, <5%

Botanical Name	Lower Montane Rain Forest	Lower Ranges Forest	Lowland Hill Forest	Well-drained Alluvium Forest	Mixed Flood-plain Forest	Dense *Campnosperma* Forest	Open *Campnosperma* Forest	Mangrove
Adinandra sp.	R	R						
Aegiceras corniculatum								LD
Aglaia spp.			R					
Ailanthus integrifolia			R					
Albizia falcata		R						
Aleurites moluccana				R				
Alphitonia incana		R						
Alstonia scholaris		R	O	C	C			
Alstonia sp.			R					
Araucaria cunninghamii	O							
Artocarpus altilis		R	O	C	C			
Avicennia eucalyptifolia								LD
Barringtonia spp.			R	R	R			
Bischofia javanica					O			
Bombax ceiba			R					
Brownlowia argentata								C
Bruguiera gymnorrhiza								D
Buchanania spp.			O	O	R			
Campnosperma brevipetiolata				R	C	D	D	

TABLE 14 (*Continued*)

Botanical Name	Lower Montane Rain Forest	Lower Ranges Forest	Low-land Hill Forest	Well-drained Alluvium Forest	Mixed Flood-plain Forest	Dense *Campno-sperma* Forest	Open *Campno-sperma* Forest	Man-grove
Cananga odorata		R		R				
Canarium spp.		C	C	O	O			
Casearia sp.		R						
Castanopsis acuminatissima	C	O						
Casuarina sp.			R					
Celtis nymanii			O	C	C			
Celtis philippensis		C	C	C	R			
Celtis latifolia			O	C				
Celtis sp.			R	R				
Ceratopetalum succirubrum		R						
Cerbera floribunda		R	R					
Chisocheton spp.		R		O	R			
Chrysophyllum lanceolatum		R	O	C	R			
Cryptocarya spp.	C	O	R					
Dillenia papuana					R			
Dillenia sp.		O						
Diospyros sp.		R						
Dolichandrone spathacea								C
Dracontomelum dao			O	O	O			
Dracontomelum mangiferum		R	O	C	O			
Dysoxylum spp.		O	C	C	R			
Elaeocarpus spp.	C	R	O					
Endospermum sp.			R					
Engelhardia rigida	R							
Erythrina sp.					R			
Erythroxylon ecarinatum		R						
Euodia spp.	R	O	R					
Ficus spp.		O	O	C	C			
Ficus sp. (strangler)		R	C	O	C			
Firmiana papuana			R					
Flindersia spp.			C					
Galbulimima belgraveana	R							
Garcinia subtilininervis					R			
Garcinia spp.		O			R			
Garuga floribunda			R					
Gmelina sp.	R	R						
Gonocaryum sp.	R							
Gordonia papuana		R						
Gynotroches axillaris					R			
Harpullia sp.			R					
Hernandia ovigera			R	R				
Homalium sp.		O	O					
Horsfieldia spp.		R	R		C			
Ilex sp.		R	R					
Intsia bijuga		R	C	O				
Kingiodendron alternifolium			R	R				
Laportea sp.			R					
Litsea spp.	O	C	R		R			
Macaranga spp.			R					
Mangifera spp.		O	R					

TABLE 14 (*Continued*)

Botanical Name	Lower Montane Rain Forest	Lower Ranges Forest	Low-land Hill Forest	Well-drained Alluvium Forest	Mixed Flood-plain Forest	Dense *Campno-sperma* Forest	Open *Campno-sperma* Forest	Man-grove
Maniltoa spp.			O	R	O			
Metroxylon sagu						D	D	
Microcos sp.			R	R				
Myristica spp.		R	O	R	C			
Nauclea sp.				R	C			
Neonauclea spp.		O	R	R	R			
Nypa fruticans								C
Octomeles sumatrana			R	C	C			
Opocunonia kaniensis	O							
?*Owenia* sp.		R						
Palaquium spp.			R		R			
Pangium edule		R	O	R				
Parartocarpus venenosus		R	R	R				
Parinari sp.		C	R					
Pimeleodendron amboinicum			O	O	R			
Pisonia sp.				R				
Planchonella spp.		O	O	C	R			
Planchonia papuana		R	R	O	O			
Podocarpus neriifolius	O	R						
Polyalthia spp.			R		R			
Pometia pinnata		R	C	C	C			
Pometia tomentosa		C						
Prainea papuana		R						
Pterocarpus indicus		R	O	O	O			
Pterocymbium beccarii		R	O					
Pterygota horsfieldii			R					
Pygeum sp.		R						
Rhizophora sp.								D
Sapium indicum					R			
Schizomeria spp.	C							
Semecarpus spp.			R	R	R			
Serianthes dilmyi			O					
Siphonodon sp.	R							
Sloanea spp.		O	O	C	R			
Sonneratia caseolaris								LD
Spondias dulcis			O	O	O			
Sterculia spp.		R	O	O	C			
Syzygium spp.	C	C	C	O	R			
Terminalia kaernbachii		R	C		R			
Terminalia spp.		O	O	C	C			
Teysmanniodendron bogoriense				C	C			
Thespesia sp.			R					
Toona sp.			O					
Tristiropsis sp.		C	O	O				
Vitex cofassus		O	C	C	R			
Xanthophyllum papuanum		O	O		R			
Xylopia sp.			O					
Icacinaceae (J.125)			R	R				
Leguminosae (J.27)		R	R	R				
Myristicaceae ("dahol")		R	R	R	C			

(*a*) *Lower Montane Rain Forest*

This forest type covers 2 sq miles on steep and rugged land occurring above 3500 ft altitude on Mt. Turu and Mt. Wesagunimi. The forest is analogous to the lower montane rain forest of Part VI found on Turu land system.

It attains a height of 80 to 100 ft and boles, though straight, are short and slender. No detailed stand assessment has been made but a visual estimate of 8 trees per ac would give 4000 super ft per ac of mixed species composition. The presence of *Araucaria cunninghamii* is reported on the coastal side of the range.

(*b*) *Lower Ranges Forest*

This type covers 410 sq miles on steep and rugged land below 3500 ft altitude on the Prince Alexander Mountains and on Kairiru Island. The ecotone between this higher-rainfall forest and the lowland hill forest is broad. The eastern boundary of Nagapam land system has been chosen as the boundary of the lower ranges forest and thus the ecotonal forest falls into lowland hill forest. Lower montane rain forest elements enter the forest at higher altitudes. The lower ranges forest is equivalent to its synonym in Part VI, which occurs in Turu, Nagapam, Imbia, Kumbusaki, and Wonginara land systems.

The forest attains a mean height of 100 ft and boles are straight and long. Approximately 14 trees per ac produce 14,000 super ft per ac. Species composition is very mixed, the most common trees being *Parinari*, *Syzygium*, *Pometia* ("bamara"), *Litsea* ("haluna"), *Canarium* ("enal"), *Celtis philippensis*, and *Tristiropsis*.

(*c*) *Lowland Hill Forest*

This type of forest covers 590 sq miles on gentle topography and 210 sq miles on steep or rugged land. These two categories are shown separately on the forest resources map. Typical aspects of this forest are shown in Plate 5, Figure 1, and Plate 7, Figure 1. The greater part of the forest extends from the eastern boundary of the lower ranges forest across Numoikum, Passam, and Tring hills to the Angoram hills. Isolated occurrences are found on the southern foothills of the Prince Alexander Mountains, in the northern and central parts of the middle Sepik grass plain, on the higher parts of the Ramu flood-plain, and on Muschu Island. It comprises the climatically drier and/or anthropogenically disturbed hill forest below 1500 ft altitude. Because of the scale of mapping used, some alluvium forest is included, particularly in the Angoram hills area and in the gully forests of the middle Sepik plain. The forest corresponds to the lowland hill forest in Part VI and is found in a large number of land systems (Numoiken, Kaboibis, Senambila, Wonginara, Passoram, Winge, Muschu, Kworo, Yambi, and Bosman).

The height of the forest is 100 to 120 ft, with a few emergent trees reaching 140 ft. Boles are generally straight and large in girth. Density, however, is low, approximately 6 trees per ac producing an average of 5000 super ft per ac. The density and stocking rate figures vary considerably from as high as 9 trees per ac producing 8000 super ft per ac near Prince Alexander Mountains to 4 to 5 trees per ac in the Angoram hills producing barely 3000 super ft per ac. Species composition is mixed but *Intsia bijuga* often becomes locally dominant.*

The most commonly occurring species are *Intsia bijuga, Celtis philippensis, Pometia pinnata, Dysoxylum* sp. ("toamek"), *Canarium* spp., *Vitex cofassus, Syzygium* sp., *Ficus* spp., *Flindersia* sp., and *Terminalia kaernbachii.*

(*d*) *Well-drained Alluvium Forest*

This type covers 80 sq miles on gentle topography. Its main occurrences are on the deltaic plain of the Sowam River and on the coastal plain a few miles west of Wewak. Many small areas occur along the coastal rivers and the upper and middle river courses of the middle Sepik plain. There are three areas along the edge of the lower Sepik flood-plain. The forest is located on better-drained areas of Nagam land system and is equivalent to the well-drained alluvium forest in Part VI.

