Lands of the Ramu–Madang Area, Papua New Guinea

Comprising papers by R. G. Robbins, H. A. Haantjens, J. A. Mabbutt, R. Pullen, E. Reiner, J. C. Saunders and Karen Short

Compiled by R. G. Robbins

Land Research Series No. 37

View complete series online

Commonwealth Scientific and Industrial Research Organization, Australia
1976

ISBN 0 643 00175 1

Printed by CSIRO, Melbourne

75-443-3300

CONTENTS

MAPS

PART I. INTRODUCTION

By R. G. Robbins*

I. The Survey Area

The area surveyed covers approximately 7900 sq miles between lat. 4°00′S. and 6°05′S. and long. 144°30′E. and 146°00′E. on the north coast of New Guinea (Fig. 1). Administratively the survey area lies within the Madang District of Papua New Guinea, including Madang, the seat of district headquarters, but omitting most of the Saidor subdistrict.

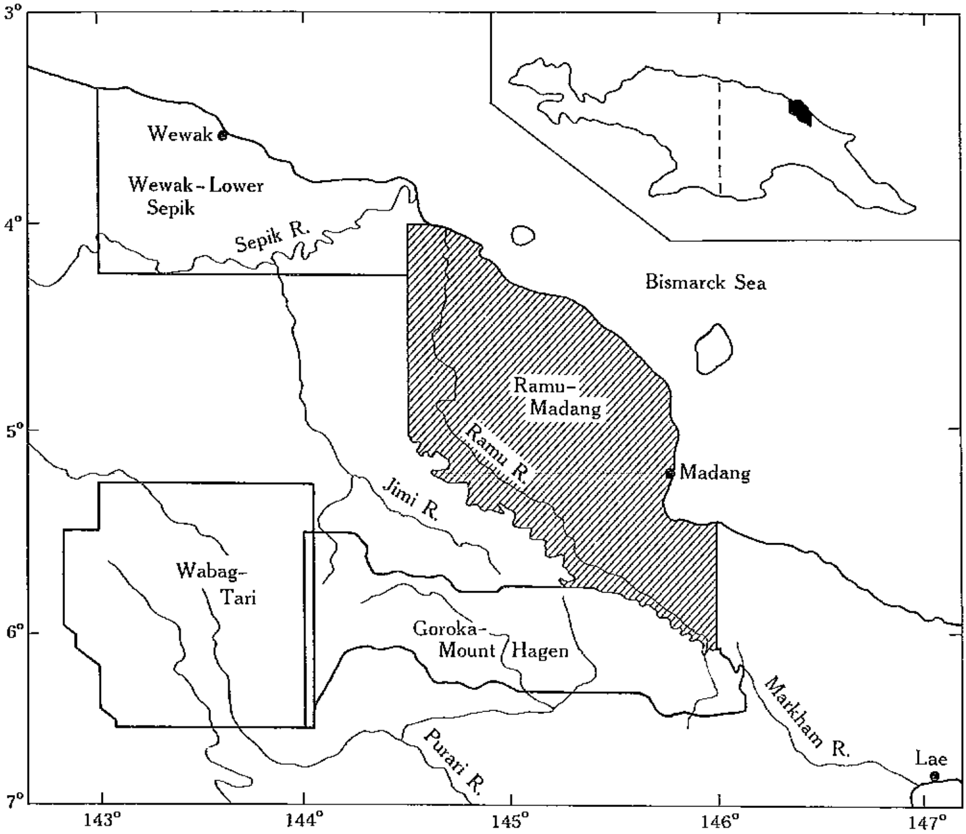


Fig. 1.—Location of the Ramu–Madang area and adjoining survey areas.

The Ramu–Madang survey encloses the coastal area of northern New Guinea from the mouth of the Sepik River to just east of the Kabenau River. It extends south-west to take in the lower slopes of the Schrader and Bismarck Ranges and

* Formerly Division of Land Use Research, CSIRO, Canberra. Present address: Department of Applied Plant Sciences, University of Nairobi, Kenya.

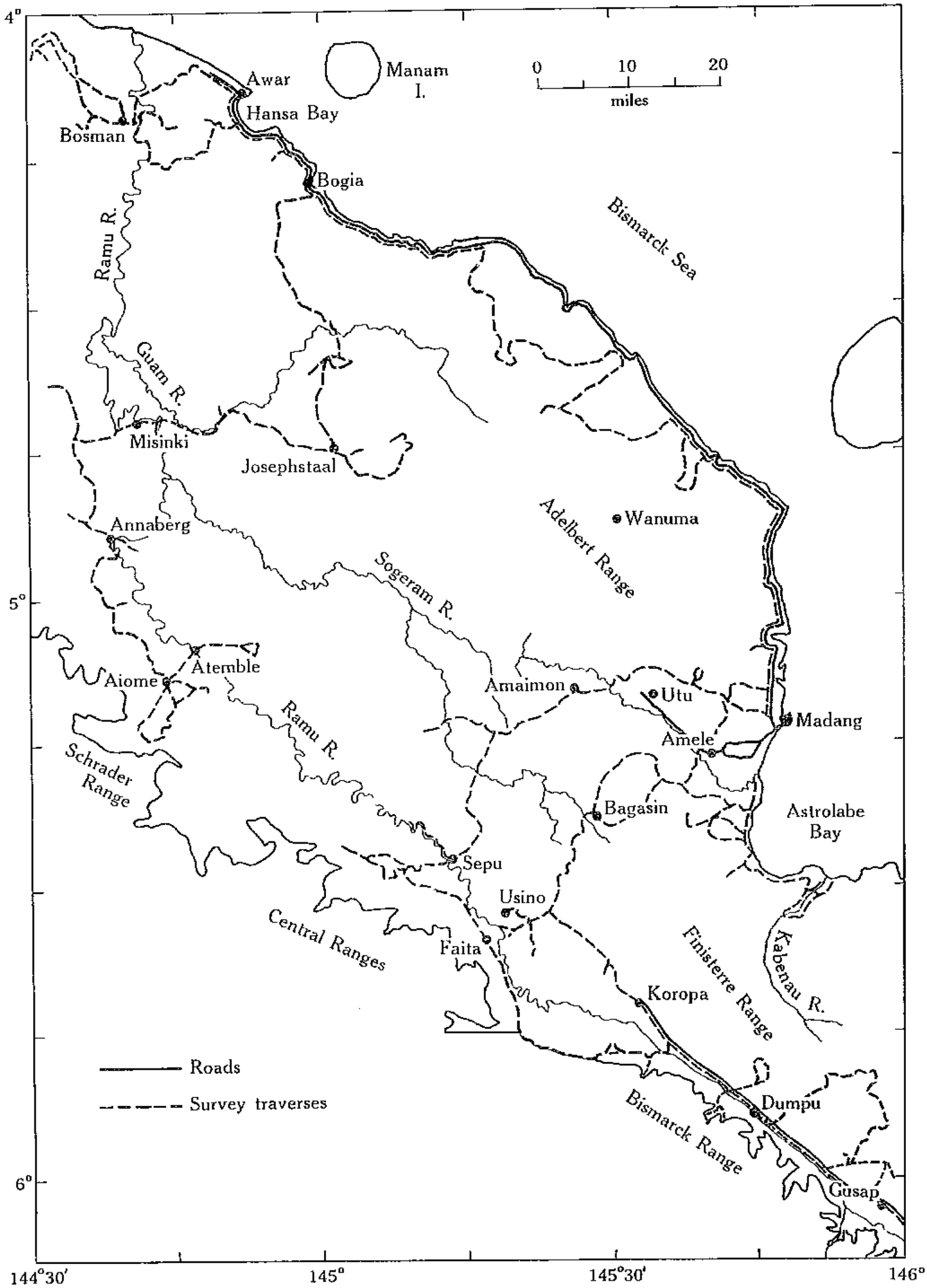


Fig. 2.—The Ramu–Madang area showing major rivers, roads and centres. The survey traverses of the two surveys are shown.

then eastwards to include the north-west extension of the Finisterre Mountains (Fig. 2).

Physiographically the area comprises the lowland course of the Ramu River of which three sectors may be recognized (Fig. 3). Emerging from the highlands near Gusap, the first lowland sector of the Ramu valley flows in a braided stream bed (Plate 2, Fig. 1; Plate 3, Fig. 2). The middle Ramu valley begins at Faita where the river enters the Usino basin (Plate 6, Fig. 1) with a meandering course but is soon confined within a graben fault valley. The lower Ramu valley is where the river emerges at Atemble onto the broad Ramu flood-plain (Plate 6, Fig. 1; Plate 7, Fig. 1). Apart from the slopes of adjoining ranges the area includes the whole of the coastal Adelbert Range (Plate 7, Fig. 2) together with foothills and coastal plains.

To the west the Ramu–Madang area adjoins the Wewak–Lower Sepik area (Haantjens *et al.* 1968) and to the south-west the inland Goroka–Mount Hagen area (Haantjens *et al.* 1970).

II. Objective and Procedure

The aim of the survey is to describe, classify and map in a broad but systematic way the lands of the area in terms of land form, soils, geology, vegetation and climate. These attributes have been combined and expressed as land systems.

The present Ramu–Madang area combines the Gogol–Upper Ramu and Lower Ramu–Atitau areas, for which only unpublished divisional reports (Nos. 57/2 and 59/1 respectively) have previously been available.

Field work for the Gogol–Upper Ramu was carried out in July, August and September 1956 and covered some 3200 sq miles. The survey of the Lower Ramu–Atitau area of a further 4700 sq miles was carried out between 1 August and 21 October 1958 (see Fig. 2 and land systems map). The survey team consisted of H. A. Haantjens (pedologist), E. Reiner (geomorphologist), J. C. Saunders (forest botanist), J. R. McAlpine (transport officer) and, for the lower Ramu only, R. G. Robbins (ecologist), R. Pullen (botanical collector) and D. W. Corbett (geologist from the Bureau of Mineral Resources).

The party worked along the traverse routes shown in Fig. 2. Although some use was made of the motor roads along the coast and excursions using canoes and outboard motorboats were made on the river and swamps, most traverses were carried out on foot using foot tracks between villages. Airlifts were made on several occasions.

The air photos used for mapping were taken by Adastra Airways Pty. Ltd. in 1955 and 1957–58 respectively. They were taken from a height of 25 000 ft and have a scale of 1:50 000 at sea level. A base map at a scale of 1:250 000 was made by the Division of National Mapping, Department of National Development, Canberra, in 1967 from compilations from the air photos of 1956 and 1958.

III. Population, Land Use and Transport

Indigenous Melanesian population data have been obtained from village assembly censuses of the Madang district, 1966. Total population for the survey area is 74 000 or almost 10 per sq mile; however, there are quite large areas of sparse to no popu-

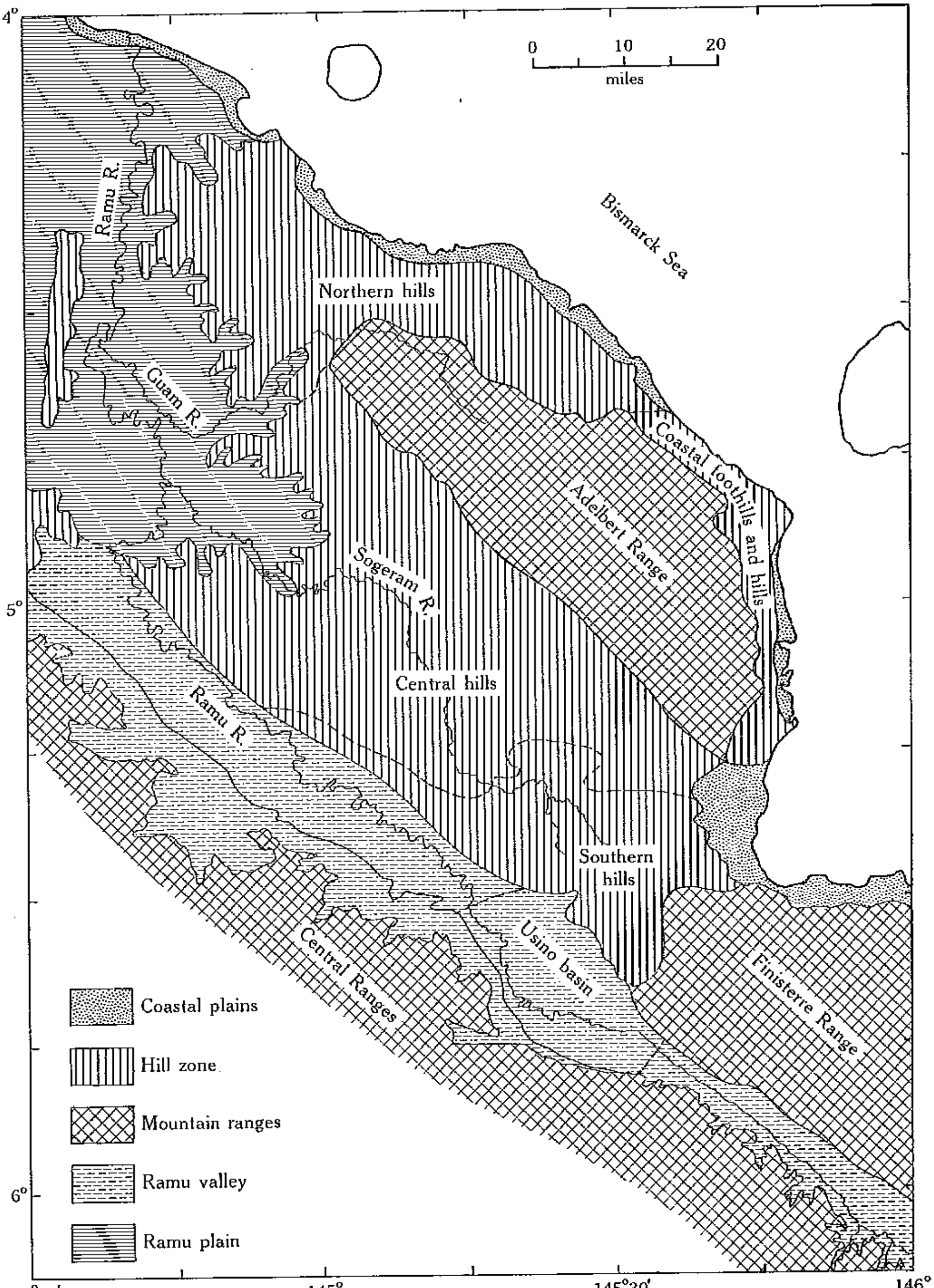


Fig. 3.—Physical regions of the Ramu–Madang area.