The canopy level is 100 to 120 ft in height with some emergent trees reaching 140 ft. Boles are generally straight, long, and large in girth with notable exceptions such as the often twisted and low-branching *Pometia pinnata,* which tends to lower the expected stocking rate. Up to 14 trees per ac can produce 12,000 super ft per ac. The composition of the forest is mixed. *Pometia pinnata,* though often locally abundant, is commonly present throughout the forest and comprises 20% of the trees present. Other species of common occurrence are *Alstonia scholaris, Artocarpus incisus, Celtis* spp., *Ficus* spp., and *Teysmanniodendron bogoriense.*

(*e*) *Mixed Flood-plain Forest*

This type covers 170 sq miles on gentle topography. It is found mainly on the middle and lower river courses of the middle Sepik plain and on the levees and their back slopes along the Keram River and Pora Pora Creek. Other isolated occurrences are found on the coastal plain near the Sowam and Hawain Rivers and on the lower Sepik flood-plain. The forest is equivalent to the mixed flood-plain forest in Part VI occurring on the wetter part of Nagam land system, in Misinki land system, and in small areas of Pandago land system.

It is similar in many respects to the well-drained alluvium forest. The mixed flood-plain forest is lower in overall height, boles are shorter in length and smaller in girth, and tall palms are common. The canopy has a mean height of 60 ft and is often laced with rattan palms. The average stocking rate is low, 3500 super ft per ac from 5 to 6 trees per ac. Species composition is mixed, no single species contributing more than 5% of trees present.

(*f*) Campnosperma *Forest*

This type covers 50 sq miles on gentle topography. It is located on the flood-plains of the lower Sepik and lower Ramu east of the Keram River, and mainly between the latter and Pora Pora Creek. The forest is swampy in nature and the water-table

* Aerial photographs taken during the dry season often exhibit a distinctive pattern of lighter-coloured crowns. Contributing to this pattern are seasonally deciduous trees, notably Sterculiaceae, which are characteristic components of lowland hill forest.

is near the surface in the dry season, and may be up to 4 ft above the surface in the wet. It is equivalent to the *Campnosperma* forest in Part VI found on part of Pora land system. *Campnosperma* forest was not investigated in the field and estimates are based on data for a similar forest type occurring in the Ramu valley.*

The forest has been divided into two subtypes, which were mapped separately.

(i) *Dense* Campnosperma *Forest*.—This covers 10 sq miles. The forest has an overall height of 60 to 70 ft and consists of two layers. The uppermost is a pure dense stand of *Campnosperma brevipetiolata* exhibiting a very distinctive air-photo pattern. The under-layer is sago. Approximately 16 trees per ac produce 8000 super ft per ac.

(ii) *Open* Campnosperma *Forest*.—This covers 40 sq miles and differs from the above subtype in that it has an open layer of *Campnosperma brevipetiolata* with an under-layer of sago. Approximately 6 trees per ac give 3500 super ft per ac.

(*g*) *Mangrove*

This type covers an area of 90 sq miles on gentle topography of tidal flats and fringing tidal creeks near the Murik lakes and Watam. It is equivalent to the mangrove woodland in Part VI, found in Murik land system. The figure quoted for area includes virtually all mangrove communities, but since mangrove attains its best development in a narrow (1 chain) band along the fringe of lagoons and tidal creeks, this figure is not a reliable indication of potential.

Avicennia eucalyptifolia is the main species on sandy spits near the coastline. On the shelving fringe of mud flats, where there is a mid to high tide rise of 2 ft, a short stand of *Aegiceras corniculatum* is found. Where the rise is only 1 ft, *Bruguiera gymnorrhiza* forms an almost pure stand (60–70 ft high) of trees up to 5 ft in girth and 10–15 ft apart. Inland along the upper reaches of tidal creeks *Sonneratia caseolaris*, individuals of which may reach 80 ft in height, is often dominant, associated with *Rhizophora* sp., *Nypa fruticans*, *Brownlowia argentata*, and other swamp-inhabiting species.

* Lands of the Lower Ramu–Atitau area, New Guinea. CSIRO Aust. Div. Land Res. Reg. Surv. divl Rep. 59/1 (unpublished).

PART VIII. POPULATION, LAND USE, AND TRANSPORT IN THE WEWAK–LOWER SEPIK AREA

By J. R. McAlpine*

I. Population

Indigenous Melanesian population data have been obtained from the quasi-annual censuses by village assembly of the Sepik District for 1959–60. McArthur (1955) has dealt with the inconsistencies and qualified the reliability of these censuses, but the village population totals given are considered sufficiently reliable for the purpose of this report.

The non-indigenous population is recorded only for the Sepik District as a whole; an estimation of the proportion residing within the area surveyed has been made.

The population is: indigenous† 76,000 (1959–60); non-indigenous‡ 800 (1961); imported labour§ 400 (1963–64).

Because of changes in census division and subdistrict boundaries, and the inclusion of estimates for uncounted population in some subdistricts, figures for population increase are difficult to determine. It appears that no census division has an average annual increase of less than 1·8%, whilst the average for the whole survey area is in excess of 2%. Increases in excess of 3% per annum occur in two census divisions near Maprik.

The indigenous population, which resides in village and hamlet settlements, is engaged chiefly in subsistence cultivation and sago processing, except for an estimated 5000 people employed for wages outside the district and 2000 within it. Other sources of non-subsistence income derived by the indigenous population are cash cropping and the production of wood carvings for sale. The non-indigenous population, of which 560 reside in the township of Wewak, is engaged chiefly in government, mission, and trading activity.

The overall population density of the area surveyed is 17 persons per sq mile. The uneven distribution of the population is indicated on the land use–population distribution map. The heaviest concentrations are found in the Maprik–Yangoru area, the western coastal fringe, and along the banks of the Sepik River. Locally, within the Maprik area Lea (1965) has found densities on tribal lands to reach over 400 persons per sq mile, the highest recorded in the lowlands of New Guinea.

* Division of Land Research, CSIRO, Canberra.

† Source: 1959–60 census of villages listed in the "Village Directory, 1960", Department of Native Affairs, Port Moresby.

‡ Source: Based on figures listed in Territory of New Guinea Report for 1963–64, Commonwealth of Australia.

§ Source: Estimate based on figures listed in Labour Information Bulletin No. 2, March 1965, Department of Labour, T.P.N.G.

Detailed descriptions of ethnography are outside the scope of this Part, but the reader is referred to the Sepik District Anthropological Bibliography (Anon. 1968). The great diversity of cultural groupings of the indigenous population is indicated very broadly by Capell's (1962) language distribution map (Fig. 9). A comparison of Capell's map with the accompanying population–land use map and Figure 10 indicates a close correlation between language groups and physical environmental types in conjunction with land use.

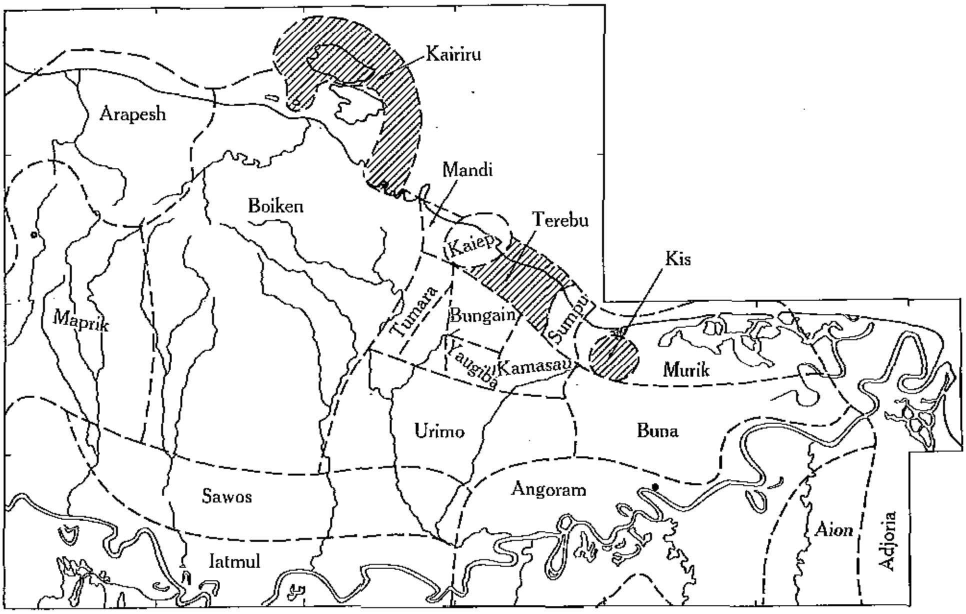

Fig. 9.—Distribution of languages after Capell (1962). The shaded areas indicate Melanesian languages.

II. Land Use

(a) *Subsistence Cultivation*

The main type of agricultural land use is subsistence cultivation based chiefly on root crops. The system of subsistence cultivation can be described as bush fallowing and not as true shifting cultivation (the general limitations of these terms are discussed by Brookfield and Brown (1963) and Barrau (1958)). New gardens are prepared annually, while the garden rotation cycle is restricted to clearly defined areas near villages. Harvesting usually takes place over a one- to two-year period.

The main crops cultivated are yam (*Dioscorea esculenta, D. bulbifera*), including giant yams (*Dioscorea alata*) in the Maprik area, taro (*Colocasia esculenta*), sweet potatoes (*Ipomoea batatas*), bananas (*Musa* spp.), taro "kongkong" (*Xanthosoma sagittifolia*), cassava (*Manihot esculenta*), sugar-cane (*Saccharum officinarum*), edible pit-pit (*Saccharum edule*), papaw (*Carica papaya*), and winged beans (*Psophocarpus tetraglobus*). Additionally, maize, tomatoes, pineapples, peanuts, cucurbits, and various other recently introduced crops are planted in small amounts. All villages also plant coconuts (*Cocos nucifera*) and breadfruit (*Artocarpus atilis*).

(*b*) *Sago*

Sago (*Metroxylon sagu*) forms a substantial, but regionally variable, part of the diet of the population in this area. Oomen (1959) states that 38% of the average adult calorie intake at Tambunam, a Sepik River village, comes from sago. Lea

Environmental type	Forested alluvial plain	Forested mountains	Forested and grass-covered hills		Rolling to flat grassland plains separated by forested alluvial plains		Sago, grass, forest, and mangrove separated by forested alluvial plains	
Subtype			Steeper hills	Gentler hills	Grassland plains	Inland alluvial plains		
Main land forms used	Beach ridges, raised coral, alluvial plain, fans	Broader rounded crests and upper hill slopes (also low intramontane basins)	Ridge crests and upper hill slopes	Lower rounded ridges		Wide and narrow flood-plains and higher terraces	Sago swamps (as food source)	Higher levees and scrolls
Population density Overall	40	10	40		7	30	0	120
On used land	400	90	160		0	150	0	>200
Land use Percentage	24	10	25		2	15	0	40
Intensity	Moderate	Moderate to low	High to moderate		Moderate	High to moderate		Very high

Fig. 10.—Land use in relation to environment.

(1964) found that the sago calorie contribution of the diet of Stapikum and Yenigo villages, near Maprik, is respectively 5·3% and 24·5% in August, rising to 70·0% and 46·3% in March. Lea stresses not only the seasonal but local variations in diet (and hence cropping) indicated by these and other figures. Generally, along the Sepik River sago is collected and processed from natural stands (shown on the land use and population distribution map), while elsewhere it is usually processed from planted palms.

The distribution of population along the Sepik River in relation to natural stands of sago is important in explaining the barter trade system in this area, referred to by Henry and Muia (1959). River villages which have little or no access to sago, because of land ownership and usufructuary rights, trade fish for sago from those villages that own the sago stands, which are normally some distance from the main river.

(c) *Cash Cropping and Non-indigenous Plantations*

The development of cash cropping had only recently commenced when the survey was made in 1959. Since then, extension of crop areas has been continuous, resulting in the following areas* for the year 1964–65:

Crop	Area (ac)
Coffee (robusta)	1300
Cacao	200
Rice (upland)	600
Coconuts	1800

These areas have not actually been measured. Figures given for coffee and cacao are based on tree counts converted to acreage, and those for rice and coconuts are based on rice and copra commercial production converted to acreage at the production rate of 8 cwt per ac. Since coconuts are used for subsistence in addition to cash cropping, total acreage for this crop is much larger than indicated. Cash cropping of cacao and coconuts is restricted almost solely to the coastal zone. Rice production is centred in the Maprik area. Coffee plantings are distributed throughout Wewak subdistrict and the hilly regions of Maprik subdistrict. Small recent coffee plantings have been made in the Sepik plains region and near Angoram. To a large degree the distribution and intensity of cash cropping are correlated with better transport facilities (Fig. 11).

Non-indigenous plantations cover only 2624† acres for the Sepik District as a whole and produced 537† tons of copra in the year ended March 31, 1964. Approximately half of this area lies in the area surveyed and is mission owned.

(d) *Distribution and Intensity of Land Use*

Information on distribution of land use was obtained by air-photo interpretation. Data on land use intensity are derived partly from aerial photos and partly from very limited field observations, official statistics, and reference to the literature, particularly Lea (1964, 1965). The small scale of the aerial photos and map precludes mapping of individual gardens and small patches of regrowth. Thus, the four land use intensity classes shown on the accompanying map represent distinct photo patterns consisting of varying areal proportions of primary vegetation, anthro-

* Figures supplied by Department of Agriculture, Stock, and Fisheries (areas include mature and immature trees).

† Source: Rural industries production. Bull. Bur. Statist. T.P.N.G. No. 6, 1964.

pogenous vegetation, and cultivation. In the interpretation of the air photos, older secondary forest and grassland have been included with primary vegetation, except in those few peripheral grassland areas where gardens are found. Although both vegetation types are in fact anthropogenous vegetation, advanced secondary forest is very difficult to distinguish from primary forest at the air-photo scale used, whilst the grasslands are related to past cycles of land occupation (Reiner and Robbins 1964) and play little part in present-day land use.

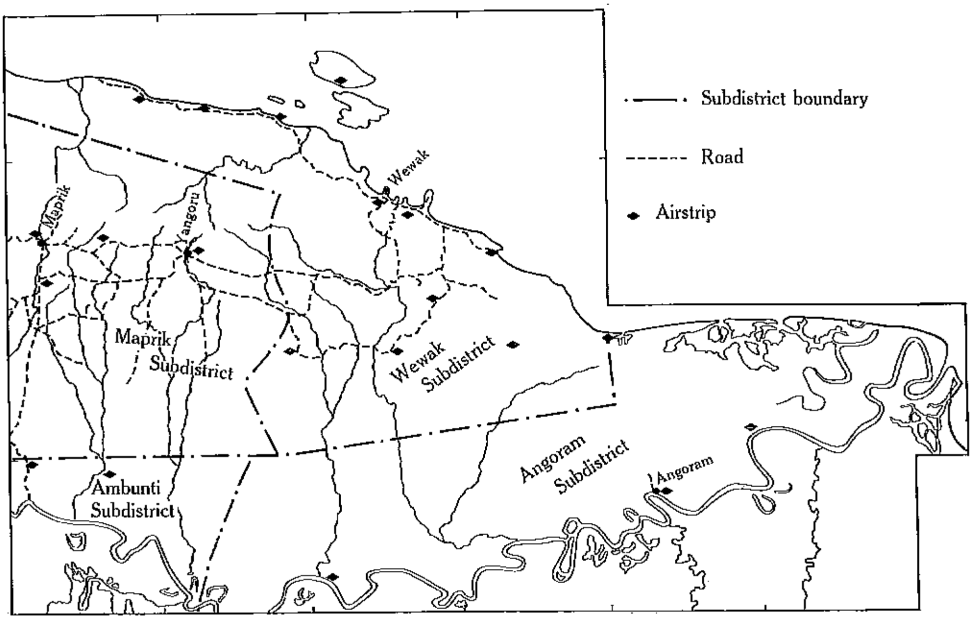

Fig. 11.—Administrative divisions and transport facilities.

The percentage ranges of the land use intensity classes are modal and hence do not include extremes. It must be emphasized that only in two village areas near Maprik (Lea 1964) are there any field observations to support the air-photo interpretation. The grouping of percentages used is designed solely to present a reasonable indication of overall land use intensity at the scale used, and the class criteria have no other significance apart from this. Class 1 distinguishes the areas of very intensive use of river terraces and levees. Class 2 delineates areas of high-intensity use associated with high population density. It should be noted that in class 2 the percentage of anthropogenous vegetation may be higher than 75% but the proportion of land in cultivation is always lower than in class 1. Class 3 may be considered as the "norm" of subsistence agriculture land use intensity for lowland areas in New Guinea. Class 4 may indicate areas of recent outward migration, very scattered land use in difficult mountain terrain, or the limit of air-photo interpretation of land use at this scale.

The area of land comprising all the land use intensity classes is 375 sq miles or 8% of the area surveyed.

TABLE 15

POPULATION AND LAND USE WITHIN LAND SYSTEMS

Land System	Area (sq miles)	Population: Total	Population: Density per sq mile on Land Used	% Use of Land System	Land Use — Intensity of Area Used on Land System (sq miles): Very High	High	Medium	Low
Intensively used								
Yangoru	9	1200	133	100	—	9	—	—
But	8	2600	371	90	<1	2	5	—
Kaboibis	160	15,800	128	77	—	118	5	—
Moderately used								
Palimbai	40	4100	300	35*	7*	8*	—	—
Winge	65	3700	160	35	—	17	6	—
Imbia	25	700	87	32	—	1	7	—
Nubia	15	2300	575	30	—	<1	4	—
Madang	11	1500	500	27	—	<1	3	—
Lightly to moderately used								
Muschu	12	500	250	17	—	—	2	—
Numoiken	140	3100	155	14	—	—	20	—
Nagam	340	7100	157	13	7	18	17	3
Wonginara	35	1000	250	11	—	<1	4	—
Passoram	550	14,500	246	11	—	38	19	2
Lightly used								
Nagapam	250	1300	59	9	—	3	2	17
Senambila	160	2000	181	7	—	—	6	5
Misinki	35	600	300	6*	—	2*	—	—
Turu	170	300	37	5	—	1	7	—
Kworo	390	3300	194	4	—	2	15	—
Little used or unused								
Sanai	580	5500	500	2*	5*	6*	—	—
Yambi	600	4400	773	1	—	—	6	—
Kobar	220	400	400	<1*	—	—	<1*	—
Murik	100	400	400	<1*	—	—	<1*	—
Kumbusaki	13	—	—	—	—	—	—	—
Bosman	80	—	—	—	—	—	—	—
Pandago†	260	—	—	—	—	—	—	—
Pora	120	—	—	—	—	—	—	—
Kabuk	200	—	—	—	—	—	—	—

* Estimated only, photo scale precludes measurement.