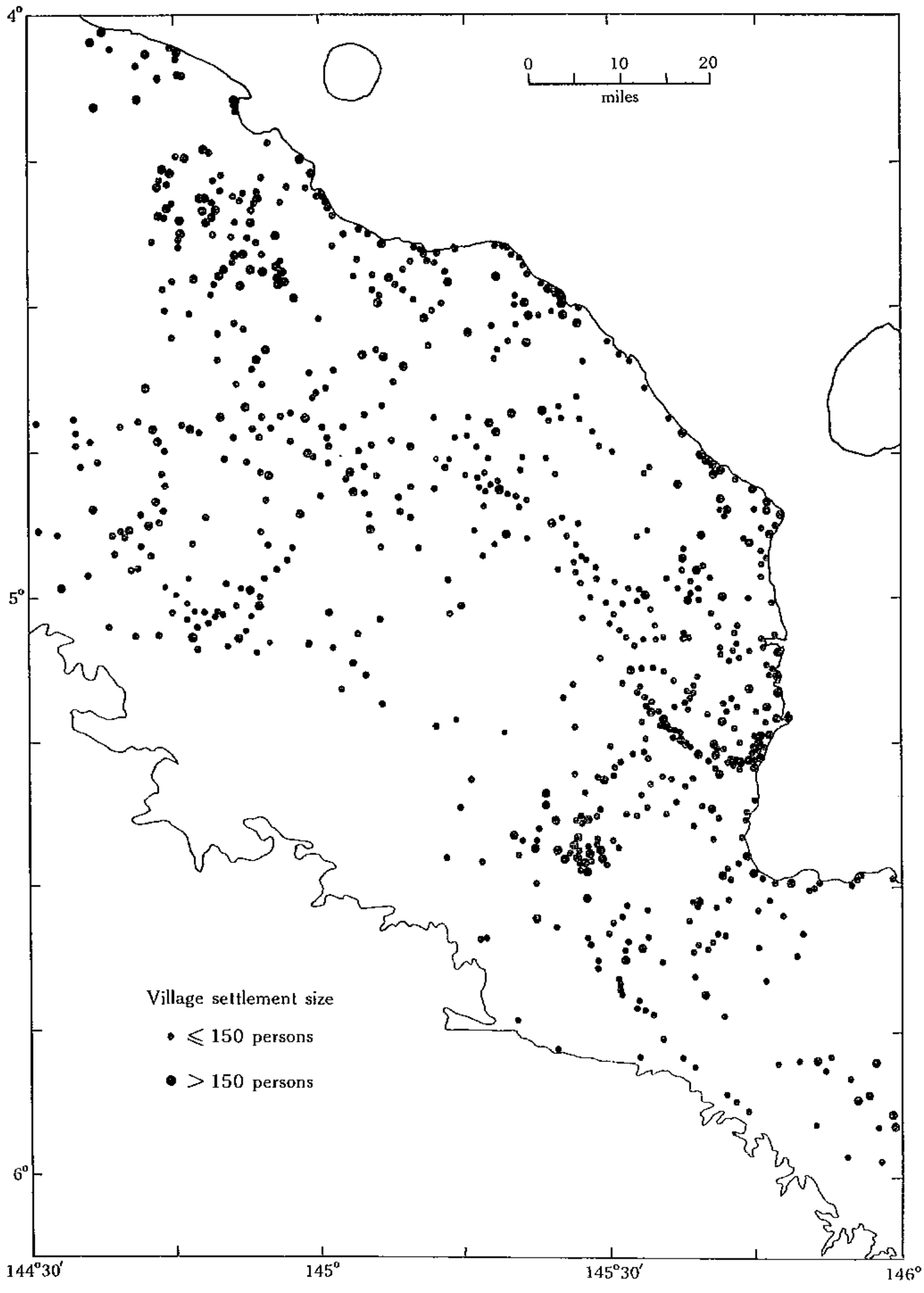


Fig. 4.—Population distribution by village settlements.

lation. Fig. 4 shows heaviest concentrations around Madang and inland from Astrolabe Bay, along the north coast and again inland from Bogia. This indigenous population, which resides in villages of about 100 inhabitants or in hamlet settlements, is chiefly engaged in subsistence cultivation and sago processing. Of those employed for wages most are engaged in agriculture and the 'rural' population is classified at over 90%. Cash cropping, coconuts and fishing occur along the coast but settlements in the hilly inland still rely on a traditional shifting cultivation of garden plots predominantly of root crops (Plate 4 and Plate 5) and have minimal contact with the administration. Sago starch or 'sac sac' is a major source of food throughout the swampy plains (Plate 8, Fig. 2; Plate 9, Fig. 2). Migration into the district and natural increase amount to some 3% annually. The impact of missions, administration posts, schools and plantations is having an increasing effect upon the population. The non-indigenous population, of which the majority live in and around Madang, numbers some 2000 and is engaged in government, mission and trading activity. While there is a number of small industries in Madang primary products are still the chief exports; 12 000 tons of copra and 2000 tons of cocoa are produced annually from the district as a whole. A large cattle holding occupies 100 000 acres in the upper Ramu valley near Gusap.

The 404 miles of roads (Fig. 2) are located mainly on the coast and serve as a link between Bogia and Madang, joining the copra plantations lying between. An inland road of 30 miles via Amele to Mawan and beyond serves the upper Gogol River timber lease. A road link from Madang to the Ramu and thence to the Highlands is being constructed.

Large areas are linked only by 'government roads' in the form of foot tracks. The Ramu River is navigable by small launch as far upstream as Atemble but has a meandering course with many hazards such as sand-bars and log snags. It is not bridged at any point.

Air transport is important and there are some 20 aerodromes and airstrips for light aircraft found in the area. Government stations are found at Usino, Aiome and Josephstaal while Bogia with a population of 600 is a subdistrict headquarters.

IV. References

Haantjens, H. A., Arnold, Jennifer M., McAlpine, J. R., Mabbutt, J. A., Reiner, E., Robbins, R. G., and Saunders, J. C. (1968).—Lands of the Wewak–Lower Sepik area, Territory of Papua and New Guinea. CSIRO Aust. Land Res. Ser. No. 22.

Haantjens, H. A., McAlpine, J. R., Reiner, E., Robbins, R. G., and Saunders, J. C. (1970).—Lands of the Goroka–Mount Hagen area, Territory of Papua and New Guinea. CSIRO Aust. Land Res. Ser. No. 27.

PART II. SUMMARY DESCRIPTION

By R. G. Robbins*

I. Land Systems

Thirty-six land systems ranging in size from 8 to over 1000 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. They 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.

The mountains include 4 land systems and comprise 1770 sq miles or 22% of the area. Maximum altitudes go above 9000 ft. Slopes are frequently over 30° and relief well over 1000 ft. Lowland hill forest dominates but lower montane and even montane forest is found at higher altitude. Soils are mainly immature, undifferentiated and residual.

Hills, mostly under grassland, include 11 land systems comprising 300 sq miles or 4% of the area. Altitudes go to 1000 ft but relief is generally below 50 ft and slopes gentle with exceptions in Panakatan land system. Weathered soils and alluvial soils predominate.

Coastal plains include 6 land systems, cover 375 sq miles and occupy 5% of the area. Partly liable to flooding, these flood-plain and terrace tracts have developed alluvial soils of varying textures and drainage conditions. The vegetation ranges from alluvial forests, grasslands and swamps to strand woodland and mangroves.

Flood-plains comprise 7 land systems which account for 1395 sq miles or 18% of the area. Mostly inundated during the wet season, the vegetation is either alluvial well-drained or alluvial flood-plain forest and river-bank succession. The soils are young alluvial soils of varying textures.

Sago palm, reed and grass swamps include 4 land systems comprising 700 sq miles and accounting for 9% of the area. Whilst the soils comprise mainly alluvial clay soils and organic soils, the various types of swamp vegetation are closely related to ground-water fluctuations and degree of flooding and inundation.

II. Climate

The area generally has a wet humid tropical climate. Mean temperatures are around 80°F along the coast and slightly higher inland and are most uniform through-

* Formerly Division of Land Use Research, CSIRO, Canberra. Present address: Department of Applied Plant Sciences, University of Nairobi, Kenya.

out the year. Total rainfall and its seasonal distribution, however, vary considerably throughout the region. Mean annual rainfall for most of the region lies within the 100–140-in. range. Rainfall in the mountains is generally over 180 in. but more significantly there are two drier areas where the mean annual rainfall drops to 70–85 in. In the south-east of the Ramu valley this lower mean rainfall is accentuated by strong drying winds that sweep across the open grasslands during May to September. The second dry area is along the north-western coast; this is reflected inland from Bogia by seasonal secondary forest, bamboo brake and the many small tracts of induced grasslands.

Seasonality of rainfall is a feature of the climate in the Ramu–Madang area. The dry season occurs from May to October, and in droughty areas where seasonality is more marked, limitations on plant growth may occur.

III. Geomorphology

Five major physical regions have been recognized in the area: coastal plains, hill zone, mountain ranges, Ramu valley and Ramu plain (Fig. 3).

Cretaceous schists on the lower slopes of the Central Ranges are the oldest rocks within the survey area. Mostly, however, the rocks extend in age from the middle Miocene to Pliocene, beginning with limestone and passing into a varied sequence of sandstone, conglomerate and mudstone with associated volcanic rocks.

The history of the area is one of uplift and faulting with marine deposition in the central depression during the Miocene and Pliocene. The coastline was demarcated by the uplift of the coastal ranges accompanied by vulcanism. Renewed uplift caused dissection of the hill zone and this was followed by down-faulting of the Ramu trough to form the present structural basin or flood-plain. Rejuvenation of drainage followed with the capture of the extensive catchment of the present Guam River.

Rapid uplift of the Finisterre Mountains and the central range was accompanied by increased erosion which led to the formation of extensive alluvial fans at the foot of the mountains. Most of these have now been dissected.

The braiding channels of many of the rivers still transporting great amounts of coarse-grained sediments indicated that these processes are continuing.

Such tectonic activity has largely determined the course of the Ramu River and this, together with the history of the landscape, is strongly related to the land systems, the geomorphology of which is discussed further in Part III.

IV. Soils

Many more observations were made of the soils of the alluvial plains and fans than of soils of the hills and mountains which occupy the greater part of the survey area. The latter appear to be mostly not strongly developed, presumably as a result of surface wash and denudational mass movement on the hill slopes. On sedimentary rocks the soils tend to be fine-textured and plastic although coarser-textured soils are common on interbedded sandstones and conglomerate. On igneous and metamorphic rocks soils tend to be more friable and permeable and often contain many weathered rock fragments. Strongly weathered soils occur locally throughout the hills and mountains and are most common where related to old surfaces, as on very low hills near the lower Ramu River, and compact with mottles and concretions on sedimentary rocks. In all residual soils it is very common for the topsoil to be less clayey than the subsoil.

The flood-plains have almost totally undeveloped alluvial soils. The strongest aggradation appears to take place in the middle sector of the Ramu plain where it is common to find thin layers of flood deposits on top of the generally very silty alluvial soils. As would be expected, there is a marked increase in clay content in these soils from the upper to the lower sectors of the major rivers. Also rivers with a mainly sedimentary rock catchment area have the most clayey alluvial soils, whereas the very silty middle Ramu soils appear to derive from schists in the Bismarck Range.

Although undifferentiated alluvial soils also occur on the terraces above flood-plain level, higher terraces, and in particular alluvial fans in the upper and middle Ramu sectors, have soils with increasingly developed profiles. Initially this is reflected in browner subsoils and the development of very dark organic topsoils. With increasing age such soils become acid, very clayey and red.

Dark topsoils are particularly common under grassland, also on the hills. This tendency is reinforced in areas of lower rainfall in the upper Ramu valley and along the north-west coast. The influence of a drier climate may also be reflected in the presence of slightly alkaline black earths at the lower edge of fans in the upper Ramu valley and in the prevalence of very shallow soils along the north coast.

V. Vegetation

Tropical rain forests predominate over two-thirds of the survey area. Centred in the ranges these extend out over the foothills and onto the alluvial plains.

The forest vegetation of the humid lowlands below 3000 ft is in optimum development a mixed three-tree-layered forest with a canopy over 100 ft and emergents to 150 ft. While much of it has a good timber potential, large areas have been downgraded and in places even replaced by grasslands due to a long history of shifting cultivation. On the extensive alluvial plains and river terraces there are alluvial forests in which well-drained and flood-plain aspects have been recognized.

Above 3000 ft the optimum number of tree layers is reduced to two and the forest is lower in stature and within the lower montane formation. Here tree-ferns largely replace the palms of the lowland forests; trunk buttresses and woody lianes are less evident and there is a shift in species composition. Some of the lower montane forest is dominated by oaks or beeches. The true optimum single-layered, often mossy, montane forest is only found above 9000 ft on the Finisterre Range.

Swamp lands account for over 800 sq miles, mainly on the broad Ramu River flood-plain where there is a complex pattern of sago palm groves, reed and grass swamps and open lakes with aquatic plants, all reflecting the seasonal floods and alternating wet and dry seasons.

Strand woodland occurs along the beaches and is only interrupted by mangrove forest and woodland on muddy estuaries.

Much of the vegetation shows the impact of man; this is expressed in the many phases of garden regrowth and in the tracts of open grassland which are now entrenched by annual firing.

VI. Forest Resources

Commercial forests cover almost 50% of the Ramu–Madang area. Undoubtedly the regions having the greatest timber potential are the middle Ramu valley and the central hills. The former region is not only well stocked with timber on accessible terrain but also provides easy access to the forests of the more accessible foothills and lower slopes of the Central Ranges and southern hills and to parts of the lower Ramu plain and the Usino basin. The upper Ramu valley, although almost devoid of forest, provides easy access to the above regions from Lae and the Highlands highway via Gusap.

The central hills region carries a large area of timber of generally moderate to low stocking rate. Access varies from good on the alluvial terraces and higher plains to moderate on the low hills of Amaimon land system to poor, and locally very poor, on the higher steeper hills. Generally, however, by careful selection of routes the region is almost totally accessible and allows access to the foothills of the Adelbert Range and the lower slopes of the southern hills. Extending westwards from the existing road-head of the Madang road system to the middle Ramu valley, the central hills provide a possible access to much of the inland part of the Ramu–Madang area.

The Central, Adelbert and Finisterre Ranges, although generally well stocked with timber, are for the most part inaccessible except along the foothills, and their forests play an important role in watershed protection. The same applies to the southern hills but the timber resources here are much smaller in area.

The lower Ramu plain has generally low stocking rate forest covering approximately 25% of its area, for the most part following the courses of the main rivers. The terrain although flat is subject to poor soil drainage conditions and is often inundated for long periods or is permanently swampy. Consequently access is very poor to impossible except for small areas of higher land or large areas for short periods during the driest part of the year.

The northern and coastal hills carry very little forest due to clearing for agriculture and access for the most part is poor.

Most of the present road system is located on the coastal plain which although almost devoid of forest affords access and outlets to the lower slopes of the Adelbert Range. The plain itself generally has a good access rating except for parts of Astrolabe land system.

VII. Land Use Capability

Land use capability of the survey area as a whole has been assessed from a study of the land system units. The method used is adapted from the Soil Conservation Service, U.S. Department of Agriculture, and land is grouped into categories of increasing limitations and problems. Suitability for development is based upon its use for arable crops, tree crops, wet rice, grazing or forestry, in that order.

About 7% or 550 sq miles of the survey area includes land with moderate limitations such as flood hazards, drainage and slope problems. This land is primarily suitable for improved pastures but marginal for permanent cultivation. Wet rice growing is a possibility.

A further 22% is classed as land with some serious limitation among which are erosion hazards, shallow soils and moisture deficits. While locally much used for shifting agriculture some could be used for grazing; however, the higher parts are best suited to forestry or watershed protection.

The remainder of the survey area or nearly half the land (48 % or 3730 sq miles) has severe limitations for development.

The other 2800 sq miles is rugged mountainous land the main use of which is as catchment areas.

PART III. LAND SYSTEMS

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

I. INTRODUCTION

The 36 land systems described in this Part and shown in 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, consideration is also given to their land use potential. The 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.

II. SUMMARY DESCRIPTION

The 36 land systems are grouped into the following types of land in order of decreasing relief. A broader grouping based on this classification has been used for presentation of land system information and on the land system map.

(a) *Land Systems of the Mountains*

These are the areas of strongest tectonic uplift, greatest relief and most severe erosion. Relief attains 3000 ft and altitudes range to 10 000 ft above sea level. The characteristic land forms are high serrate ridges and steep-sided narrow valleys; plains are lacking. The land systems in this group form important watersheds and naturally contain the most inaccessible terrain in the survey area.

Finisterre together with Kubari land system is essentially the Finisterre Range. It is formed mainly of greywacke and tuff and exhibits the steep rugged land forms characteristic of such rocks in areas of strong relief. The area is subject to frequent earth tremors; slopes are broken by numerous landslide scars and there are also small

* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

† Formerly Division of Land Use Research, CSIRO, Canberra. Present address: Nieder Gelpe 13, 5251 Post Kalkkuhl Über Ingles-Kirchen, West Germany.

‡ Formerly Division of Land Use Research, CSIRO, Canberra. Present address: Department of Applied Plant Sciences, University of Nairobi, Kenya.

fault scarps. River gradients are high and torrential flooding is especially severe in this land system.

Atitau land system comprises hilly upland tracts 2000–3000 ft above sea level in watershed areas in the Adelbert Range.

Gal land system consists of low mountains formed of sandstone, mudstone and greywacke with smaller areas of limestone and volcanic rocks and is essentially the Adelbert Range. It consists mainly of narrow ridges up to 1500 ft high with an accordance of altitude between 2000 and 4000 ft above sea level. Gal land system also includes prominent escarpments formed by block faulting.

Bismarck land system consists of mountains of granodiorite and schists forming the lowermost slopes of the Central Ranges. It has particularly massive ridges up to 2500 ft high. The units are traversed by parallel tributaries of the Ramu River. The effects of youthful faulting and uplift are seen in the faceted lower spurs, gorge incision up to 200 ft in valley bottoms, and a general steepening of lower slopes. Small hilly upland areas and spur benches between 2000 and 3000 ft above sea level may have formed during pauses in uplift.

(*b*) *Land Systems of the Higher Hills*

This group of land systems has a relief range between 400 and 1000 ft and is generally less than 2000 ft above sea level. The land systems occur in areas of less strong tectonic uplift in continuation of and on the flanks of the Adelbert and the Finisterre Ranges. They are formed on a variety of rocks but commonly they owe their moderately strong relief to the presence within the mudstone sequence of sandstone, limestone and greywacke which form steep slopes or prominent ridges and escarpments.