† Main sago source for Sepik River people.

III. Relations between Population, Land Use, and Environment

(a) *Land Use in Relation to Land Form*

The detailed relationships between land use and land forms are given in the tabular descriptions of the land systems of Part II, where land use is directly related to the units of the land systems. A broader schematic correlation between land use and environment is presented in Figure 10, based on the environmental types discussed in Part II and shown in Figure 3.

(b) *Population and Land Use in Relation to Land Systems*

Table 15 lists the population and areas of the four land use intensity classes for the land systems in order of decreasing percentage of use.

Additionally, the table gives population density figures for each land system based on the sum of the unweighted areas of the different land use intensity classes. These densities form a continuum within which three broad categories may be distinguished. Land systems with densities below 100 persons per sq mile indicate that part of the land is used by persons living on adjoining land systems (Imbia and Turu), or that use is very light and disperse (Nagapam), or that recent outward migration has left large areas of secondary growth (Nagapam and Turu). Densities between 101 and 250 generally indicate an increasing intensity of use within the land mapped as used for each land system. In considering this category two modifications must be made. The density of Nagam land system rises to 240 persons per sq mile, if the population on Yambi land system that uses Nagam land system is included. On Muschu land system the population also gains subsistence from fishing. Densities over 250 persons per sq mile indicate other sources of subsistence than use of the land system in which the population resides. The populations of Nubia, Madang, But, Kobar, and Murik land systems derive part of their subsistence diet from the sea and from surrounding land systems. The population on Yambi land system, as stated above, carries out most of its cultivation on adjoining sections of Nagam land system. The population on Palimbai and Sanai land systems depends to a large degree on sago for its diet, and hence uses less land per head agriculturally.

IV. Transportation

In comparison with most parts of New Guinea the area is readily accessible. Figure 11 indicates the road and airstrip network. The Wewak–Maprik–Pagwi and coast roads are passable in all seasons. Other roads become virtually impassable, even for four-wheel drive vehicles, after heavy rain because of flooded river crossings and slippery surfaces on mudstone slopes.

In addition to these roads, there are numerous walking tracks that are well maintained in populous areas. However, sparsely populated or unpopulated areas are generally almost inaccessible because of lack of tracks. The major areas of difficult accessibility are the western part of the Prince Alexander Mountains, the hills between Angoram and Tring, and the eastern sector of the grassland plains.

The Sepik River forms another important internal traffic artery. It has no appreciable bar at its mouth and is navigable for at least 300 miles upstream by small seagoing vessels throughout the year. Snags, which are particularly common during periods of receding floods, form the main obstacle to navigation. Of its tributaries, the Yuat and Keram Rivers, Pora Pora Creek, and several of the larger channels through the swamps are navigable by smaller vessels, whilst nearly every part of the swamps is accessible by canoe. Aquatic vegetation and floating grass frequently block these waterways, especially the smaller ones.

External communication with the area is by sea and air only. Wewak is the only port, but is of insufficient depth to allow large ships to berth at wharves. Cargo is handled by lighterage. During the year ended June 1964, 53 vessels discharged 20,308 tons, whilst 51 vessels cleared the port with 8739 tons laden.* The nature of the coastline precludes first-class anchorages and the anchorages that do exist are frequently made difficult by coral reefs. The only exception to this is the mouth of the Sepik River, which provides year-round shelter for shipping.

Air transport is the major external passenger service within the area and is also important internally in this respect. There are at least 20 airstrips, of which only Wewak, under D.C.A. control, handles other than light aircraft. Five airstrips are under Administration control, whilst the remainder are privately operated. For the year ended June 1964, Wewak airport handled 19,460 passengers and 1194 short tons of freight in 4656 aircraft movements.*

V. Acknowledgment

The advice of Dr. D. A. M. Lea, of the Geography Department, Monash University, Vic., is greatly appreciated. However, the author accepts complete responsibility for the figures given.

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* Source: Transport and communications. Bull. Bur. Statist. T.P.N.G. No. 2, 1965.

PART IX. LAND USE CAPABILITY OF THE WEWAK–LOWER SEPIK AREA

By H. A. Haantjens*

I. Introduction

Within the survey area there is an enormous variability in land types, with many different combinations of factors that impose limitations upon, or present problems for, agricultural development. Moreover, these land characteristics commonly vary over short distances, and there is generally a complex distribution pattern of the many types. As a result the land systems, although each has its characteristic dominant type of land use capability, embrace smaller or larger areas of land with slightly or strongly different characteristics. In order to give the most accurate and quantitative account possible of the land use capability of the area as a whole, all land has been grouped in this Part according to its similarities in land use potential, irrespective of the land systems in which it occurs. To preserve a broad picture and avoid having too many separate categories, the land use groups described in this Part are still rather broad units, each accommodating several types of land with minor differences in land use capability.

Readers who are interested in the land use potential of particular land systems rather than that of the area as a whole should refer to the assessment given at the bottom of each land system description in Part II.

Some additional aspects of land use capability in relation to climate are discussed in Part III. Others, in relation to soil fertility, are mentioned in Part V.

II. Land Use Capability Categories

All land has been grouped into six categories, which have been subdivided into 16 groups. The categories indicate, and are arranged in order of, increasing limitations or problems imposed on land use. They have been adapted from the system of eight land classes (I–VIII) used by the United States Soil Conservation Service (Klingebiel and Montgomery 1961). In that system, classes I–IV are suitable for permanent cultivation (I without limitations, II and III with slight to moderate limitations, and IV as marginal arable land), whilst classes V–VIII are unsuitable for cultivation (V for good pasture land, VI with moderate limitations for pastures, VII marginal for pastures, and VIII unsuitable for any form of agriculture). For the purposes of this report, the suitability of land for tree crops and for wet rice-growing and the possibilities of major land reclamation have been incorporated in the American system (Haantjens 1963).

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TABLE

DISTRIBUTION AND NATURE OF LAND USE

Potential is indicated as H (high), M (moderate), L (low), S (potential for sago production),

Estimated Area of Land Use Capability Groups in Land Systems (sq miles)																										
Turu	Nagapam	Imbia	Numoiken	Kaboibis	Yangoru	Wonginara	Kumbusaki	Winge	Senambila	Passoram	Muschu	Kworo	Yambi	Bosman	Madang	Nubia	But	Nagam	Misinki	Palimbai	Pandago	Kabuk	Sanai	Pora	Kobar	Murik
				4	1		1	4			3				5		2	61								
									2			15	4		3	7	2	170								
7				14				26	15	12	2	24	38	22			3									
									14	13		4														
																		57	10	10						
								1	5	59		55	294	40												
									5	58		272	236	10												
										12				8		2		25	23	20			5			
9	20		10	84		14		25	40	381	2	6	12				1									
			12			3			10	47	1															
				3	1				1	8		5	6					25					15	160		
100	221	20	118	55	7	16	11	8	66	42	4															
												12			2											
															1				2	10	100	200		100		
54	9	5							3	13					1											
																		2					560		220	100

† Only in Pandago land system.

16

CAPABILITY CATEGORIES AND GROUPS

F (potential for fish ponds). * Recommended land use. ( ), Potential after land reclamation

Total Area (sq miles)	(%)	Land Use Capability Category and Group	Principal Limitations for Development	Potential for: Arable Crops	Tree Crops	Improved Pastures	Wet Rice	Forestry	Sago, Fisheries
		Land without limitations or with only minor soil problems	Land class I, some II. None or slightly droughty or slowly permeable soils	H*	H	H	L	H	
		Land with slight limitations	Land classes II and III						
200	4·5	Poorly drained level land	Slight to moderate surface drainage problems	H*	M	H*	M	H	
160	3·5	Sloping land	Slight to moderate erosion hazards	M*	H*	H*		H	
30	0·7	Sloping land with poor soils	Serious fertility problems and slight erosion hazards	M*	M*	M*		H	
		Land with moderate limitations	Land class IV, little III						
80	1·5	Level land subject to minor flooding	Shallow flooding, short and rare or predictable; commonly poor surface drainage	L(H)	L(M)	M*(H)		H	
450	10	Land with physically poor soils	Poor drainage, difficult to improve because of slow permeability; locally poor surface drainage or slight erosion hazards	L*		M*	M*	L	
580	12	Land with chemically and physically poor soils	Serious fertility problems; poorly drained slowly permeable subsoils and drying topsoils; commonly slight erosion hazards; locally poor surface drainage	L		M*	L	L	
		Land with serious limitations	Land classes V and VI						
100	2	Very poorly drained level land	Serious surface drainage problems; commonly flood hazards	L(M)		M*(H)	M*(H)	L	S
600	13	Steeply sloping land	Serious erosion hazards; locally shallow soils		M*	M*		M*	
70	1·5	Steeply sloping land with physically poor soils	Serious erosion hazards; drainage problems due to slowly permeable soils		L	M*		M*	
220	5	Very poorly drained level land subject to flooding	Rather deep and frequent or prolonged floods; serious surface drainage problems	(M)		L(H)	L(H)		
		Land with very serious limitations	Land class VII						
670	14·5	Very steeply sloping land	Very serious erosion hazards and poor accessibility; commonly shallow soils		L	L		L*	
15	0·3	Land with very poor soils	Gravelly, very infertile soils with slowly permeable subsoils			L*		L	
430	9	Swampy land subject to flooding	Very serious surface drainage problems aggravated by serious flood hazards	(H)		(H)	(M)		S†
		Land without agricultural potential	Land class VIII						
90	2	Very steep or rocky land	Extreme erosion hazards or lack of soil; commonly poor accessibility					L	
880	19	Severely flooded and/or swampy land	Uncontrollable deep and prolonged flooding and/or extreme surface drainage problems						F

The land use capability groups, into which the categories are subdivided, are based on the *nature* of the limitations, because of which land is placed in a particular category.