The most typical upland forms are short interconnecting narrow ridges, although more continuous strike ridges also occur. Lower slopes formed in mudstone are liable to severe dissection and landslides and mudflows occur on a minor scale, possibly triggered by frequent earth tremors. There is generally a dense pattern of steep-sided narrow valleys. Discontinuous narrow flood-plains of the smaller through-going valleys are included within the land systems and alternate with narrow, often gorge-like tracts where the drainage traverses strike ridges.

Bagasin land system contains the strongest relief in this group. It consists mostly of branching ridges of sandstone and mudstone which extensively attain 2000 ft above sea level. This land system is traversed by prominent hog-back ridges up to 1000 ft high formed on tilted fault blocks of sandstone and limestone which locally attain an altitude of 3000 ft. The drainage is very deeply entrenched.

Otaki land system consists of steep limestone strike ridges up to 1000 ft high on the flanks of the Bismarck Range in the upper Ramu valley and also one in the lower Ramu plain near the Keram River.

Musak land system consists of a few continuous strike ridges with a regular pattern of long serrate spurs and narrow transverse valleys. The ridges are up to 400 ft high and locally attain 1200 ft above sea level. The land system forms the Musak hills on the watershed between the Ramu and the Sogeram Rivers. The winding larger river valleys in this land system may have been superimposed.

Wanabutu land system occurs in the northern hills. Its higher inland parts consist of irregular closely spaced rounded ridges formed of shale and sandstone up to 400 ft high and with crests between 500 and 800 ft above sea level. Nearer the coast is a continuous lower ridge formed of greywacke with regularly dissected flanks and with benched rounded spurs on the coastal side.

Morumu land system consists of closely dissected short ridges and hills up to 400 ft high of mudstone and interbedded sandstone and it forms the greatest part of the central hills.

(*c*) *Land Systems of the Lower Hills*

These land systems have less than 400 ft of relief, commonly less than 200 ft. They occur on a variety of unresistant rocks in areas of little uplift. They have their fullest development in the lower parts of the central hills adjacent to the Ramu plain in the coastal foothills, and flanking the upper Ramu valley.

The most typical land forms are low, narrowly rounded hills and ridges with slopes of less than 25° as in the central hills. In addition, there are areas of stronger dissection characterized by steep, sharp-crested ridges and narrow V-shaped valleys, whilst the group also includes minor areas of very subdued relief. Lower hill slopes are commonly hummocky due to mudflows. These land systems are closely dissected by narrow tributary valleys, but the main valleys are relatively open with discontinuous narrow flood-plains.

Sangan land system is characterized by interconnecting ridges mainly up to 300 ft high on the margins of the northern hills. These have unusually steep slopes and narrow crests probably because of the greater resistance of the sandstones of which they are mainly formed. The very close dissection of the ridge slopes may in part be a result of forest clearing. Relief generally attains 300 ft.

Romole land system consists of foothills up to 300 ft high along the fault scarp of the Finisterre Range in the upper Ramu valley. Vigorous erosion by closely spaced gullies has given rise to a complex of knife-edge ridges closely resembling badlands.

Amele land system forms the largest part of the coastal foothills. It is mainly underlain by soft rocks which give rise to closely spaced, low rounded hills and ridges. The through-going rivers are deeply incised but relief is generally less than 200 ft.

Sirin land system contains short ridges of two types: narrow-crested ridges up to 200 ft high and rounded ridges up to 50 ft high. These are associated with ill-drained, flat basins with gently sloping colluvial margins which may be volcanic in origin.

Amaimon land system comprises the lower parts of the central hills and is characterized by closely dissected, low rounded mudstone hills and ridges up to 150 ft high. The land system also includes low stony ridges in the Ramu plain west of the Ramu River.

(*d*) *Land Systems of the Dissected Fans*

These land systems occur mainly in the Ramu valley and they are mainly formed of boulder and cobble, gravels and sands.

Surviving upper fan surfaces have gentle radial slopes and are traversed by ill-defined drainage channels. The fans have been incised up to 200 ft by the Ramu River and its tributaries and the steep margins are subject to close dissection by narrow gullies. With regressive erosion longer knife-edge spurs are formed and eventually the fan surface is completely replaced by broken terrain.

The land systems also include narrow flights of terraces along the braiding channels of through-going tributaries of the Ramu River.

Panakatan land system consists of completely dissected fans or dissected fan margins adjoining Aiome land system and is characterized by narrow ridges and spurs. It also includes a 200-ft fault scarp.

Aiome land system comprises the surfaces of little to partially dissected fans in the lower Ramu valley. The gently undulating surfaces extend in long lobes separated by alluvial terraces in the tributary valleys and ending in a low bluff against the Ramu flood-plain. The terraced margins of the land system are sparsely gullied.

(*e*) *Land Systems of the Undissected Fans*

In these land systems, which occur in the upper Ramu valley and south of Astrolabe Bay, the gently sloping fan surfaces generally survive intact although they are trenched to differing degrees by the flood-plain and terraces of through-going braiding rivers. Locally they are still receiving alluvial deposits.

Bumbu land system is made up of little-dissected confluent fans in the upper Ramu valley flanking the foothills of the Finisterre Range. They are trenched up to 100 ft by tributaries of the Ramu and their terraces. Several small alluvial flood-out basins occur at the terminals of minor drainage debouching onto the fan surfaces.

Faita land system comprises gravel fans which flank the Bismarck Range in tributary re-entrants of the upper Ramu valley. They are young, as indicated by their stony surfaces and also by the shallowness of dissection by the through-going rivers. This land system includes short backing colluvial aprons.

(*f*) *Land Systems of the Coastal Plains*

This group includes firstly two land systems which originated as alluvial coastal plains but have since been raised to between 20 and 40 ft above the present flood-plains. They have gently undulating surfaces with discontinuous ill-defined drainage depressions and they are formed of impermeable clays which become waterlogged in the wet season.

Bosman land system is the Bosman platform and consists of estuarine clays on a coral limestone base. Its upper surface has minor swampy areas. The margins of the land system are fairly steep and are gullied in part.

Astrolabe land system is a former delta plain on the west shore of Astrolabe Bay, now entrenched up to 30 ft by narrow flood-plains. Its flat surface is sparsely dissected by narrow winding channels with steep banks. The seaward margin of the land system includes uplifted coral reefs and sand beaches.

Secondly, *Kabenau land system* consists of delta fans mainly on the south shore of the Astrolabe Bay and also at the mouths of smaller rivers on the north-east coast. Remnants of older fans form slightly higher plains near the head of the land system, generally between the younger fan lobes. The anastomosing river channels are incised only 20 ft at the heads of the fans where they are flanked by narrow alluvial terraces. The land system includes sand and shingle ridges on the coastal edge.

Thirdly, this group includes three land systems which form most of the narrow discontinuous coastal plain apart from the slightly uplifted alluvial plains fringing Astrolabe Bay. The principal marine forms are uplifted rocky coral platforms mainly up to 20 ft above sea level and low beach ridges mainly of sand but locally of shingle and areas of tidal alluvium. These land systems also include small alluvial flats behind the shoreline, swampy areas between beach ridges and minor tidal flats. In addition to features of the present shoreline the land systems include raised beach ridges and higher coral platforms a short distance inland.

Boriva land system is the broadly undulating flood-plain of the Ramu River in its tidal reach below Bosman. Although not subject to prolonged flooding from the main channel, Boriva land system is nevertheless inundated for varying periods by local run-on following heavy rains. Meanders, oxbow lakes and abandoned channel outlets are prominent in this land system.

Madang land system consists of raised coral platforms, beach ridges and minor ill-drained lagoon fills. It forms the discontinuous coastal plain between Astrolabe Bay and Hansa Bay, occupying a coastal belt generally less than half a mile wide. Locally at river mouths it may attain 2 miles in width. It is backed inland by steep hill slopes with local inner coral platforms.

Nubia land system mainly consists of parallel, broad sand ridges separated by swampy alluvial swales, but it also includes minor tidal flats at former river outlets. This land system forms the coastal fringe of the Ramu plain but it also comprises older beach ridges extending up to 7 miles inland.

(*g*) *Land Systems of the Flood-plains*

This group of land systems comprises the continuous flood-plains along all the larger rivers but they have their greatest extent in the Ramu valley and the Ramu plain. They include extensive aggradational surfaces subject to inundation for periods of up to 4 months. They are generally areas of deposition of fine-textured alluvium, particularly from the Tertiary sediments and volcanic rocks.

The flood-plain land systems in the smaller valleys are mainly less than 2 miles wide. They include flights of alluvial terraces up to 40 ft above present river level and active flood-plains up to 1 mile wide and about 6 ft above the river bed. These plains are subject only to flash flooding of short duration and at other times the meandering river bed consists of low gravel banks and anastomosing channels. These tributary plains are well drained.

In the Ramu valley the flood-plain land systems show progressive changes downstream. The flood-plain in the upper valley is merely an anastomosing channel zone with minor alluvial flats. Further down-valley the Ramu occupies a single meandering channel flanked by widening main and tributary flood-plains. Tributary drainage channels are for the most part braiding.

There is a progressive increase in the duration of flooding down-valley, the main channel meanders more widely and a somewhat uneven meander belt forms with low flood scrolls and numerous oxbow lakes. In this sector most of the alluvium is derived from the main ranges and is somewhat sandy with local gravel seams.

The flood-plain land systems in the Ramu plain occupy tracts up to 20 miles wide mainly astride the meander belts and also at the margins of the plain. They form extensive flat unchannelled surfaces with discontinuous low levees which rise a few feet above the general level. In this area the plain is flooded up to 4 months each year.

In its lowermost tidal sector the Ramu flood-plain is very gently undulating with low sandy rises which may have originated as beach ridges. The meanders are here most fully developed with large oxbow lakes and abandoned outlet channels.

Papul land system comprises the narrow flood-plains and flanking terraces of the smaller valleys.

Imbrum land system consists of gravelly plains of the braiding channel zones and meander belts of the upper Ramu River and its local tributaries, particularly the Imbrum River. It includes minor ill-drained tracts near the Andalarem valley caused by diversion of the Ongan River.

Ramu land system comprises the Usino basin and the flood-plains of the Ramu River and its tributaries in the lower Ramu valley.

Sausi land system consists of gently sloping flood-out plains of rivers entering the Usino basin on its east side. The land system also contains gently undulating gullied tracts near the backing hills.

Usino land system is mainly the flood-plain of the Peka River in the Usino basin. At the head of the land system are minor alluvial terraces flanking the slightly entrenched meandering river channels; in its lower parts the plain is diversified by broad low rises marking former channel zones.

Misinki land system forms higher better-drained parts in the Ramu plain. It consists of a flood-plain traversed by meandering river channels flanked by discontinuous levees. Although Misinki land system is flooded to a depth of 5 ft for 4 months each year the water-table falls to 7 ft below the plain in the dry season.

Jibirogo land system is the meander belt in the lower Ramu valley where it forms a discontinuous tract up to 1 mile wide. It contains the meandering channel and its cut-offs and the swales and low rises of flood scrolls. The undulating surface of the land system slopes gradually towards the river.

(*h*) *Land Systems of the Swamps*

Swamps occur in the lowest parts of the flood-plains mainly in the back plains of the Ramu River and its larger tributaries. The water-table is at or above the surface of these land systems throughout the year. The definition of land systems is mainly based on vegetation characteristics which reflect water-table conditions.

Eli land system is the swampy flood-out of tributaries entering the Usino basin on the east. It also includes a small area of ill-drained tributary flood-plains in its highest part.

Pandago land system occupies higher parts of the back plains, with more strongly fluctuating water-tables. It is most extensive in the Ramu plain but also occurs in the lower Ramu valley and the Usino basin.

Kabuk land system consists of lower permanent back-plain swamps in the Ramu plain.

Sanai land system comprises open lakes and swamps in the wettest lowest parts of the lower Ramu back plain.

III. Notes on the Tabular Descriptions

Descriptions are necessarily brief and provide easy reference to the various specialist Parts for more detailed information. For example, the soil families are all in alphabetical order under their group headings in Part VI; the named vegetation units are as those used in Part VII. Land system areas have been ascertained on a dot grid and rounded off but the unit areas are estimates. Some land systems for which very few or no field data are available have been described in general terms and no units have been defined.

The drainage classes listed in the soil column are:

Excessively drained.—Water is removed from the land very rapidly leaving it too dry for long periods.

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.

Imperfectly drained.—Water is removed from the land somewhat slowly so that 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 9 and 20 in. depth.

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.

Swampy (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 part-decomposed plant material. These gley phenomena are commonly less pronounced in seasonal swamp.

The block diagrams mainly represent composite drawings made with the help of the aerial photos; the diagrams are not all drawn to the same scale. Numbers merely illustrate the units and do not imply an areal importance.

IV. Land Classes and Subclasses

The land classes given in the last column of the tabular descriptions are an assessment of each particular unit within the land system. They are based upon the system of land classification of the U.S. Soil Conservation Service (Klingebiel and Montgomery 1961) and modified to suit conditions in Papua New Guinea (Haantjens 1963). Land is grouped into eight classes (I–VIII), each of which indicates the general suitability for different agricultural pursuits. Classes II–VII are further subdivided by using letter symbols to express the nature of the limiting factor—d, poor drainage; e, erosion hazards; f, flooding; st, stoniness; so_1, low fertility, so_2, low water-holding capacity (i.e. droughtiness or shallowness), and so_3, strong impermeability.

Thus classes I–IV are suitable for the cultivation of arable crops but in decreasing order. Classes V–VIII are not suitable for such cultivation. Class V is suitable for wet rice growing or for grazing; classes VI and VII are suitable for tree crops (coffee, cacao, oil palms, coconuts) or for grazing or forestry. Class VIII is unsuitable for any form of agriculture.

Class I Land.—This land can be cultivated safely with ordinary farming methods. It is nearly level, has deep productive soils, is well drained and not subject to flooding. It is suited to most types of land use including paddy rice growing, although this would require special water supply.

Class II Land.—This land is not subject to flooding but requires simple special farming practices to maintain or reach optimum productivity when cultivated. It can generally be used without special limitations for other types of land use but tree crops may need drainage measures. There are five subclasses in the survey area involving limitations of drainage, erosion, water-holding capacity, stoniness and fertility.

Class III Land.—This land requires intensive special farming measures to improve or maintain its productivity when cultivated. In many cases class III land can be used without special limitations for other forms of land use but when the land is imperfectly drained intensive measures are required for most tree crops. There are six subdivisions of this class within the survey area mostly with limitations of drainage, flooding and water-holding capacity.

Class IV Land.—This land can be cultivated occasionally and usually with more than normal hazards, or is only suitable for a very limited range of arable crops. Most of it is best kept in perennial vegetation but it is generally unsuitable or little suitable for tree crops. Many of the seven subclasses found in the area where flooding is present would be suitable only for paddy rice cultivation.

Class V Land.—This is land unsuitable for cultivation for reasons other than erosion hazards. It is good grazing land which can be managed without special limitations. In the survey area poor drainage is the main limitation and suitability for paddy rice or tree crops then depends upon whether flooding is present.

Class VI Land.—This land is not suitable for cultivation and is subject to moderate limitations for pastures. Some of the subclasses here may be suitable for tree crops with moderate limitations, others for forestry. There are a great number of subclasses and this land is fairly common.

Class VII Land.—This land is not cultivatable and is subject to severe limitations for pastures. Most subclasses are suitable for forestry under careful management and this appears to be the most efficient use, except in subclasses where drainage and flooding are the limitations. This is a fairly extensive land class.

Class VIII Land.—This land has such unfavourable conditions that it is unsuited to any cultivation, tree crops, grazing or forestry.

V. References

Haantjens, H. A. (1963).—Land capability classification in reconnaissance surveys in Papua New Guinea. *J. Aust. Inst. Agric. Sci.* **29**, 104–7.

Haantjens, H. A., Reiner, E., and Robbins, R. G. (1968).—Land systems of the Wewak–Lower Sepik area. CSIRO Aust. Land Res. Ser. No. 22, 15–48.

Haantjens, H. A., Reiner, E., and Robbins, R. G. (1970).—Land systems of the Goroka–Mount Hagen area. CSIRO Aust. Land Res. Ser. No. 27, 24–65.

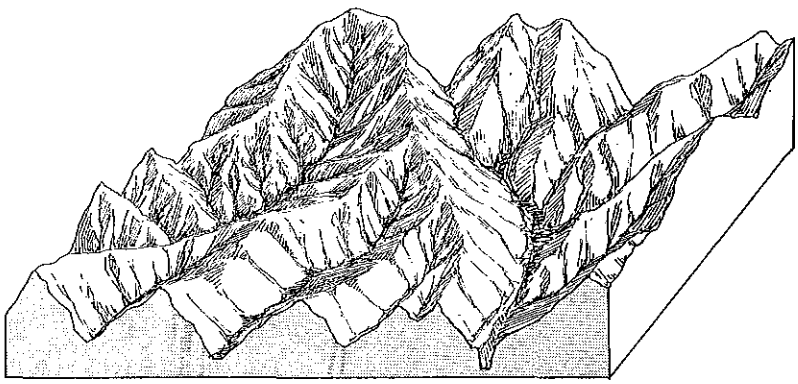
Klingebiel, A. A., and Montgomery, P. H. (1961).—Land capability classification. U.S.D.A. Agric. Handb. No. 210.

(1) Finisterre Land System (290 sq miles)

Rugged high mountains of unstable greywacke with interbedded tuffs. (Plate 1, Fig. 2.)

Geology.—Strongly faulted and uplifted Tertiary greywacke overlain by thick tuff with intercalated marine sandstone and siltstone; an area of continuing tectonic instability.

Physical Features.—Very rugged mountain ranges, slopes above 3000 ft above sea level with branching, steep-sided narrow ridges and V-shaped valleys with torrential rivers; many landslide scars; close dendritic drainage with structurally controlled longitudinal valleys in central parts; relief up to 2000 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
Whole of land system	290	High mountain ridges: long very steep slopes above 3000 ft, 25–60° and narrow, serrate crests; relief 400–2000 ft	Immature brown residual soils (Damanti, Sisimba). Undifferentiated residual soils (Nininko) and rock outcrops. Organic soils (Gomunu) in small swamps and lakes due to landslides. Mostly well drained	Lower montane forest including oaks and beeches. *Casuarina* trees on old landslips; *Phragmites* swamps locally. On the highest ridges above 9000 ft montane forest	Mostly VIII; little VIe and VIIe

Population and Land Use.—Very sparsely occupied. There are less than 2000 people in 111 villages on the southern inland slopes giving a density of 7 people per sq mile. Gardening is carried out mainly on old slump areas.

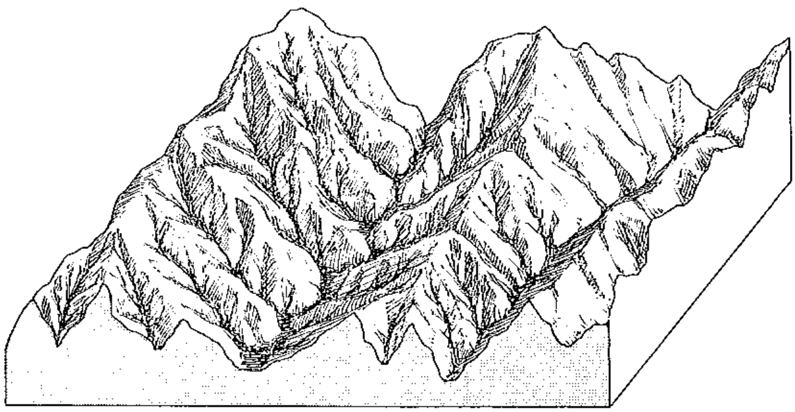
Assessment.—Very rugged country of high relief with the range rising to 9000 ft or more within a few miles. This is an important catchment area although landslides, colonized by *Casuarina* trees, reflect the instability and erosional nature.

(2) Kubari Land System (400 sq miles)

Rugged lower slopes of mountains with greywacke overlain with thick tuff. (Plate 1, Fig. 2; Plate 3, Fig. 2.)

Geology.—Strong faulting and uplift of greywacke with interbedded tuffs, sandstone and siltstone. Minor rhyolitic flows in the south-west.

Physical Features.—Rugged mountain slopes and ridges below 3000 ft of the Finisterre Range.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
Whole of land system	400	Lower mountain ridges: steep slopes below 3000 ft, 15–45° and narrow crests; relief 500–1000 ft	Mainly immature brown residual soils (Karamsarik) and undifferentiated residual soils (slope soils, shallow). Well drained	Lowland hill forest with secondary forest and garden regrowth. Some *Themeda–Arundinella* short grassland along the inland margin	VIII; some VIe and VIIe

Population and Land Use.—Population is relatively sparse and scattered, only reaching a density of 6 persons per sq mile. The 24 villages scattered in the north-western part have a total population of 2310.

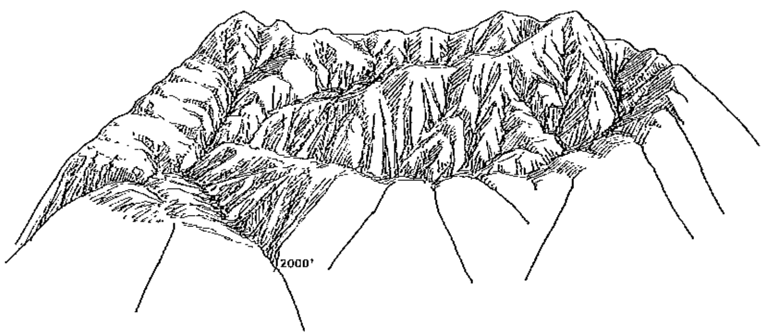
Assessment.—This is mountainous country with a very low potential value. The young volcanic soils, although often acid and shallow, may not be a serious limitation to land use, but the slopes are more often very steep and stony and there are erosional hazards.

(3) Atitau Land System (80 sq miles)

Uniform remnants of old uplifted Tertiary sediments.

Geology.—Presumably as in Gal land system.

Physical Features.—Closely dissected, rounded hill ridges on watersheds above 2000 ft within Gal land system; narrow, V-shaped valleys; relief 100–400 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
Whole of land system	80	Hill ridges: rounded crests and dissected, moderately steep slopes, 15–30°	Strongly weathered red and brown clay soils (Autobak, Korog). Well drained	Lowland hill forest with some stands of *Castanopsis* (oak)	VIe and VIIe

Population and Land Use.—Some 20 villages with 2300 inhabitants are found throughout this small scattered land system giving a density of 28 per sq mile. This no doubt reflects the gentler topography.

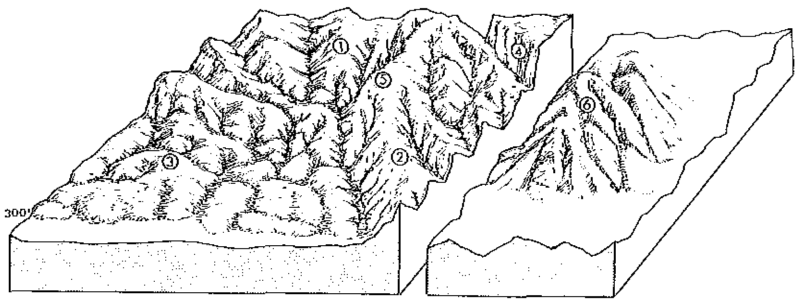
Assessment.—Although less rugged and offering better potential for tree crops, Atitau land system is really an aspect of Gal land system. Soils are generally of low fertility.

(4) Gal Land System (1000 sq miles)

Rugged low mountains of greywacke with interbedded sediments and tuff. (Plate 7, Fig. 2.)

Geology.—Sandstone and mudstone of Miocene and Pliocene age with interbedded greywacke, limestone, and volcanic tuff and agglomerate; anticlinally folded and block faulted on NW.–SE. lines.

Physical Features.—Rugged low mountains with narrow steep-sided ridges, V-shaped valleys and steep bounding escarpments; minor areas of closely dissected lower ridges, probably on softer rocks, and narrowly dissected low hilly terrain; close dendritic drainage pattern, with longitudinal valleys in central part and shorter transverse valleys on margins; relief up to 1500 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	600	Higher mountain ridges: narrow crests and long very steep slopes, 25–40°; relief 500–1500 ft	Undifferentiated residual soils (slope soils, deep; slope soils, shallow) and immature brown residual soils (Karamsarik, Warwin). Well drained	Mainly lowland hill forest with some garden regrowth and secondary forest. Lower montane forest on crests above 3000 ft	VIII and VIIe
2	330	Lower mountain ridges: closely dissected ridges with short narrow crests and gullied slopes, 15–35°; relief 300–600 ft	Mainly undifferentiated residual soils (slope soils, shallow, and locally, slope soils, deep). Also strongly weathered red and brown soils (Autobak, Korog). Well drained	Mainly secondary forest and garden regrowth of lowland hill forest	VIIe and VIe
3	50	Hilly terrain: low rounded ridges with moderate slopes, 10–20°; forming sectors up to 1 mile wide between river gorges	Strongly weathered red and brown clay soils (Autobak, Korog). Well drained	Lowland hill forest	IIIe and IVe
4	15	Escarpment and cliffs: very steep to precipitous slopes, 45–60°, with weathered rocky surfaces; relief up to 1500 ft	Undifferentiated residual soils (slope soils, shallow) and lithosols. Excessively drained	Stunted slope aspect of lowland hill forest	VIII
5	<5	Flattish crests: spur and ridge crests up to 300 ft wide and between 1000 and 3000 ft above sea level	Strongly weathered red and brown clay soils (Korog, Koropa, and more rarely Kaove). Well drained	Well-developed lowland hill forest. Some garden regrowth near village sites	III
6	<5	Volcanic cones: small strato-volcanoes up to 1500 ft high with very steep strongly gullied slopes	Undifferentiated residual soils (slope soils, shallow). Well drained	Lowland hill forest, secondary forest and garden regrowth	IIIe

Population and Land Use.—Over 100 villages are scattered throughout and account for 11 300 people making a density of 11 per sq mile. However, population and land use are centred in unit 1 with virtually little use in the others.

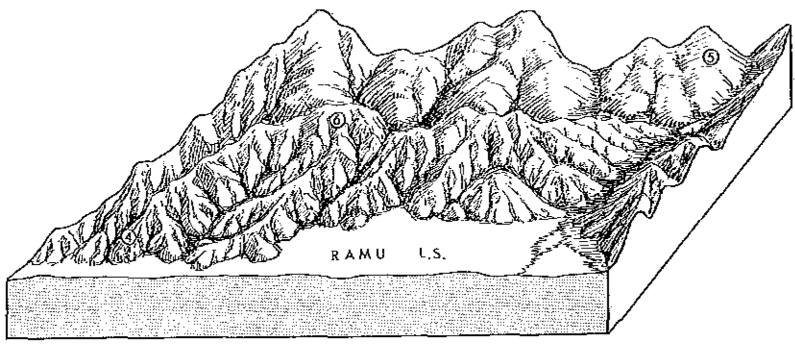
Assessment.—Because of the ruggedness any large-scale development is impractical. The great importance of this land system is as a catchment and higher parts should be left in protective forest. However, some exploitation may be feasible around the margins. The impact of shifting agriculture is still local. Tree crops could be introduced.

(5) Bismarck Land System (560 sq miles)

Lower montane slopes and foothills forming the northern lowland fringe of the Bismarck Range. (Plate 4, Fig. 2.)

Geology.—Along the NW.-SE.-trending border Tertiary sediments of shale are found inland to Aiome where Tertiary gabbros, diorite and other igneous rocks continue to the Usino basin. From here to Gusap metamorphics of low-grade schists dominate.

Physical Features.—Long densely dissected lower mountain ridges and slopes with narrow crests; less-dissected massive round-crested ridges and much-dissected lowland foothill slopes and ridges. Altitude all below 3000 ft with relief up to 800 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
4*	245	Very severely dissected lower foothill country with steep, 17–35°, short and long slopes and V-shaped valleys; relief 200–800 ft but all below 3000 ft altitude	Undifferentiated residual soils (slope soils, shallow) and lithosols. Excessively drained	*Themeda–Arundinella* short grassland with remnants of lowland hill forest	VIIe,so_2 and minor VIe,so_2
5	170	Massive lower mountain ridges: long straight slopes, 25–35°, decreasing to 10°, nearly rounded crests; relief 200–800 ft. All under 2500 ft altitude	Strongly weathered red and brown clay soils (Ainan, Baia, Korog). Weathered gleyed clay soils (Bibi). Undifferentiated residual soils (slope soils, shallow, and locally, lithosols). Mostly well drained	Lowland hill forest with some *Themeda–Arundinella* short grassland	VI and VIIe
6	145	Dissected lower mountain ridges: long but densely dissected slopes, 17–45°, narrow crests; relief 200–400 ft. All under 3000 ft altitude	Undifferentiated residual soils (slope soils, shallow) and strongly weathered red and brown clay soils (Baia). Well drained	Secondary lowland hill forest and garden regrowth	VIIe; VII; minor VIe and VIIe,so_2

* Bismarck land system is described in the report on the Goroka–Mount Hagen area (Haantjens *et al.* 1970). Only three units lying in the lowlands are dealt with in this report. Units 1, 2, 3, 7, 8 occur in the Goroka–Mount Hagen area.

Population and Land Use.—Population is sparse along these rugged foot slopes. Only 11 villages are found in the southern part and account for some 2000 inhabitants making a population density of 4 per sq mile for the whole area.

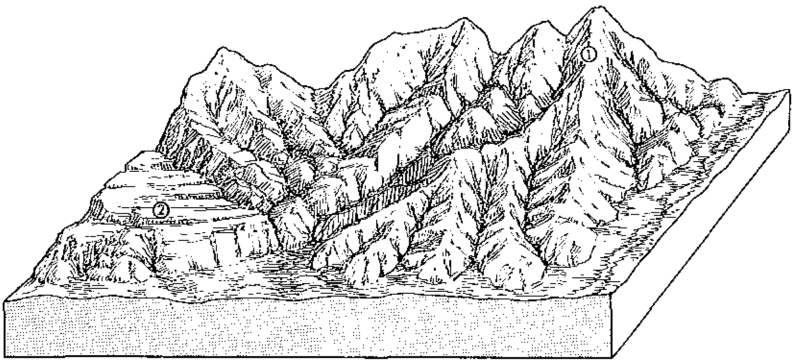
Assessment.—The ruggedness and general inaccessibility as well as the need to preserve the watershed make it unsuitable for any development; hence the land class classifications VIIe and VIII predominate. However, some shifting cultivation with secondary forest and grassland is already evident.

(6) Romole Land System (55 sq miles)

Strongly dissected steep foothills along the south flanks of the Finisterre Range. (Plate 2, Fig. 2.)

Geology.—Pliocene sandstone and siltstone with rhyolitic lava beds in the west; Pleistocene boulder and cobble conglomerate in the east.

Physical Features.—Very severely dissected foothills with 'badland' topography of extremely close sharp ridges and gullies in the east; surviving flattish interfluves with gullied margins in the west; the through-going large rivers are part of Bumbu land system; up to 300 ft relief.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	45	Very narrow ridges: intensely gullied steep slopes, 30–40°, locally precipitous; relief 100–300 ft	Immature brown residual soils (Bopirompon). Undifferentiated residual soils (lithosols). Rarely limestone soils (Mosia), rarely strongly weathered red and brown clay soils (Koropa). Excessively drained	*Themeda–Arundinella* short grassland	VI-VIIe,so_3
2	10	Small plateaux: flattish interfluves up to 1½ miles wide, sloping gently from backing ranges; less than 20 ft local relief	Mostly undifferentiated residual soils (lithosols and slope soils, shallow). Excessively drained	Short grassland as above with some lowland hill forest	VIso_2 and VI

Population and Land Use.—The population is nil.

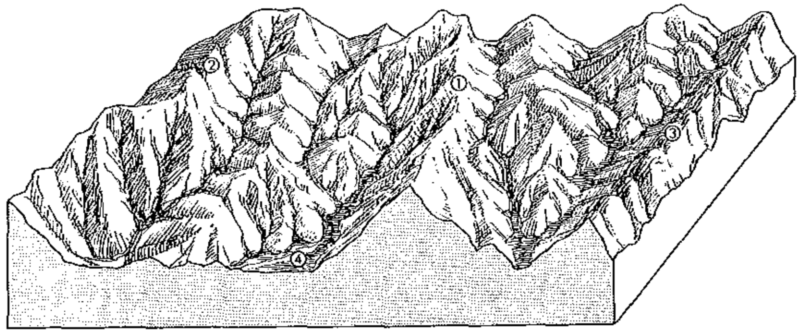
Assessment.—Although now unoccupied the short grassland cover with some forest remnants points to a past history of clearing. Subsequent gully dissection of the soft rock, irregular stream flow, and small landslips have led to degradation and hence the present classification is to a very low land use potential.

(7) Bagasin Land System (585 sq miles)

Steep rugged sandstone and limestone hills to low mountains. (Plate 5; Plate 12, Fig. 1.)

Geology.—Steeply dipping sandstone, mudstone, calcareous sandstone, marl and coral limestone of Miocene and Pliocene age, with minor greywacke and basalt; locally block faulted on NW.-SE. strike lines.