A summary of the land use capability in the survey area is given in Table 16. This will help in assessing the distribution of the groups on the land system map.

(*a*) *Land without Limitations or with only Minor Soil Problems*

This comprises non-flooded level land with mostly well-drained alluvial soils, which rank amongst the most fertile in the area. Somewhat droughty sandy or shallow soils occur in Madang and Nubia land systems, whilst soil fertility problems may arise in Kaboibis and Winge land systems. Somewhat poorly drained soils with slowly permeable subsoils are found in Winge land system.

This land, which is suitable for a large range of arable and tree crops and for grazing, occurs scattered throughout the area, commonly in small pockets. By far the largest areas are in Nagam land system. It is mostly covered with tall forest of moderate commercial value, but locally is used intensively for garden land. Arable farming is the most recommended form of land use. Rotations with legumes will be needed to maintain a satisfactory nitrogen level, as the soils have generally rather low contents of this plant nutrient.

(*b*) *Land with Slight Limitations*

This is good agricultural land provided simple measures are taken to maintain or increase its productivity.

(i) *Poorly Drained Level Land.*—This comprises level non-flooded land with generally fertile alluvial soils. Drainage can be improved easily by the intensification of surface drainage, but in many areas of fine-textured soils this may be effective only to a limited depth. Although suitable for several types of tree crops, the most recommended land use is mixed farming of arable crops and pastures. There also appear to be good possibilities for wet rice-growing. Minor fertility problems can be expected in Kworo land system, where the soils are not suitable for tree crops.

Much of this land is covered by tall forest of low commercial value. Large areas are found in Nagam land system, associated with land of category (*a*); elsewhere it is found only in small scattered pockets.

(ii) *Sloping Land.*—This comprises land with rather gentle and commonly short slopes, which is suitable for arable cropping provided adequate erosion control measures are taken, such as contour planting, frequent rotations with cover crops and ley pastures, and avoidance of the most erosion-sensitive crops. Land of this group in Turu land system is likely to be rather stony, whilst in Kworo, Yambi, and Bosman land systems the soils are commonly imperfectly drained, because of slowly permeable subsoils. Here, too, a pitted land surface may locally require land grading. The soils are brown forest soils, gleyed forest soils, uniform red clays, and dark colluvial soils, commonly of moderate fertility but least so in Kworo and Yambi land systems. The vegetation ranges from forest to grassland and the land occurs in scattered strips and pockets, usually associated with land of poorer quality. Mixed farming with rotational pastures is the most recommended form of land use, with tree crops on the steepest slopes.

(iii) *Sloping Land with Poor Soils.*—This comprises land with highly leached podzolic and gleyed red and yellow earth soils, which also would require simple measures to protect it from erosion. However, low fertility is the main problem. This group forms an intergrade between group (*b*)(ii) and groups (*c*)(ii) and (iii), and also forms a complex with these groups in its distribution, especially in Senambila and Passoram land systems. Heavy applications of phosphate and potash are necessary if this land is to be used for arable crops. Legumes should play an important role in the crop rotation to maintain nitrogen levels. Lighter fertilizer dressings may be sufficient for the use of this land for grazing or tree crops. Mixed farming appears to be the most suitable type of land use on this land, which is now mostly covered by grassland.

(*c*) *Land with Moderate Limitations*

In general, this category comprises land of which the capability cannot be assessed with certainty. As it constitutes one of the largest categories in the area, there is a clear need for agricultural research on this land. On present indications it is marginal, or hardly even that, for cultivation, but if research leads to positive results land of this category could make a very substantial contribution to the agricultural development of the area.

(i) *Level Land Subject to Minor Flooding.*—Flooding on this land is non-destructive and shallow. It occurs rather rarely or is restricted to a narrowly defined period during the wet season. Although best used for pasture land, arable crops could be grown during the flood-free season. About half of this land is poorly drained and therefore rather unsuitable for perennial tree crops, but it may be possible to grow such crops on well-drained land in this group. In a considerable proportion of this land flood control appears to be relatively easily possible by means of improved surface drainage, low levee banks, and widening of river channels. Such reclaimed land would be suitable for intensive arable cropping. The soils are alluvial and of good fertility. Most of this land is at present covered with dense forest of low commercial value, but in Palimbai land system and locally in Nagam land system it is already fully occupied by native gardens.

(ii) *Land with Physically Poor Soils.*—Poor drainage is the principal limitation to land use. As this is caused by the slow permeability of the heavy clay subsoils of the meadow soils, it appears to be difficult to fully rectify this soil deficiency. However, improved surface drainage, especially on low-lying areas that receive much run-on, may make possible the cultivation of a limited number of crops. A relatively small proportion of this land (mainly in Passoram and Kworo land systems) is gently sloping and also would require simple measures to prevent erosion.

Nearly all of this land is at present under grass. Grazing appears to be the most promising form of land use but, to be successful, would almost certainly involve conversion of the natural grassland into sown pastures and leguminous crops, with simultaneous improvement of the surface drainage. In areas with a slightly pitted surface land grading may be required. Wet rice-growing deserves consideration, especially in the very poorly drained depressions, where sufficient water control may be achieved with simple means. Irrigation commanded by gravity appears to be generally impossible, but on some of the large flat areas of Yambi land system it may be achieved by pumping up water from nearby rivers. Although soil fertility does not appear to be a serious problem, above-average additions of phosphate and potash are likely to be essential for sustained agricultural production.

On present indications, grazing and wet rice-growing would be the most recommended forms of land use, but continued investigations into the possibilities of growing arable crops are strongly recommended as they would give a more stable mixed farming system, possibly based on ley farming. Land of this group commonly occurs in a complex with that of group (*c*)(iii), but is definitely superior in respect of soil fertility and physical conditions.

(iii) *Land with Chemically and Physically Poor Soils*.—The meadow podzolic soils of this group are extremely infertile. The rectification of the deficiencies would be difficult, as fertilizer applications would need to be heavy and residual effects are slight. The soils appear to be particularly lacking in phosphate and potash, but in addition there appear to be trace element deficiencies. As nitrogen levels are generally low, legumes should be an integral part of any agricultural system, but may in turn require liming of these acid soils. The soils are easily waterlogged because of slowly permeable subsoils, whilst coarse-textured topsoils in many areas cause water stress after relatively short periods without rain. To overcome these difficulties it would be necessary to ensure adequate surface drainage, maintain the water-holding capacity of the topsoil at the highest possible level by regular incorporation of organic matter, and search for crops that will penetrate the plastic subsoils with their roots, thus both reducing the waterlogged condition of the land and decreasing water shortage during long dry periods. A large proportion of this land, mainly in Passoram and Kworo land systems, occupies sloping ground and would require careful management, if used for arable crops, to prevent erosion. A small proportion, in Kworo and Yambi land systems, occurs in depressions with swampy conditions where the surface drainage commonly could be easily improved and fertility problems are likely to be somewhat less serious. Finally, much of this land on very gentle slopes has a strongly pitted surface and would require land grading before it could be used either for cropping or grazing.

Grazing, possibly largely based on leguminous pasture crops, appears to offer the best possibilities on most of this land, with a possible gradual increase of arable crops as experience accumulates and land improvement proceeds. Irrigated rice may be grown locally in the poorly drained depressions.

(*d*) *Land with Serious Limitations*

Land of this category is unsuitable for cultivation but has a moderately high potential for grazing, tree crops, or wet rice-growing; or it may be made capable of higher productivity by relatively simple reclamation projects.

(i) *Very Poorly Drained Level Land*.—This group occupies land which, because of its low topographical position and generally heavy clay alluvial soils, cannot be drained sufficiently for arable crops and tree crops. Soil fertility will not be a problem. With rather simple measures to improve the surface drainage, this land could be converted into good pasture land or used for wet rice-growing. In Misinki, Palimbai, and Sanai land systems, flooding is a more serious limitation than drainage and pastures could be used for only about half the year. It may be feasible to keep a large proportion of this land in Misinki land system free from floods, by means of levee banks and increased discharge of river floodwater through channels dug through levee banks into the surrounding swamps. This would open up possibilities for wet rice-growing and the cultivation of a limited range of arable crops.

Land development is handicapped by the dense vegetation of sago palm and mixed flood-plain forest of very low commercial value. Although the sago resources are very limited at present, this land offers excellent growing conditions for this crop if it is planted on cleared land or in thinned-out forest. Much of this land occurs scattered throughout the area and may be developed with land of higher potential in comprehensive development projects.

(ii) *Steeply Sloping Land*.—Erosion hazards are too severe for permanent cultivation on this land with steep but rather short slopes, which is topographically suitable, however, for tree crops and grazing. The soils are mainly brown forest soils of moderate fertility and variable but commonly rather shallow depth. They appear to be suitable for undemanding crops like rubber, but further trials and careful selection of sites are recommended before crops like cocoa are planted on a large scale. Especially on the most shallow soils, moisture conservation by mulching and checking of run-off is required. Most of this land is at present under forest of moderate commercial value, but large areas are being used for shifting cultivation and small areas are under grass. This land is very suitable for native gardening provided the bush fallow rotation is kept to at least eight years, as otherwise there will be a danger of erosion and conversion into grassland. This is now taking place in Kaboibis, Winge, and parts of Passoram land systems. The possibilities of increasing the output of shifting cultivation on this land by extension work appear to be very limited, whilst intensification to permanent cultivation systems would be dangerous.

Recommended land use is a combination of tree crops and grazing, whilst arable agriculture should be restricted to occurrences of land category (*a*) and groups (*b*)(i) and (*b*)(ii), which are found locally associated with land of this group.

(iii) *Steeply Sloping Land with Physically Poor Soils*.—This group is very similar to the previous one, but the rather poorly drained gleyed forest soils with slowly permeable subsoils appear to be unsuitable for tree crops and more exclusively adapted to grazing. Land of this group occurs in small pockets, associated with that of the previous group.

(iv) *Very Poorly Drained Level Land Subject to Flooding*.—This group comprises mainly the least swampy parts of Pandago land system, covered with sago palm communities on fertile, but usually slowly permeable, heavy clay alluvial soils. Apart from sago production, which could be considerably increased by the clearing of forest trees, planting, and proper spacing of good-quality sago palms, this land could also be used as poor pasture land for part of the year, or for the growing of swamp rice. It appears possible to reclaim much of this land by means of flood protection and artificial drainage, but only in major schemes and not by the individual efforts of land users. Such reclaimed land would be very suitable for pastures or wet rice-growing. Arable cropping might present problems on puggy heavy clay soils, but could be successful on areas with medium-textured soils.

Included in this group are narrow strips of regularly flooded alluvial valley floors, where flood protection is impossible and land use must be confined to extensive grazing. Such land is now covered with forest of low value.

(*e*) *Land with Very Serious Limitations*

This land is unsuitable for cultivation and only marginal for grazing or tree crops. Parts of this category could yield very productive land if reclaimed in major schemes, but the technical possibilities of these are doubtful at present.

(i) *Very Steeply Sloping Land.*—Although these lands may be suitable for tree crops or grazing where population pressure is high, they are generally best kept under forest because of the steepness and great length of the slopes. This policy is also desirable from a hydrological point of view, especially in Turu, Nagapam, Imbia, and Numoiken land systems, which constitute the principal water catchments in the survey area. Because of the rugged nature of the terrain and associated poor accessibility, most of this land is difficult even for forest exploitation, although a very large part of it is covered with forests of moderate commercial value.

Although the proportion of this land used for shifting cultivation is small, this nevertheless constitutes a rather high percentage of land used for gardening in the survey area, especially in Numoiken, Kaboibis, and Yangoru land systems. Yet there appears to be no scope for developing a more intensive system of native agriculture on this land and, unless it is decided to maintain the present type of shifting subsistence agriculture, land of this group is better not used for agriculture at all, but given over to reafforestation projects. In this way it could substantially contribute to the local requirements of timber and fuel, especially where it occurs in scattered association with less steep land of groups (*b*)(ii) and (*d*)(ii). Reafforestation may be difficult locally because of the shallowness of the brown forest soils.

(ii) *Land with Very Poor Soils.*—This very small group is characterized by very infertile meadow podzolic soils, with quartz gravel topsoils and slowly permeable subsoils. It can be used only as very poor grazing land and occurs as small scattered patches associated with land of group (*c*)(iii). Included is a small area of very shallow soils on limestone in Madang land system.

(iii) *Swampy Land Subject to Flooding.*—In its present state this land is unsuitable for any agricultural use except the local exploitation of sago resources, but most sago stands are too poor for commercial exploitation.

Plant nutrients have accumulated in these swamps and the organic soils especially, which are very common in this group, possess a high level of chemical fertility. As flooding is not deeper than 4 ft, there are theoretical possibilities of flood protection by levees and the establishment of polders with artificial drainage. The construction of levee banks will be difficult in areas with a thick cover of peat or sloppy clay, whilst care must be taken that the formation of polders does not cause a dangerous rise of floodwater upstream. Empoldering of areas with organic soils is most worth while, because this will make available very productive land that could be used for a large variety of crops. Drainage of these soils should be kept to a minimum, and the possibility of water supply by infiltration during dry periods should be provided in order to prevent undue lowering of the land level by shrinkage and oxidation. Areas of heavy alluvial clay soils may be suitable only for wet rice or grazing. It is clear that these considerations are purely academic at present and might only be investigated more seriously in a distant future, when the area has proceeded to a much higher level of development and the acquisition of additional agricultural land becomes necessary.

(*f*) *Land without Agricultural Potential*

This category comprises land that has such unfavourable characteristics as to be unsuitable for any agricultural development. Land reclamation appears to be impossible.

(i) *Very Steep or Rocky Land.*—This land is either too steep, too rocky, or both to have any potential for development. It occurs scattered throughout the mountainous and hilly parts of the survey area and is mostly covered with rather poor forest.

(ii) *Severely Flooded and/or Swampy Land.*—Part of this land is flooded to a depth of 6–10 ft for up to half of each year, and remains swampy during the drier months. Soils are mostly slowly permeable heavy alluvial clays, but organic soils are also common. As flood control appears to be impossible in these parts of the Sepik flood-plain, nothing can be done to make agricultural development possible.

Land of this group near the coast in Kobar land system is even more swampy, but not subject to large fluctuations of the water level. As this land has no real soils, but only raw peat and organic mud, it may be possible to convert parts into freshwater fish ponds. Similar possibilities for brackish water ponds may exist in the mangrove swamps of Murik land system, where fishing on the tidal lagoons is already an important feature of native livelihood.

III. References

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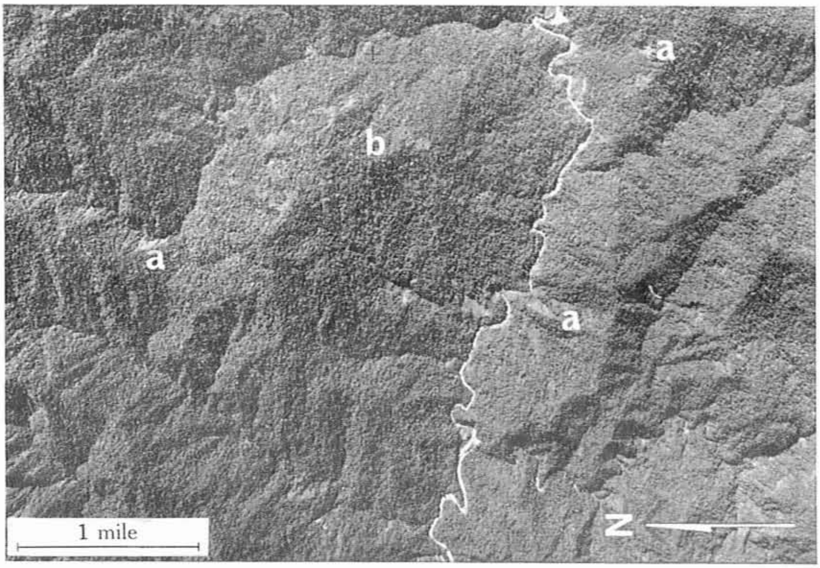

Fig. 1.—Land systems of the mountains. Forest-clad ridges of Nagapam land system on sedimentary rocks. Common small landslide scars (*a*); few signs of previous shifting cultivation (*b*). Dense drainage with much structural control.

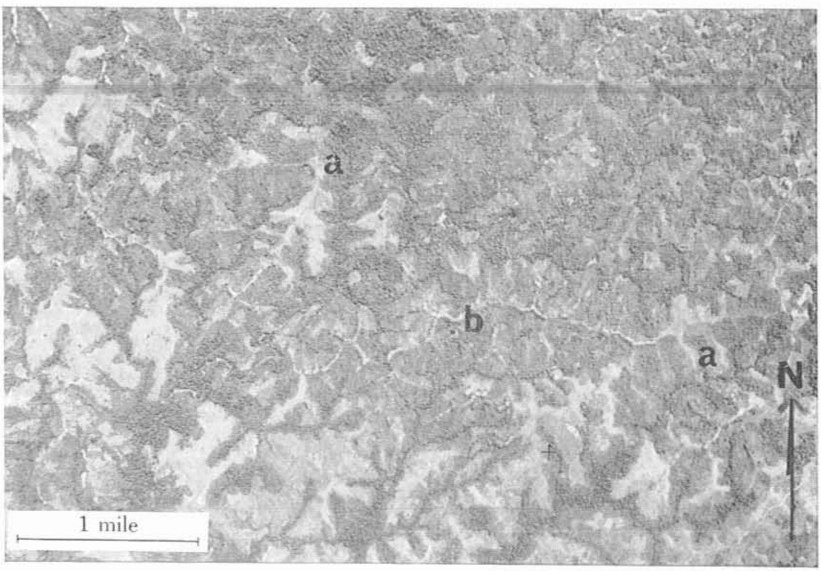

Fig. 2.—Land systems of the hills. Very intricate branching patterns of hill spurs of Kaboibis land system on sedimentary rocks. No original forest left; much grassland, mainly on upper slopes. Colluviated valley heads and valleys (*a*). Strings of villages on crests (*b*).