Physical Features.—High hilly terrain with closely dissected branching ridges on softer rocks and higher continuous hogback ridges on sandstone and limestone fault blocks; steep hill slopes, locally with landslide scars; close dendritic pattern of narrow valleys with small flood-plains; relief up to 1000 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	430	Branching ridges and hills: narrow-crested closely dissected ridges and hills, generally wth steep slopes, 30–45°, locally with recognizable gentler dip slopes and steeper irregular escarpments; relief 400–800 ft	Predominantly immature brown residual soils (Karamsarik, Banam, Warwin), more rarely immature mottled residual soils (Aiha, Tebinsarik). Locally undifferentiated residual soils (slope soil, mudstone, and slope soils, shallow). Well to excessively drained with some seasonal waterlogging	Lowland hill forest with garden regrowth and secondary forest. Patches of *Ophiuros–Imperata* mid-height grassland and *Themeda–Arundinella* short grassland	VIe; VIe,so$_2$; VIIIe; VIIIe,so$_2$ and VIII. Small areas of IIIe; IVc,so$_3$; VIe,so$_8$
2	145	Limestone strike ridges: narrow-crested straight ridges with steep slopes, 30–45°; prominent rocky escarpments with numerous landslide scars; relief up to 1000 ft	Undifferentiated residual soils (Podago, slope soils, shallow). Mostly well to excessively drained	Lowland hill forest, small areas of secondary forest and garden regrowth with *Themeda* and *Ophiuros* grassland patches near the coast	VIII
3	10	Sandstone strike ridges: as for unit 2 but with less prominent escarpments; relief 200–800 ft	Mainly undifferentiated residual soils (slope soils, shallow, and on crests, lithosols). Locally immature brown residual soils (Banam). Well to excessively drained	Lowland hill forest and some garden regrowth	VIIe,so$_4$ and VIII
4	<5	River terraces and flood-plains: flights of narrow alluvial terraces 6–20 ft above the river level; narrow flood-plains; combined width up to 300 ft	Young alluvial soils (7). Well to imperfectly drained	Garden regrowth within alluvial well-drained forest	I and IIe

Population and Land Use.—This land system is fairly well populated as there are 78 villages scattered throughout with a population of 11 100 making a density of 19 persons per sq mile. Thus, intensive shifting cultivation occurs in several areas to the point where it is inducing grassland and some erosion.

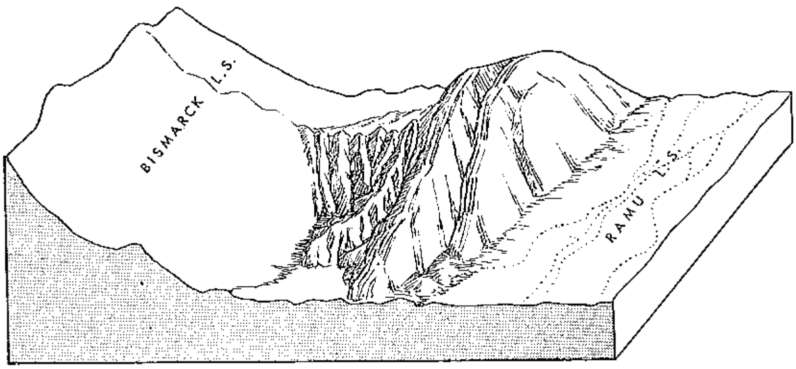
Assessment.—Apart from very small areas the land is too rugged for permanent cultivation. Much of the land system, which constitutes a second-order catchment, should be conserved. The soils are generally shallow and there are both slip and erosion hazards.

(8) Otaki Land System (10 sq miles)

Steep limestone ridges. (Plate 2, Fig. 1.)

Geology.—Steeply dipping, massive siliceous limestone of Miocene age.

Physical Features.—Discontinuous single ridges up to 1000 ft high.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
Whole of land system	10	Limestone ridges: narrow crests and steep rocky slopes	Probably mainly lithosols. Excessively drained	Mainly bare rock but with some sparse grasses and woody plants	VIII

Population and Land Use.—Unpopulated.

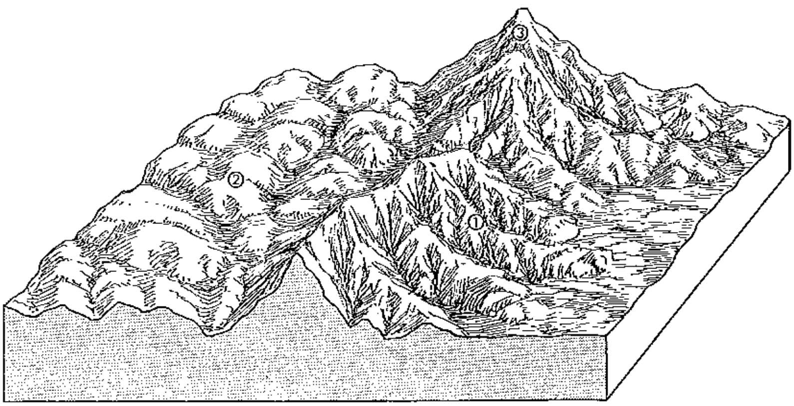
Assessment.—Useless from a land use point of view.

(9) Musak Land System (160 sq miles)

Very rugged hilly country in one tract along the north-eastern edge of the Ramu valley.

Geology.—Steeply dipping mudstone, sandstone and minor conglomerate of Miocene to Pleistocene age; anticlinally folded and block faulted on NW.–SE. axes.

Physical Features.—High hilly terrain; a regular pattern of a few higher continuous strike ridges and long serrated spurs dissected on strike lines, with a central belt of lower, rounded hills and short ridges; closely spaced, transverse tributary drainage in steep narrow gorges, and winding major valleys; relief up to 500 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	100	Dissected spurs: narrow-crested serrate ridges dissected by strike-guided ravines; slopes 25–40°; relief 300–500 ft	Mainly undifferentiated residual soils (slope soils, shallow) and immature brown residual soils (Banam). Well drained	Lowland hill forest. Some secondary forest and garden regrowth with incipient patches of *Themeda–Arundinella* short grassland	Complex of VIIe,so$_2$ to VIII
2	55	Rounded hills and ridges: moderate to steep slopes, 1–30°, and rounded crests; relief 100–400 ft	Mainly immature brown residual soils (Karamsarik, Warwin). Well drained but with possible waterlogging in wet season	Lowland hill forest; some garden regrowth	VI to VIIe and VIIe,so$_2$
3	5	Strike ridges: very narrow-crested sandstone ridges with long steep dip slopes and precipitous rocky escarpments	Undifferentiated residual soils (slope soils, shallow, and lithosols). Also rock outcrops. Well to excessively drained	Lowland hill forest	VIII with some VIIe,so$_2$

Population and Land Use.—There is a population of 720 occupying 6 villages in the eastern part only. Total population equals 5 persons per sq mile. There is limited land use for gardens and such shifting agriculture has initiated grassland patches.

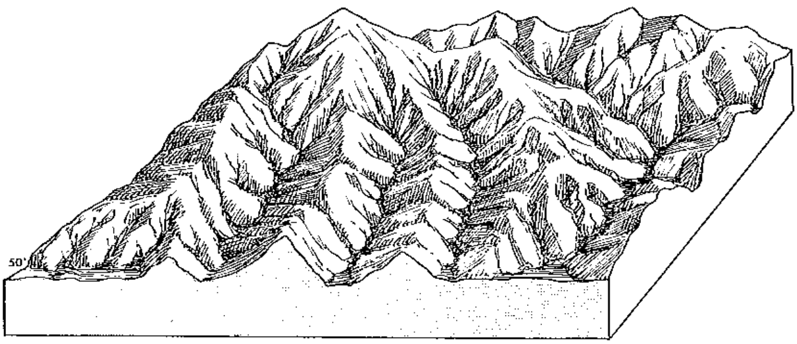
Assessment.—There may be moderate timber resources but the country is rugged and generally inaccessible for agricultural development.

(10) Wanabutu Land System (20 sq miles)

Steeply dissected hilly country along the north coast.

Geology.—Weathered greywacke, shale, sandstone, and minor rhyolite lavas of upper Tertiary to Pleistocene age; thin gravel cappings locally.

Physical Features.—Secondary watershed areas of closely dissected high ridges and hills, with steep, strongly gullied slopes; close dendritic drainage pattern of incised, V-shaped valleys; altitude up to 800 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
Whole	20	Short ridges and hills: mainly narrowly rounded crests and steep gullied slopes, 25–40°; relief 50–500 ft	Predominantly undifferentiated residual soils (Podago and, locally, lithosols with rock outcrops). Excessively drained	Remnants of lowland hill forest border streams, but mainly grassland of both *Ophiuros–Imperata* and *Themeda–Arundinella*	VIIc,so$_4$

Population and Land Use.—There is only 1 village with a population of 70. However, the extent of grassland indicates a past history of greater land use.

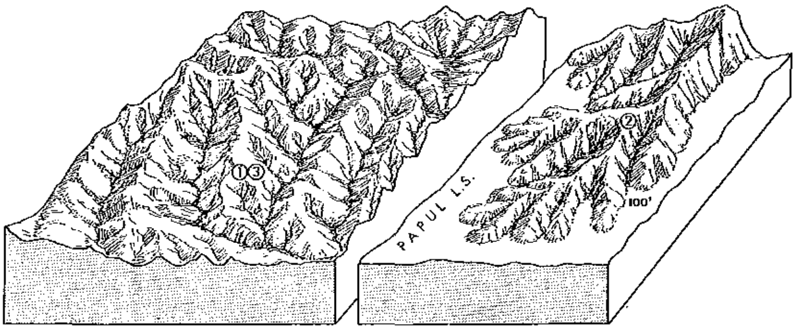
Assessment.—The area, which has good access, has a potential for extensive grazing and reafforestation.

(11) Morumu Land System (960 sq miles)

Very strongly dissected hilly country of widespread occurrence.

Geology.—Mainly gently dipping mudstone, siltstone and sandstone of Pliocene and possible Pleistocene age, with minor coral limestones and interbedded gravels.

Physical Features.—Closely spaced short ridges and hills and a few higher strike ridges; close dendritic drainage pattern of narrow valleys; relief up to 400 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	900	Hills and ridges: narrowly rounded undulating crests, and steep slopes, 15–35°, locally irregular due to minor landslips	Mostly immature brown residual soils (Banam, Karamsarik, Origa, Warwin). Locally undifferentiated residual soils (slope soils, mudstone and lithosols). Small areas of immature mottled residual soils (Aiha, Tebinsarik). Well to excessively drained but with some temporary waterlogging	Lowland hill forest. Large local regions of secondary forest and garden regrowth and patches of grassland of *Ophiuros–Imperata* and *Themeda–Arundinella*	Mostly VI; VIIe and VIIIe,so$_1$; small patches IIIe and IVe,so$_1$
2	40	Steep hills and ridges: strongly dissected with very steep slopes, 25–50°, deep gullies in higher parts	Immature brown residual soils (Banam, Warwin). Excessively drained	Mainly garden regrowth with lowland hill forest along ridge crests	VIII and some VIIe
3	20	Limestone cappings: platforms up to 20 ft high and generally less than an acre in extent; uneven rocky surfaces and low cliff margins	Undifferentiated residual soils (lithosols) and, locally, limestone soils (Opar). Excessively drained	As for unit 1	VIe,so$_2$ and VIIe

Population and Land Use.—Although population density is about 9 per sq mile for the whole land system, local population intensity is high with 73 villages with a total of 8480. Shifting agriculture is active over much of the area but grassland is only incipient.

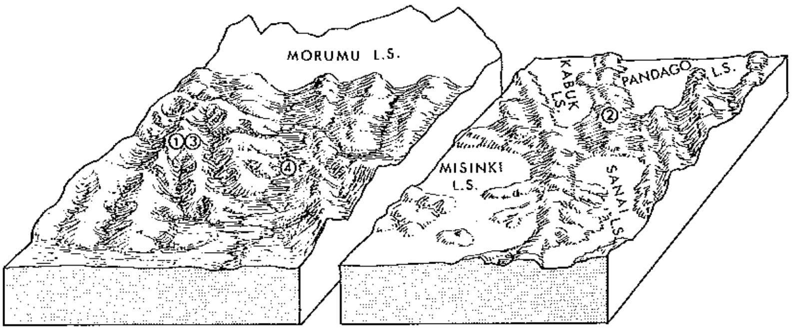
Assessment.—Too steep for permanent cultivation and there are soil hazards such as shallowness and temporary waterlogging. The area has some importance as a catchment to the Sogeram and Guam Rivers. When access is available there are some timber resources along the lower margins.

(12) AMAIMON LAND SYSTEM (670 SQ MILES)

Low hilly country with narrow alluvial valleys. Widespread but scattered occurrence over a large part of the survey area.

Geology.—Gently dipping mudstone and sandstone of Miocene and Pliocene age, with minor coral limestone and overlying gravels.

Physical Features.—Closely set irregular low rounded hills and ridges flattening out into adjoining alluvial plains; very fine dendritic pattern of incised minor valleys tributary to more open valleys with discontinuous narrow flood-plains and terraces; relief up to 150 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	450	Higher hills and ridges: rounded crests and moderate to gentle slopes, 4–12°; locally hummocky lower slopes; relief up to 150 ft	Immature mottled residual soils (Aiha, Tebinsarik) and immature brown residual soils (Karamsarik, Reinduk, and Warwin). Undifferentiated residual soils (slope soils, mudstone). Some weathered gleyed clay soils (Giri) and alluvial black clay soils (Kasamp). Poorly drained except locally	Small areas of lowland hill forest but mostly secondary forest and garden regrowth with much *Ophiuros–Imperata* grassland	IIIe; $IVso_3$ and IVe,so_3; IVe,so_2 and $VIso_3$
2	185	Lower hills and ridges: broad, rounded crests and short, moderately steep slopes, 10–25°; relief up to 100 ft	Strongly weathered red and brown clay soils (Koropa) with weathered gleyed clay soils (Giri). Immature mottled residual soils (Tebinsarik) and immature brown residual soils (Karamsarik). Mostly well drained but locally poorly drained	As in unit 1 but with more remaining forest	As in unit 1
3	15	Limestone cappings: rocky platforms and blocks up to 1 ac in extent with precipitous margins up to 30 ft high	Undifferentiated residual soils (lithosols) and, very locally, limestone soils (Opar). Excessively drained	Lowland hill forest	As in unit 1
4	20	Flood-plain and terraces: discontinuous alluvial terraces up to 300 ft wide and 20 ft above water level; narrow flood-plains about 6 ft above low water	Mainly young alluvial soils (4, 7, 8), alluvial black clay soils (Mungin) on terraces and colluvial slopes. Well to poorly drained, often flooded in wet season. Water-table still high in the dry season	Well-drained alluvial forest, locally alluvial flood-plain forest, sago palm forest and swamp	$IVso_3$; IVf and IVf,d

Population and Land Use.—There are 28 villages in the area. With over 100 persons in each the total population is some 3200, making a density of only 5 per sq mile.

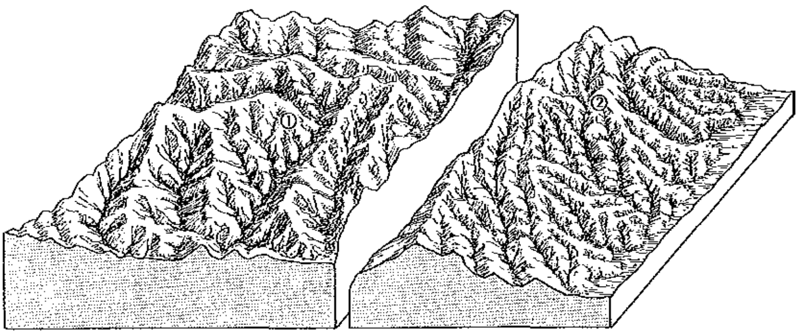
Assessment.—The irregular topography and predominance of poorly drained and impermeable or of shallow soils make this land generally unattractive for permanent development. Parts already under grassland may be suitable for grazing. The fragmentation of the land system is a disadvantage and in particular the agricultural value of the scattered hills of unit 2 is almost negligible. Small flat areas subject to flooding could be used for wet rice. Timber resources will have to await access roads.

(13) Sangan Land System (120 sq miles)

Strongly dissected steep hilly country near the coast.

Geology.—Gently dipping sandstone, mudstone and minor greywacke and conglomerate of Miocene and Pliocene age.

Physical Features.—An irregular pattern of closely spaced, dissected ridges and hills, with minor strike ridges; close dendritic drainage pattern of narrow valleys; mainly up to 300 ft relief, locally attaining 400 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	110	Ridges and hills: narrowly rounded crests; dissected steep slopes, 15–35°, with irregular profiles due to landslips; relief mainly 100–300 ft	Predominantly undifferentiated residual soils (Podago, locally lithosols). Some immature brown residual soils (Karamsarik, Warwin) and rock outcrops. Well to excessively drained	Lowland hill forest remnants and secondary forest, especially along gullies. Extensive gardens and regrowth. Much *Themeda–Arundinella* short grassland	VIe,so_2
2	10	Dissected strike ridges: narrow crests, very steep escarpments, and steep dip slopes, 20–35°; extremely dissected into rounded branching spurs in lower parts; relief mainly 100–200 ft, locally attaining 300 ft	Undifferentiated residual soils (Podago and lithosols). Excessively drained	As in unit 1 with some garden regrowth	VIIe,so_2

Population and Land Use.—Intensive shifting agriculture due to high population, especially in unit 1. There are 30 villages with a total population of over 4000, making a density of 34 per sq mile.

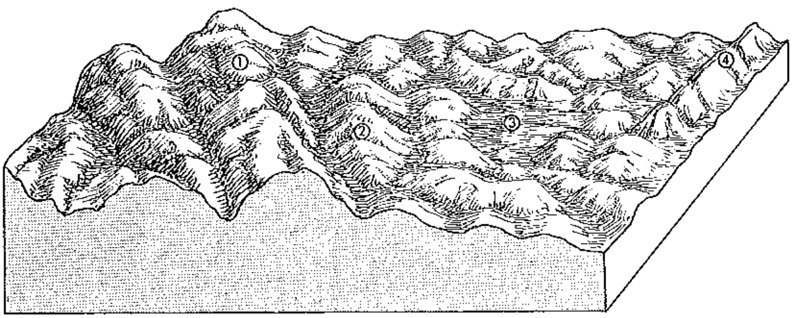
Assessment.—The inherently drier climate coupled with shallow soils make grazing the most immediate feasible land use. Access from the coast is good and forest plantations of commercial timber species are possible.

(14) Amele Land System (200 sq miles)

Strongly dissected hilly country up to 800 ft high along the coast. (Plate 8, Fig. 1.)

Geology.—Subhorizontal soft marl, siltstone, sandstone and minor conglomerate of Pliocene and Pleistocene age, with coral reef limestone on coastal margin.

Physical Features.—Coastal foothills with closely spaced rounded hills and short ridges; steep coastal fault scarp with minor cliffing; branching tributary valleys, very steeply incised in upper sectors; up to 300 ft relief.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	125	Ridges: narrowly rounded, undulating crests with moderately steep upper slopes, 10–30°, steepening in lower sectors; up to 300 ft relief	Immature brown residual soils (Karamsarik, Banam, Origa). Weathered gleyed clay soils (Hudini) and immature mottled residual soils (Tebinsarik). Good to imperfect drainage, excessive in river gorges	Lowland hill forest and secondary forest locally replaced by garden regrowth and plantation	VIe; VIIe and VIII in gorges
2	65	Hills: rounded hills with moderately steep slopes, 10–30°; up to 200 ft relief	Immature brown residual soils (Banam, Kalai, Reinduk, Origa, Warwin). Weathered gleyed clay soils (Hudini). Immature mottled residual soils (Aiha, Tebinsarik). Well to imperfectly drained with waterlogging in the wet season	As for unit 1	Mostly VIe; VIe,so$_3$. Also VIIe; IVe,so$_3$ and IIIe
3	5	Alluvial basins: gently undulating, undissected floors	Young alluvial soils (7). Poorly drained	Alluvial forest, much of it secondary	IVso$_3$
4	5	Coral ridges: narrow rocky ridges with steep slopes; up to 200 ft high	Limestone soils (Waguk). Undifferentiated residual soils (lithosols). Excessively drained	As for unit 1	VIIe,so$_2$ and VIII

Population and Land Use.—Locally densely populated and sustaining intensive shifting agriculture. There are 38 villages with an average of 157 inhabitants. This makes a total population of 5950 and a density for the whole land system of 30 per sq mile.

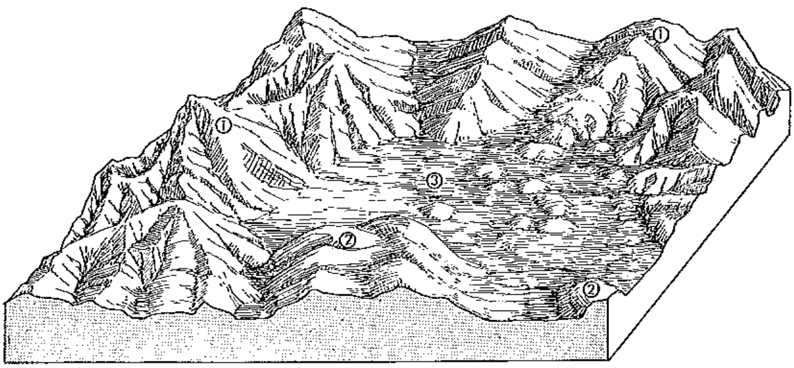
Assessment.—A coastal land system with easy access. However, land suitable for permanent cultivation is very scattered. Impermeable soils, often waterlogged in the wet season, present problems and would indicate a grazing economy. There are some timber resources.

(15) Sirin Land System (10 sq miles)

Complex pattern of grass-covered steep hills enclosing swampy basins. (Plate 12, Fig. 2.)

Geology.—Gently dipping sandstone of Miocene and Pliocene age interbedded by Pleistocene rhyolitic lavas and volcanic agglomerates.

Physical Features.—In the south, isolated steep ridges partly enclosing an alluvial basin; in the north, lower rounded ridges and hills; drainage consists of incised, branching ravines, in part tributary to the ill-drained alluvial basin; relief up to 200 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	5	Higher ridges and hills: narrow crests and concave slopes of moderate steepness, 15–35°; relief 100–200 ft	Undifferentiated residual soils (Podago and, locally, lithosols). Excessively drained	*Ophiuros–Imperata* and *Themeda–Arundinella* short grassland	VIe,so$_2$ and VIIe,so$_2$
2	5	Low ridges and hills: broad, rounded crests and convex or straight slopes of moderate steepness; relief up to 50 ft	Immature mottled residual soils (Sirin). Weathered gleyed clay soils (Naupi) and undifferentiated residual soils (Podago). Excessively drained in the dry but liable to waterlogging in the wet season	*Ophiuros–Imperata* grassland. Some secondary forest and bamboo brake, little garden regrowth	As for unit 1
3	<5	Alluvial basins: undissected ill-drained floors sloping very gently from colluvial aprons on margins and in tributary valleys	Alluvial black clay soils (Kasamp). Poorly drained but drying out in the dry season	*Ischaemum* short grassland and some low sago palm swamp	Vd

Population and Land Use.—Only one large village is left in this small predominantly grassland land system. This has a population of 210 which makes a density of 18 per sq mile.

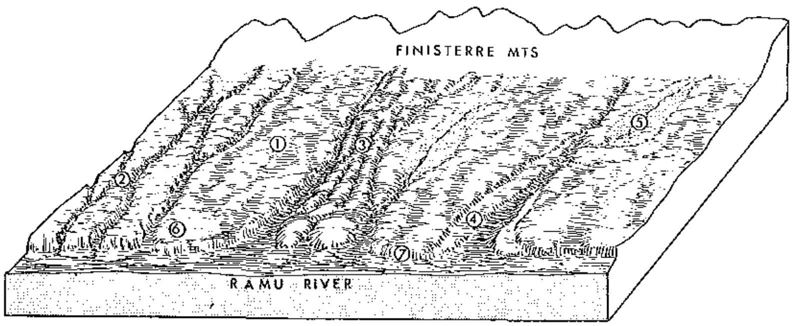
Assessment.—The hills are at best suitable only for grazing whilst the poorly drained alluvial basins with heavy clay soils are suitable for paddy rice. Access to these open grasslands is good but in all the area is very small.

(16) Bumbu Land System (105 sq miles)

Very gently sloping to undulating alluvial plain between the Ramu River and the Finisterre Range. (Plate 2; Plate 3, Fig. 2.)

Geology.—Bedded cobble gravels and coarse sands.

Physical Features.—Little-dissected coalescent fans up to 4 miles long and sloping up to 2° from backing hills; flat to gently undulating surfaces becoming more irregular in areas of incipient dissection or continuing deposition; alluvial terraces of tributaries and locally of the Ramu River; marginal bluff up to 30 ft high against Ramu flood-plain.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	80	Fan surfaces: level or gently undulating surfaces traversed by unchannelled drainage depressions up to 150 ft wide	Well-drained old alluvial soils (Ouarara, Lanu, Kaigulan, Sausi, Bembi, Dumpu). Well to excessively drained	*Themeda–Arundinella* short grassland and some garden regrowth	IVso$_2$ and VIso$_2$; less of IIe and I
2	10	Dissected fan surfaces: flat-crested interfluves up to 600 ft wide separated by narrow steep-sided gullies incised up to 20 ft	Well-drained old alluvial soils (Dumpu, Bembi, Lanu). Well drained	As for unit 1	IIe and IIe,so$_2$; some II; IIIe,st
3	10	Undulating surfaces: accordant rounded crests 10–40 ft high, moderately steep concave slopes, and unchannelled valley floors	Immature mottled residual soils (Biwi) and alluvial black clay soils (Surinam). Mostly imperfectly drained	*Themeda–Arundinella* short grassland	IVe,so$_3$
4	5	Tributary terraces: flat surfaces up to 1200 ft wide and 60 ft above the incised river plains	Well-drained old alluvial soils (Ouarara, Lanu). Excessively drained but liable to flooding on the lower terraces	*Themeda–Arundinella* short grassland	VIso$_2$
5	< 5	Younger fan surfaces: irregular stony flood-outs less than 1 mile wide and extending up to 1 mile from small tributary valleys	Young alluvial soils (1, 5). Unstable sand, gravel, and stones. Excessively to well drained	*Themeda–Arundinella* short grassland and herbaceous river-bank succession	Mainly VIII and IIso$_2$
6	< 5	Ramu terrace: flat surface up to ¾ mile wide and about 20 ft above the flood-plain	Alluvial black clay soils (Sangkian). Poorly drained	*Ophiuros–Imperata* grassland	IVso$_3$
7	< 5	Escarpments: low bluffs flanking terraces and fans; steep to vertical banks, gullied in sectors	Fine-textured sediments. Excessively drained	Bare	VIII

Population and Land Use.—Some gardening is still carried out by the population of 400 in 4 villages but mainly the area is uninhabited short grassland.

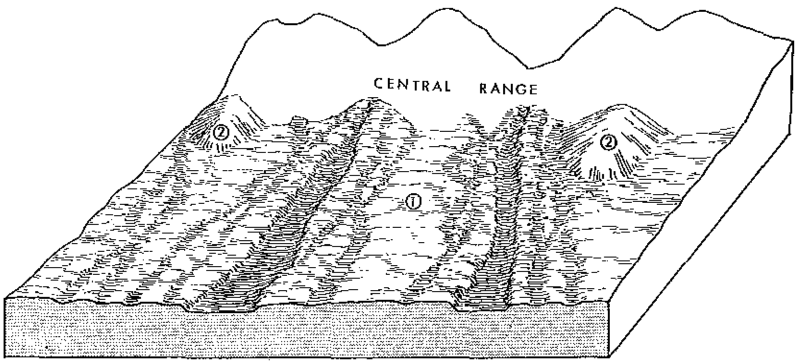
Assessment.—Small pockets of deeper soils and the alluvial soils offer limited agricultural development but on the whole the soils are shallow and stony and may suffer seasonal water stress.

(17) Faita Land System (25 sq miles)

Slightly sloping colluvial fans from the central ranges.

Geology.—Unsorted cobble gravels and sands.

Physical Features.—Undissected gravel fans less than 1 mile long; gently sloping stony surfaces, traversed by abandoned shallow braiding drainage channels; backing colluvial slopes of moderate steepness.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	15	Fan surfaces: stony surfaces with slopes less than 5°, with abandoned channels up to 100 ft wide and 6 ft deep	Well-drained old alluvial soils (Tumu, Weisa). Strongly weathered red and brown clay soils (Aimi). Well drained	Tall *Saccharum* grassland with some *Themeda–Arundinella* short grassland. Patches of alluvial forest and garden regrowth	Mostly I and $IIso_2$
2	10	Colluvial aprons: backing slopes of moderate steepness up to ½ mile long, gullied locally	Unstable gravel and stones. Excessively drained	*Themeda–Arundinella* short grassland	$VIso_2$ and $VIIso_2$

Population and Land Use.—Virtually none. There is 1 village of 160 inhabitants on this land system.

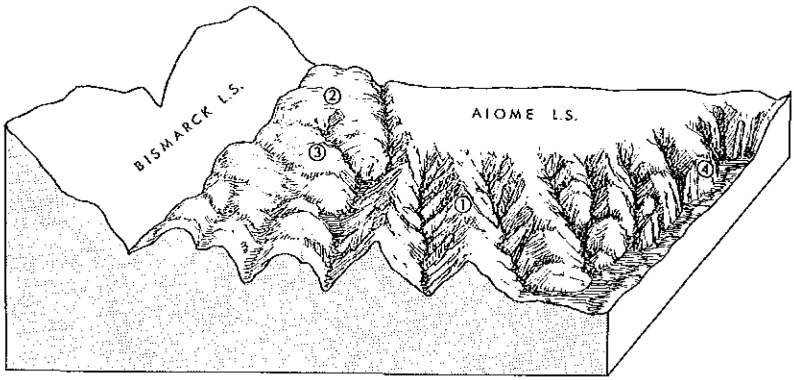
Assessment.—Soils often stony and droughty and there appears little potential for this land system.

(18) Panakatan Land System (105 sq miles)

Low but steep hilly country forming part of the fans from the central mountains.

Geology.—Unsorted, locally bedded, cobble and boulder gravels with sand lenses.

Physical Features.—Very closely set narrow ridges and hills formed by the dissection of older fans, with minor rounded hills in less-dissected areas; gently sloping, undissected distal fan remnants; fault scarps; narrow spurs on dissected fan margins; very closely spaced small gullies; relief up to 200 ft.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	75	Dissected terrain: very narrow-crested ridges, spurs, and hills with steep slopes, 15–40°; relief up to 200 ft	Mostly strongly weathered red and brown clay soils (Sepu, Aiome). Well drained	Lowland hill forest and garden regrowth	VI–VIIe,so_2 and VII
2	10	Gentle slopes: flattish or gently undulating, undissected surfaces	Dominantly strongly weathered red and brown clay soils (Sepu, Mambu) with weathered gleyed clay soils (Mea) and well-drained old alluvial soils (Weisa). Well drained	Lowland hill forest with secondary forest and garden regrowth. Some *Themeda–Arundinella* short grassland and tall *Saccharum* grassland	Mostly IIso$_1$
3	20	Rounded hills: broad rounded crests with steep convex slopes; relief to 100 ft	Strongly weathered red and brown clay soils (Aiome), locally stony. Well drained	Lowland hill forest with small patches of *Ophiuros–Imperata* grassland	VI
4	<5	Escarpments: very steep slopes, up to 45°, dissected by gullies and broken by rock falls; 30–200 ft high	Undifferentiated residual soils (slope soils, shallow). Well drained under forest cover	Lowland hill forest	VIIe to VIII

Population and Land Use.—Only 1 village of 170 inhabitants. Only locally used for shifting cultivation which has been followed by some grassland.

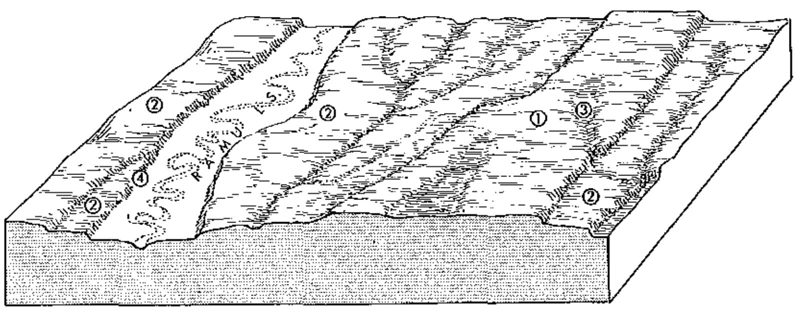
Assessment.—This land is much too strongly dissected for permanent cultivation. The chemical fertility of the soils appears to be very low. Some forest exploitation will be possible when access is made.

(19) Aiome Land System (60 sq miles)

Gently sloping fan surfaces. (Plate 6, Fig. 2.)

Geology.—Unsorted locally bedded cobble and boulder gravels with sand lenses.