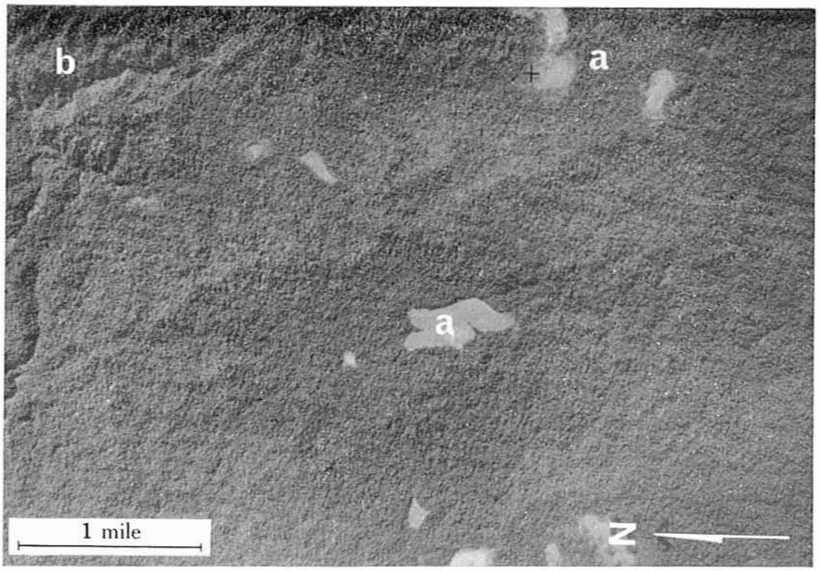

Fig. 1.—Land systems of the hills. Forested low hills of Senambila land system on volcanic rocks with some weathered remnant surfaces, mainly in grassland (*a*). Higher relief (*b*) due to rejuvenation of stream incision.

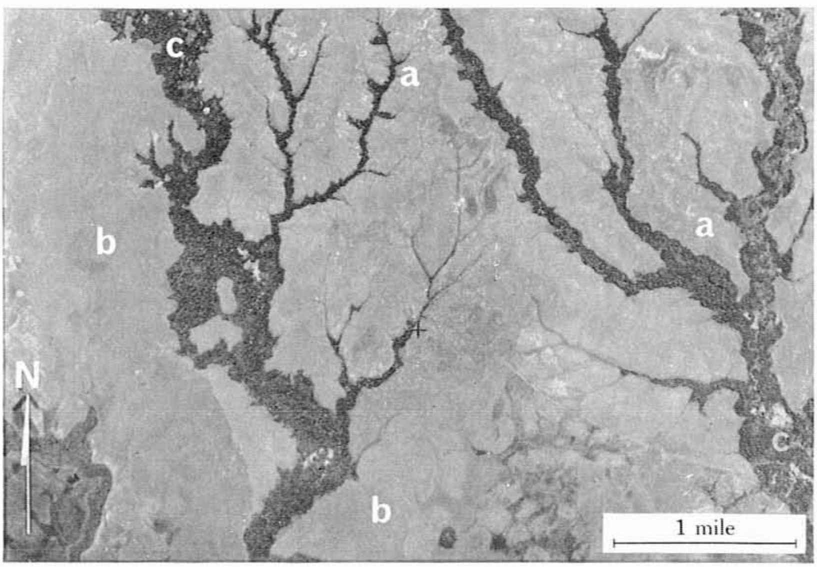

Fig. 2.—Land systems of the rolling grass plains. Strongly weathered Pleistocene sediments: low hilly relief of Kworo land system (*a*); gently undulating plains of Yambi land system (*b*). Forest on slopes to incised streams, where villages and gardens are concentrated (*c*).

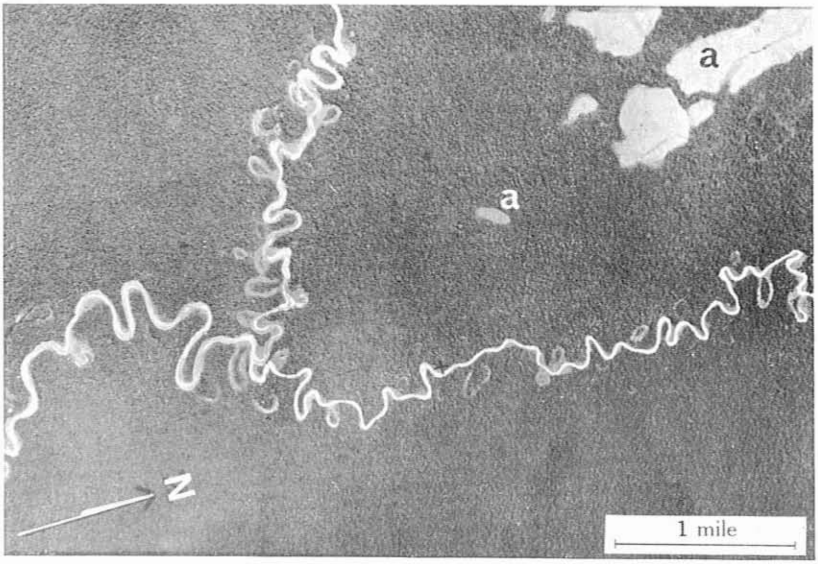

Fig. 1.—Land systems of the alluvial plains. Wide southern part of Screw River flood-plain with tall alluvium forest (Nagam land system). Grasslands (*a*) represent fretted edge of upper plain of Yambi land system.

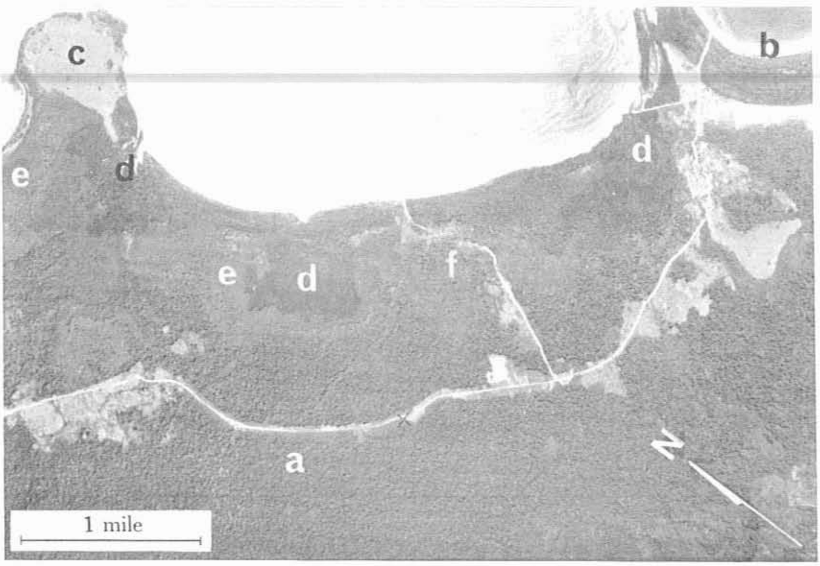

Fig. 2.—Land systems of the alluvial plains. Flood-plain of Nagam land system (*a*) with much clearing for cultivation along road. Beach ridges of Nubia land system (*b*) and coral headland of Madang land system (*c*). Land systems of the swamps. Tidal mangrove swamps of Murik land system (dark tone, *d*) are backed by woodland swamps of Kobar land system (*e*) and sago swamps of Pandago land system (*f*).

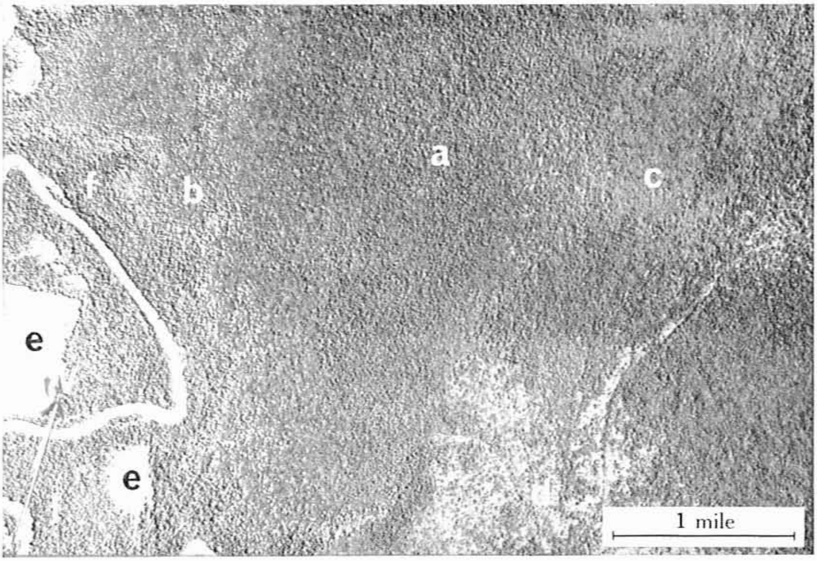

Fig. 1.—Land systems of the swamps. Swamp forest on organic soils of Pora land system (*a*) merges into sago woodland with emergent white-crowned trees (*b*). *Campnosperma* swamp forest has a grey closed canopy (*c*). At the bottom, the forest merges into *Phragmites* swamp (*d*), which is seen in pure form in depressions (*e*), surrounded by the forested levees and back plains (*f*) of Misinki land system of the alluvial plains.