Physical Features.—Little-dissected, lobate alluvial fans up to 2 miles wide and 5 miles long, attaining between 100 and 150 ft above present flood-plains; very gently undulating surfaces with regional slopes up to 3°; parallel through-going rivers (Ramu land system) with flanking alluvial terraces.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	40	Fan surfaces: gentle slopes up to 3°	Dominantly strongly weathered red and brown clay soils (Aiome, Sepu). Some weathered gleyed clay soils (Mea). Well drained	Lowland hill forest. Much *Ophiuros–Imperata* grassland	$IIso_1$
2	15	Terrace surfaces: flat surfaces up to ¼ mile wide, 30–60 ft above present flood-plains	Strongly weathered red and brown clay soils (Sepu, and locally Mambu). Also well-drained old alluvial soils (Weisa). Well drained	Alluvial well-drained forest	$IIso_1$
3	5	Shallow depression: elongate depressions up to ½ mile wide and 30 ft below fan surface	Organic soils (Jamenke). Inundated in wet season and poorly drained	*Ischaemum* moist grassland	IId and IIId
4	< 5	Escarpments: up to 60 ft high, with steep, gullied slopes above 25°	Strongly weathered red and brown clay soils (Sepu). Well drained	Lowland hill forest	VIe to VIIe

Population and Land Use.—Mostly uninhabited grassland. There are only 2 villages accounting for 100 inhabitants.

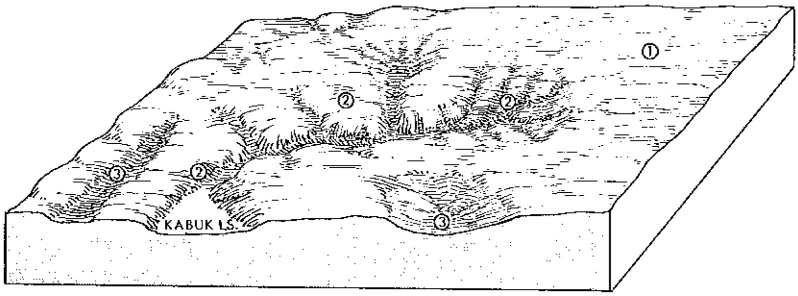
Assessment.—This land system comprises very good agricultural land. Generally topsoil conservation will be necessary and some parts will require improved drainage. However, access is at present nil.

(20) BOSMAN LAND SYSTEM* (75 SQ MILES)

Low flat to undulating plateau west of the Ramu River mouth and continuing into the Sepik District.

Geology.—Estuarine clays, minor sands, and thin shell beds of Pleistocene age on a base of coral limestone.

Physical Features.—Low platform, up to 40 ft above adjacent flood-plains; gently undulating, ill-drained upper surface with shallow depressions; with moderately steep margins partly dissected by deep branching gullies.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	35	Plains: flat to very gently undulating, with slopes below 2°	Alluvial black clay soils (Bosman). Poorly drained	*Ophiuros–Imperata* and moist *Ischaemum* grasslands	$IVso_3$
2	35	Margins along edges of land system: short, moderately steep slopes, up to 25°, partly dissected into short rounded spurs with steep gullied margins	Alluvial black clay soils (Bosman). Immature brown residual soils (Kalai). Poorly drained	Lowland hill forest and some *Ophiuros–Imperata* grassland	IIIe and IVe,so_3
3	5	Shallow depression: circular or elongate marshy depressions up to 300 ft across and a few feet below the general level of the plain	Alluvial black clay soils (Kasamp) and young alluvial soils (?). Depressions are very poorly drained to swampy	Sago palm forest and swamp and *Phragmites* swamp	Vf,d

Population and Land Use.—Virtually nil as there is only 1 village in this land system with 160 people.

Assessment.—Deserves some attention because it comprises large areas of unoccupied flood-free accessible flat grassland with its doubled extension into the Wewak–Lower Sepik area. Paddy rice may be suitable in the depressions depending upon drainage of the heavy clay soils. The plains appear to be suitable for grazing.

* There are also 80 sq miles of Bosman land system in the Wewak–Lower Sepik area (Haantjens *et al.* 1968).

(21) Astrolabe Land System (60 sq miles)

Alluvial coastal plains of the Gogol, Sogeram and Naru Rivers.

Geology.—Alluvium; minor reef corals and marine sands.

Physical Features.—Uplifted alluvial coastal plain up to 5 miles wide, entrenched up to 30 ft by through-going river plains; flat surface, slightly irregular near larger rivers, with colluvial aprons on inland side and sandy beach ridges and coral reefs on coastal margins; disorganized local drainage.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	50	Plains: flat surfaces	Poorly drained old alluvial soils (Palipa) dominate. Alluvial black clay soils (Mungin) and young alluvial soils (3, 4, 5, 6, 7). Poorly to very poorly drained	Alluvial forest. Garden regrowth and some secondary forest with tall *Saccharum* grassland	Mostly $IVso_2$; also IId, I and IIe
2	5	Colluvial aprons: gentle slopes, below 2° and up to ½ mile long, slightly gullied by small channels from backing hills; locally marshy due to seepage	Well-drained old alluvial soils (Bembi, Dumpu) and young alluvial soils (3, 4). Mostly well drained but locally high water-tables	Lowland hill forest with garden regrowth and secondary forest	IIe and I; also Vd and $VIso_2$
3	< 5	Coastal margins: low coral reef platforms, generally forming small headlands; parallel sandy beach ridges and swales up to 1 mile long, connecting headlands and descending to shore; swales locally swampy	Young alluvial soils (1, 4, 6, 7) and undifferentiated residual soils (lithosols). Drainage variable	Garden regrowth and *Ophiuros–Imperata* grassland. Sago palm forest and swamp; *Pandanus* swamp. Mangrove woodland and strand woodland	I; IIe; IV to $VIIso_2$ and VI to VIId

Population and Land Use.—There are 11 villages with a total population of 1250 and a density of 20 per sq mile so that scattered gardens occur throughout. Along the coast a small area is under coconut plantation.

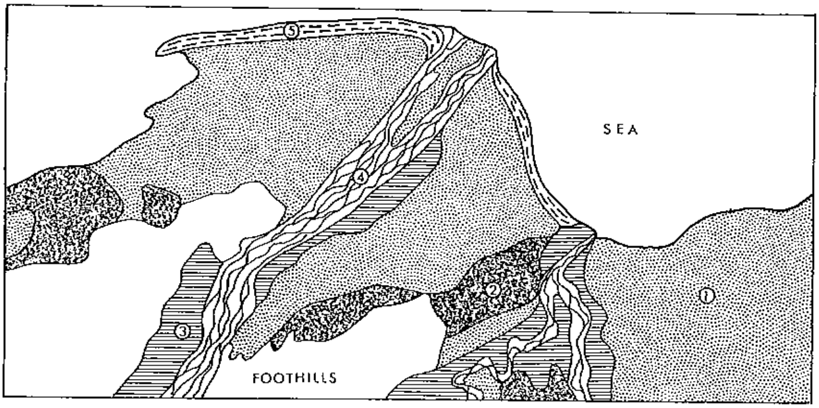
Assessment.—Because of the slow permeability of many of the soils wet rice may be a suitable crop. Otherwise grazing with limited cropping.

(22) KABENAU LAND SYSTEM (40 SQ MILES)

Coastal alluvial fans and river valleys.

Geology.—Alluvium; marine sands and shingle.

Physical Features.—Slightly dissected delta fans forming a coastal plain up to 2 miles wide; gently sloping plains traversed by braiding river channels entrenched up to 20 ft and flanked by narrow terraces; sand and shingle beaches and spits with minor raised coral reefs.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	25	Plain: flat or gently undulating surfaces partly dissected by winding narrow creeks	Well-drained old alluvial soils (Bembi, Dumpu, Lanu). Well to excessively drained	Coconut and cocoa plantations. Some tall *Saccharum* grassland. Much gardening	Mostly I with $IIso_3$
2	5	Higher plain remnants: flat or gently sloping surfaces 10–20 ft above unit 1, partly with steep gullied margins	Alluvial black clay soils (Mungin). Poorly drained old alluvial soils (Palipa). Poorly to very poorly drained	Tall *Saccharum* grassland, garden regrowth and *Ophiuros–Imperata* grassland	$IVso_3$
3	5	River terraces: up to ¼ mile wide and 12 ft above river bed; slightly stepped surfaces with steep banks against river bed; occasionally flooded	Young alluvial soils (3). Mostly well drained but flooded in wet season	Plantations, garden regrowth and *Ophiuros–Imperata* grassland	IVf
4	<5	River beds: gravelly, braided channel tracts up to 300 yd wide, locally flanked by floodplains up to 150 yd wide and less than 6 ft above river bed	Unstable sand, gravel, and stones. Very frequently flooded	Herbaceous and woody river-bank successions	VIII
5	<5	Beach ridges: shingle and sand ridges up to 150 ft wide and to 10 ft above high-water mark, locally extending as spits; minor coral platforms	Young alluvial soils (1), limestone soils (Rempi, Nubia). Well to excessively drained	Coconuts, garden regrowth and strand woodland	$IIso_2$ and VI to $VIIso_2$

Population and Land Use.—There are 10 villages with a total population of 1810 making a population density of 44 per sq mile. Garden activity is high and there are large coconut plantations.

Assessment.—The greater part of the land system comprises excellent (class I) land. Elsewhere flooding is a hazard during the wet season.

(23) Boriva Land System (70 sq miles)

Flat higher parts of alluvial plain at the mouth of the Ramu River.

Geology.—Alluvial clays and silts.

Physical Features.—Relatively stable flood-plains up to 8 miles wide; generally flat and ill drained; broadly and very gently undulating in parts, with long rises probably marking former beach ridges, and swampy lower flats representing filled-in lagoons; traversed by the widely meandering Ramu channel, with oxbow lakes, silted meanders and abandoned river outlets; up to 10 ft above low-water level.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	50	Higher areas: flat or broadly undulating, and up to 10 ft above low-water level	Young alluvial soils (5, 6, 7, 8). Well-drained old alluvial black clay soils (Mungin) and poorly drained old alluvial soils (Tumunum). Imperfectly to well drained but temporary flooding in the wet season. Brackish along the coast	Much *Ophiuros–Imperata* grassland with garden regrowth and alluvial forests	I and IId
2	20	Lower areas: flat marshy *tracts of variable extent*; locally traversed by small incised creeks	Young alluvial soils (8). Alluvial black clay soils (Mungin) and organic soils (peat soil, subsoil). Drainage poor to very poor with inundation after heavy rain. Dry season water-tables 42–72 in.	Flood-plain forest dominated by palms. Some tall *Saccharum* grassland	Vd

Population and Land Use.—There are 5 villages with a total population of 630 giving a density of 9 per sq mile. Settlement is centred in unit 1 where much of the area is already in grassland.

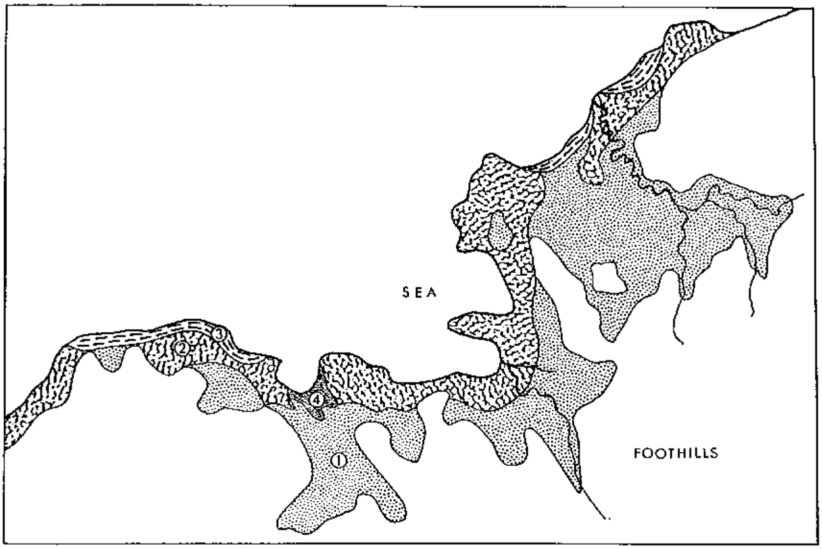
Assessment.—This land system has good access and is very good agricultural land. The wetter aspects may be suitable for paddy rice.

(24) Madang Land System (75 sq miles)

Narrow coastal plains with shallow coral limestone and alluvial soils. (Plate 14, Fig. 1.)

Geology.—Coral limestone, beach sands and alluvium.

Physical Features.—Upraised coastal plains mainly up to 2 miles wide; flat or gently undulating flood-plains extending into river valleys; low coral reef platforms, shingle beaches, and small mud flats on coastal margins, higher raised coral platforms up to 30 ft above sea level on inner margins; plains are ill drained, with swampy depressions, and are traversed by small meandering rivers with discontinuous low terraces; the plains are mainly up to 20 ft above river beds.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	45	Alluvial plains and terraces: flat, ill-drained surfaces locally traversed by shallow winding depressions and incised up to 20 ft by drainage channels; discontinuous alluvial terraces; short backing colluvial aprons at foot of unit 2; steep low banks fringing plains and terraces	Mostly young alluvial soils (3, 4, 6, 8). Alluvial black clay soils (Mungin, Kasamp). Poorly drained old alluvial soils (Palipa). Mostly well drained except locally	Coconut plantations. Alluvial forest and regrowth. Some *Ophiuros–Imperata* grassland. Strand woodland on narrow beach strip	Mainly IVso$_3$ and IVf,so$_3$ with IId; IIId and Vd; also I
2	25	Coral reef platforms: stepped rocky surfaces up to ½ mile wide and up to 20 ft above sea level; smaller platforms backing plain with cliff margins up to 30 ft high	Limestone soils (Rempi, Waguk). Locally young alluvial soils (8) on coral detritus. Immature brown residual soils (Warwin). Undifferentiated residual soils (lithosols) on coastal margin. Well to excessively drained	As for unit 1	II; IIso$_3$; IVso$_3$ and I
3	<5	Beach ridges: mainly single, locally multiple, sand or shingle ridges up to 12 ft above sea level	Well-drained old alluvial soils (Nubia, Kaian) and poorly drained old alluvial soils (Ambana). Young alluvial soils (4). Poorly drained on lower beaches, otherwise well to excessively drained	Mostly strand woodland; otherwise as unit 1	IVso$_3$
4	<5	Swampy depressions: scattered elongate depressions up to 5 ac in extent and less than 10 ft below the level of unit 1; probably former lagoon fills	Young alluvial soils (8) with marine muds, sands and coral detritus in tidal regions. Very poorly drained to swampy	Plantation and regrowth. Mangrove woodland with nipa palms	VIId and VIII

Population and Land Use.—This coastal land system is densely populated with 90 people per sq mile. In all there are 43 villages with almost 7000 inhabitants who rely on coconuts, garden produce and fish.

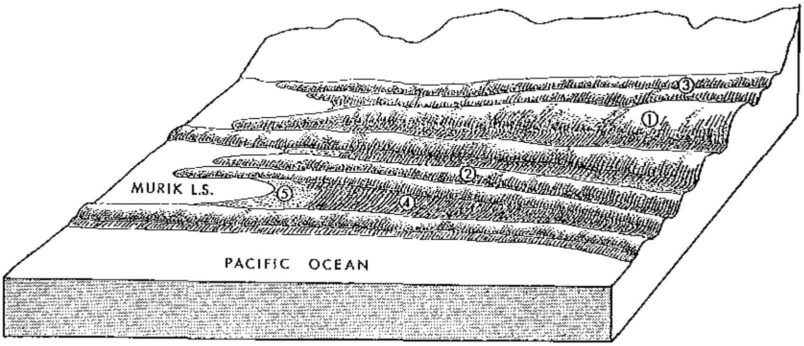
Assessment.—Soils are often shallow and sandy and more suited to tree crops (coconuts, cacao) than to arable crops. The high population is due to its good accessibility.

(25) Nubia Land System (50 sq miles)

Broad high and low beach ridges.

Geology.—Marine sands.