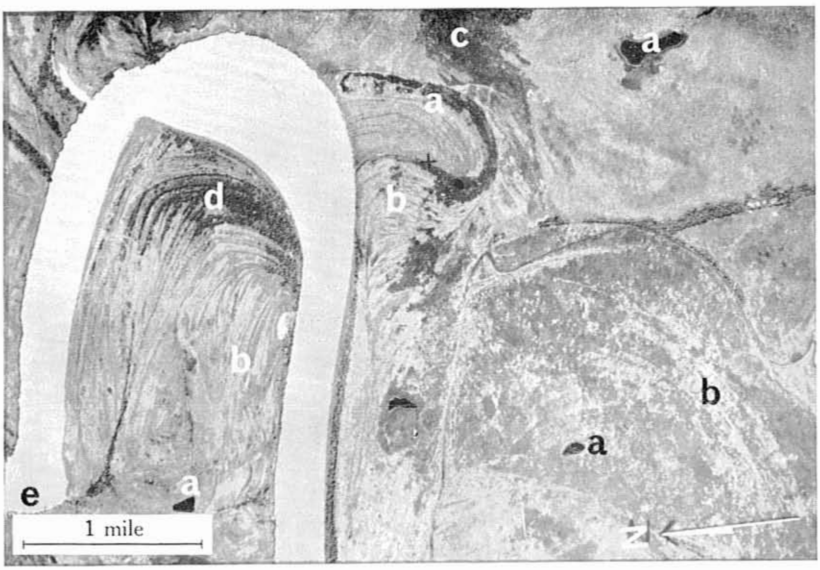

Fig. 2.—Land systems of the swamps. Grass swamps of Sanai land system in the severely flooded Sepik flood-plain. Oxbow lakes (*a*) and scroll striations (*b*) indicate shifts in the river course. A dark patch (*c*) shows that grass burning is practised even here. The forested scroll pattern within the river loop (*d*) is an occurrence of Palimbai land system of the alluvial plains. Note the village on the Sepik bank (*e*).

Fig. 1.—The low mountains of Numoiken land system: a view taken along a fault-line valley. The area has a sparse population and the steep slopes are covered by a dense lowland hill forest.

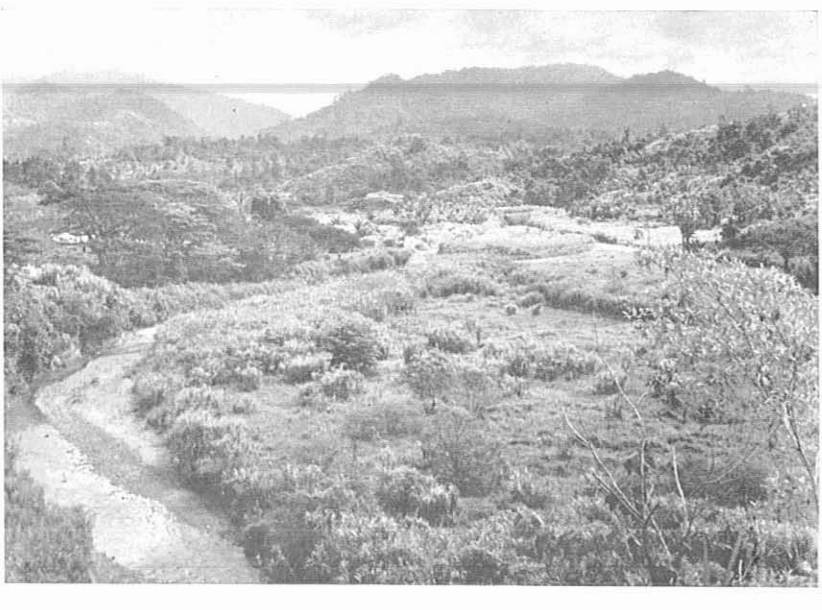

Fig. 2.—The flood-plain of the Screw River at Maprik, where it emerges from the gorge through the mountain ridges of Imbia land system. The flood-plain supports a secondary vegetation dominated by *Saccharum*. The low hills of Passoram land system are seen in the middle ground.

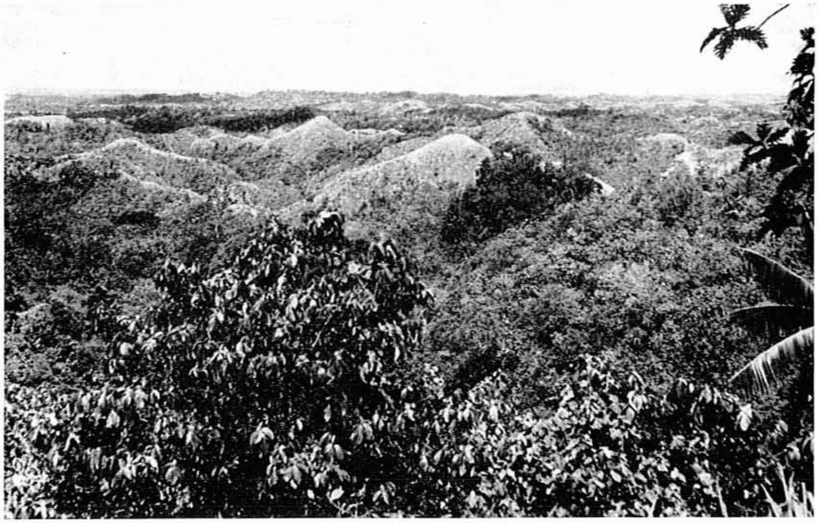

Fig. 1.—A view south from the Prince Alexander Mountains over the hilly Yangoru land system towards the upper plains. These grass-covered peaks together with the many phases of secondary vegetation reflect the present intense population pressure in this area.

Fig. 2.—In Imbia land system (Prince Alexander Mountains) large displaced blocks of mudstone reflect the unstable nature of the landscape, which is apparently no obstacle to native gardening.

Fig. 1.—Lowland hill forest in Passoram land system near the Hawain River on the north coast. This is generally stocked with mixed tree species of small girth and has only moderate timber resources.

Fig. 2.—One of the typical small grassland areas enclosed by lowland hill forest in the rolling hills of the volcanic Senambila land system just north of Tring.

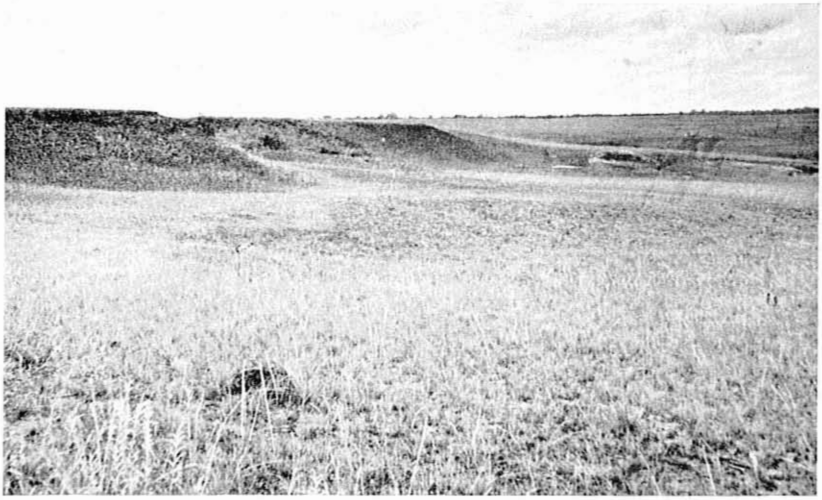

Fig. 1.—The undulating landscape of Kworo land system. Note the low scarp, which here exposes a gleyed red earth soil.

Fig. 2.—Looking over the extensive grass plains of Yambi land system. Forest strips in the valleys divide these grasslands into long broad corridors running from the northern foothills to the Sepik flood-plain.

Fig. 1.—A recent burn reveals the pattern of gravel stripes which are a local feature of Kworo land system. The densely packed quartz gravel layers alternate with moulded soil ridges about 6 in. high. Microrelief of pitted soils is common on more gentle slopes.

Fig. 2.—A wide valley head within Yambi land system. Small sago palms and giant *Scleria* swamp cover the depression while a *Themeda–Ischaemum* grassland populates the slopes. In the background is alluvium forest of Nagam land system.

Fig. 1.—Interior of a mixed flood-plain forest in Misinki land system along the Keram River.

Fig. 2.—A scroll pattern of Palimbai land system along the Sepik River. It has been cut across by the present course of the river and shows development of levee forest along the ridges. *Saccharum* dominates in the swale shown in the centre.

Fig. 1.—Swamp grassland of Sanai land system, which comprises the more deeply flooded back plains near the Sepik River.

Fig. 2.—Sanai land system with *Panicum*, swamp *Ischaemum*, and taller cane grasses floating at the edge of a waterway flowing into the Sepik River.

Fig. 1.—Floating grass and aquatic vegetation along a submerged levee in one of the more permanently flooded aspects of Sanai land system.

Fig. 2.—Shallow lake in the Chambri area with aquatic vegetation dominated by water-lilies in Sanai land system.