Physical Features.—Parallel sand beach ridges up to 15 ft above sea level, mainly in a coastal belt up to 2 miles wide with older, lower ridges masked by alluvial clay fringing backing alluvial plains; swampy swales; tidal flats at river mouths and former outlets.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	10	Higher beach ridges: rounded ridges up to 100 ft across and 8–15 ft high	Mainly well-drained old alluvial soils (Nubia, Kaian) with young alluvial soils (1, 6) closer to the coast. Well to excessively drained	Coconut plantations with regrowth and secondary forest. Strand woodland. Much *Ophiuros–Imperata* grassland	I and $IIso_2$
2	15	Lower beach ridges: as in unit 1 but 4–8 ft high	Poorly drained old alluvial soils (Ambana) and young alluvial soils (3, 6). Poorly to imperfectly drained and inundated after rain. Water-table 10–30 in. in the dry season	Tall *Saccharum* grassland and sago palm forest	IId and IIId
3	15	Older beach ridges: clay-covered ridges up to 4 ft high	Mainly poorly drained old alluvial soils (Tumunum). Young alluvial soils (3, 6). Drainage poor to imperfect. Often inundated in the wet season	Tall *Saccharum* grassland and *Phragmites* swamp. Alluvial flood-plain forest with palms; some garden regrowth on higher ground	IId; IIId and Vd
4	<5	Swales: long swampy depressions up to 200 ft wide	Young alluvial soils (6); organic soils (peat soils, topsoil). High water-tables or swampy	*Phragmites* swamp and sago palm swamp	Vf,d
5	<5	Tidal flats: small mud flats below h.w.m., flanking river outlets; traversed by tidal creeks	Young alluvial soils (4). Marine muds and sands in tidal region. Salty ground water	Mangrove woodland	VIII

Population and Land Use.—*There is a population of over 1500 in 9 villages making a density of 32 per sq mile* for this land system. There is a typical pattern of coastal settlement with reliance on coconut palms and seafood.

Assessment.—Access is good and there are some areas of good agricultural land. Some soils are droughty and perhaps suitable only for grazing. On the other hand swampy areas would be suitable for rice. Most of the land has drainage limitations.

(26) Ramu Land System (350 sq miles)

Flat alluvial plains of the Ramu River and its southern tributaries. (Plate 6, Fig. 2; Plate 9, Fig. 1; Plate 11, Fig. 1.)

Geology.—Alluvial silts and sands.

Physical Features.—Flat or very gently sloping flood-plains up to 4 miles wide traversed by meandering tributary channels.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	255	Flood-plains: flat surfaces 10–15 ft above low-water level, becoming gently sloping up to 2° near outer margins; uneven tracts with low flood banks and runnels extending up to 50 yd from river banks	Young alluvial soils (3, 4, 5, 7) on levees. Well to imperfectly drained. Subject to short flooding in the wet season	Well-drained alluvial forest and, very locally, garden regrowth. Herbaceous river-bank successions and some tall *Saccharum* grassland	Mostly IVf and IVf,d; also I and IId
2	80	Ill-drained flats	Young alluvial soils (6, 7, 8, locally, 4). Poorly to very poorly drained with high water-tables or inundation during the wet season	Flood-plain forest	VIf,d
3	15	Colluvial aprons: moderately steep slopes up to ¼ mile long closely gullied to a depth of 30 ft	Strongly weathered red and brown clay soils (Sepu). Well-drained old alluvial soils (Kausi, Tumu) and young alluvial soils (4). Well drained	Well-drained alluvial forest with secondary and regrowth phases. Some tall *Saccharum* and *Ophiuros–Imperata* grassland	Mostly II; IIIe,st,so_1 and II–IIIst,so_2

Population and Land Use.—There are only 3 villages in the land system with 220 people. Much of the area is still covered with dense forest.

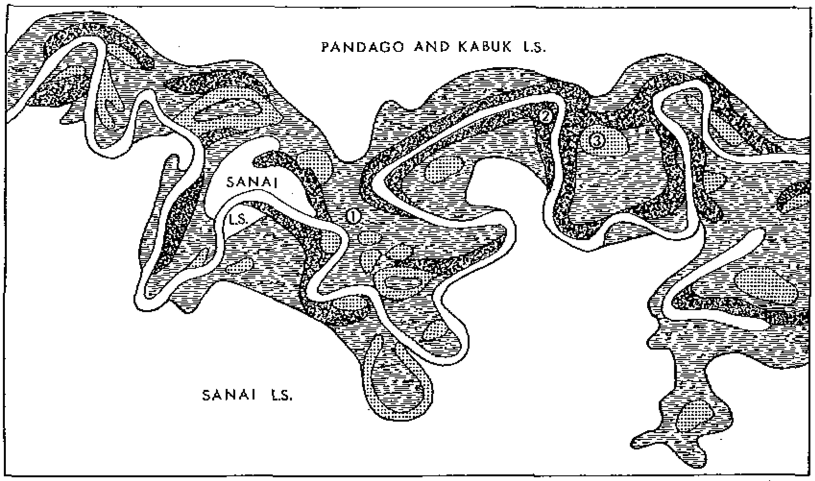
Assessment.—While small areas comprise good agricultural land much is subject to periodic inundation. Access is poor.

(27) MISINKI LAND SYSTEM (450 SQ MILES)

Flat higher parts of the Ramu, Keram, Sogeram and Guam Rivers. (Plate 7, Fig. 1; Plate 10, Fig. 1.)

Geology.—Alluvial clays and silts.

Physical Features.—Broad higher flood-plain elements in the Ramu plain; levee banks of the meandering Ramu and its larger tributaries; gentle slopes towards lower back plain; short, winding, narrow flood channels, locally incised through levees; up to 35 ft above low-water level.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	365	Flood-plains: flat areas about 20 ft above low-water level, locally traversed by low former levee banks	Young alluvial soils (7, 8). Poorly to very poorly drained. Flooded to a depth of 1–3 ft for long periods during the wet season but water-tables dropping to 5 ft below the surface in the dry season	Alluvial flood-plain forest with tall palms	Vf,d
2	75	Levee banks: up to 150 ft wide, with flat crests up to 25 ft above low-water level, and very gentle back slopes; locally hummocky, with sandy overspill flood banks up to 2 ft high	Young alluvial soils (mostly 1 but some 4 and 6). Well to imperfectly drained. Mostly inundated in the wet season	Alluvial well-drained forest. Very local gardens and regrowth; some *Ophiuros–Imperata* grassland	IVf and IVf,d
3	10	Gentle slopes: towards back plains	As for unit 1	Woody river-bank succession	Vf,d

Population and Land Use.—Although there are 15 villages accounting for a population of 1740, land use is low with 4 persons per sq mile. Small seasonal gardens and wild sago are the subsistence pattern.

Assessment.—Access is poor except from the river. Potentially there are large areas of flat land with chemically fertile although poorly drained soils. Flooding is a hazard in the wet season. Areas escaping the heavy Ramu River floods may have inadequate rainfall. Much of the area is still covered in forest of low commercial value.

(28) Jibirogo Land System (130 sq miles)

Flood banks and meander scrolls of the Ramu River. (Plate 7, Fig. 1; Plate 10, Fig. 2; Plate 13, Fig. 1.)

Geology.—Alluvial silts and clays.

Physical Features.—Meander belt; discontinuous tracts, mainly up to 1 mile wide, consisting of meanders, flood scrolls, and on inner bends oxbow lakes; up to 15 ft above low-water level.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	55	Flood banks: long curving sandy banks up to 40 yd wide and 5 ft high, descending towards river channels and continuing as sand banks	Young alluvial soils (3 on rises, 6 and 7 in depressions). The rises are flooded 2–4 ft but are well drained; the depressions, flooded to 5–9 ft, are poorly drained	Herbaceous and woody river-bank successions. Very locally gardens and regrowth	VIf; VIIf; VId; VIId
2	30	Swales: ill-drained depressions up to 150 ft wide between unit 1	Young alluvial soils (1, 4). Regularly flooded and poorly drained	Woody river-bank successions, sago palm forest and *Phragmites* swamp	VIIf
3	30	Meander scrolls: undulating tracts up to ½ mile wide, consisting of low sandy flood banks up to 50 yd wide, and narrow swampy swales; local relief up to 8 ft	Young alluvial soils (4). Well to imperfectly drained with flooding in the wet season	Woody river-bank succession and patches of tall *Saccharum* grassland	Vf; VIIf and VIII
4	20	Meander plugs: curving, flat-floored depressions up to 300 yd wide, marshy in part	Organic soils (peat soils, raw). Very poor drainage to swampy	Grass swamp	VIIf

Population and Land Use.—There is no population and only minor use of the better-drained parts during the period between floodings.

Assessment.—Flooding and poor drainage make this land system unsuitable for any large development.

(29) Papul Land System (325 sq miles)

Small alluvial valleys throughout the survey area.

Geology.—Fine-textured alluvium.

Physical Features.—Tributary valley plains up to 2 miles wide, with narrow flood-plains and flanking terraces up to 20 ft above river beds; meandering river channels, mainly less than 200 yd wide.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	220	Terraces: flat or slightly uneven surfaces up to 500 yd wide; steep marginal slopes	Predominantly young alluvial soils (6, 7, 8, locally 3 and 4), with well-drained old alluvial soils (Bembi, Dumpu). Mostly well drained. Locally inundated after heavy rain	Alluvial well-drained forest. Local gardens and regrowth. Scattered areas of *Ophiuros–Imperata* grassland	I and IId
2	105	Flood-plains: up to 1 mile wide and generally 6–8 ft above river beds; mainly flat, but uneven with low stony flood banks and depressions in narrow tracts adjoining river channel	Young alluvial soils (4, 6, 7, 8). Mostly well drained. Some short wet-season flooding but water-tables down to 2–4 ft below ground surface in the dry season	Alluvial forests, both well-drained and flood-plain. Herbaceous and woody river-bank successions along streams	IVf and IVf,d

Population and Land Use.—Although there are some 28 villages accounting for a population of 3230 and a density of 9 per sq mile, most of the land system still has a dense forest cover and is little used for gardening.

Assessment.—While there is some excellent agricultural land this is discontinuous and poor of access. Poor drainage and flooding affect unit 2. There are some timber resources.

(30) Imbrum Land System (60 sq miles)

Unstable river beds of the Ramu River and tributaries upstream from Usino basin. (Plate 3.)

Geology.—Gravels, sands, and minor silts.

Physical Features.—Gravelly, braiding channel zones up to 2 miles wide; Ramu River meander belt up to 1 mile wide in the Usino basin; braiding or meandering river channels.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	30	Braided channel zones: low gravel banks and braided channels	Recent unstable alluvial deposits; stones and gravels. Frequently flooded	Herbaceous and woody river-bank successions	VIII
2	20	Stony flood-plain terraces: uneven tracts up to ½ mile wide and less than 10 ft above river beds	As in unit 1 with young alluvial soils (1). Also well-drained old alluvial soils (Imbrum, Lanu). One profile of strongly weathered red and brown clay soil (Sepu). Mostly excessively drained and rarely flooded	*Ophiuros–Imperata* grassland and woody river-bank succession	VI–VIIso$_2$ and IIso$_2$ to IVso$_2$
3	10	Alluvial flood-plain terraces: flat surfaces up to 200 yd wide and less than 6 ft above river beds; slightly dissected by small tributary channels	As in unit 1 and with young alluvial soils (2, 3, 4, 7). Well to imperfectly drained; flooded in the wet season	Woody river-bank succession including *Casuarina* and *Octomeles* groves	IVf and IVf,d

Population and Land Use.—Four villages with 270 people are sited along this land system but there is virtually no land use. A few small gardens including irrigated taro were noted.

Assessment.—The main use is conservation of river course and banks.

(31) Sausi Land System (50 sq miles)

Flat alluvial plain liable to flooding. (Plate 6, Fig. 1.)

Geology.—Alluvial silts and minor sands.

Physical Features.—Gently sloping tributary flood-out plains up to 5 miles long, traversed in upper parts by meandering or braiding channels which become disorganized and flood out in lower parts.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	30	Upper sectors: gently sloping plains with a few small creeks incised to a depth of 10 ft	Young alluvial soils (4 dominant, but also 1 and 3). Mostly well drained. Flooding in parts	Mainly secondary aspects of alluvial well-drained forest and garden regrowth. Also tall *Saccharum* and *Ophiuros–Imperata* grassland	Mainly I and IIso$_2$, also IIIf,d; IVf
2	15	Lower sectors: flat ill-drained flood-outs with a few shallow ill-defined creeks	Young alluvial soils (7). Poorly to very poorly drained; some regularly flooded	Alluvial flood-plain forest	Vd
3	5	Undulating plains: small areas with elongate, flat or rounded rises up to 300 ft wide and 10 ft high, with shallow depressions generally incised up to 20 ft by narrow gullies	Well-drained old alluvial soils (Bembi, Sausi). Well drained	Tall *Saccharum* and *Ophiuros–Imperata* grassland with some secondary alluvial well-drained forest	IIe

Population and Land Use.—Seven villages account for a total population of 590 or 11 per sq mile. Most land use is in unit 1.

Assessment.—While some good alluvial soils are available much of the land system is subject to flooding. Some small part of this could be controlled.

(32) Usino Land System (30 sq miles)

Flat alluvial plain of the Peka River. (Plate 6, Fig. 1.)

Geology.—Alluvial silts and minor sands.

Physical Features.—Broad flood-plain up to 5 miles in extent; nearly flat, but traversed by broad low rises, probably former flood banks; narrow alluvial terraces up to 30 ft above river beds in tributary valleys at head of system; meandering river channels 10–15 ft below plains, and sparse, discontinuous gullies near upper margins.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	20	Plains: flat, mainly undissected surfaces up to 15 ft above river beds	Predominantly poorly drained old alluvial soils (Palipa). Young alluvial soils (7). Poorly to very poorly drained with regular flooding	Alluvial flood-plain forest	Vd
2	5	Rises: elongate rises up to 6 ft high and ¼ mile wide, with gentle convex slopes	Mainly young alluvial soils (7). Imperfectly drained with little or no flooding	Some alluvial well-drained forest but mainly garden regrowth and secondary forest	Mainly IId and IIIf,d; some $IVso_3$ and IVf,so_3
3	<5	River terraces: discontinuous terraces up to 150 yd wide and up to 20 ft above river beds	Young alluvial soils (7) and unstable sands and gravels. Mostly well drained but with regular flooding of lower terraces	Alluvial well-drained forest with some garden regrowth. Herbaceous river-bank succession on lower terraces	I and IVf

Population and Land Use.—A single village of 200 carries out some gardening on the rises and higher terraces.

Assessment.—Levee banks to control floods together with surface drainage could extend the agricultural use of unit 1.

(33) Eli Land System (15 sq miles)

Poorly drained flood-outs in low-lying parts of Usino basin. (Plate 6, Fig. 1.)

Geology.—Alluvial silts.

Physical Features.—Swampy flood-out plains up to 2 miles wide; upper sectors consist of tributary flood-plains with winding feeder channels which gradually die out towards marshy flood-outs and swamps in lower sectors; small incised creeks near upper margins.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	10	Marshy plains: extensive flat surfaces traversed by a few shallow creeks	Unstable sands and gravels and young alluvial soils (7). Mostly poorly drained with small swampy areas	Herbaceous river-bank succession with dead alluvial flood-plain forest and *Pandanus* swamp	VIf,d and VIIf,d
2	5	Tributary flood-plains: plains traversed by feeder channels; mainly flat, but hummocky near main channels, with small flood banks	Unstable sands and gravels. Very poorly drained with frequent flooding	Herbaceous river-bank succession	IIIf,d
3	<5	Swamps: small depressions in former drainage lines, mainly in unit 1	Young alluvial soils (4). Swampy	*Pandanus* and *Phragmites* swamp	VIII

Population and Land Use.—Nil.

Assessment.—A swampy land system with no potential.

(34) Pandago Land System (380 sq miles)

Fluctuating swamp. (Plate 6, Fig. 1; Plate 7, Fig. 1; Plate 8, Fig. 2; Plate 9, Fig. 2.)

Geology.—Alluvial clays and silts.

Physical Features.—Seasonally swampy higher parts of the back plains, and smaller areas where tributary drainage has been impeded by alluviation from larger channels; mainly 5–10 ft above low-water level, decreasing to 2–4 ft in better-drained tidal sectors.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	185	High waterlogged plains	Mostly young alluvial soils (7, 8, more rarely 6). Alluvial black clay soils (Mungin) and one example of poorly drained old alluvial soil (Kabuk). Seasonally fluctuating swamp with 6–7 months waterlogging but water-tables down to 4 ft below the surface in the dry season	Sago palm forest. *Campnosperma* swamp forest	IVd
2	195	Low seasonally flooded plains	Young alluvial soils as in unit 1. One example of an alluvial black clay soil (Kasamp). Drainage as in unit 1 but even more pronounced	Sago palm swamp	VIId

Population and Land Use.—Although there are 5 villages with a total population of 410 there is no land use within the land system except for exploiting the sago resources.

Assessment.—Swampy for the greater part of the year. No potential.

(35) Kabuk Land System (150 sq miles)

Permanent swamp. (Plate 7, Fig. 1.)

Geology.—Alluvial clays and silts; peat.

Physical Features.—Permanent swamps occupying lower parts of back plains, including small areas where drainage is impeded by beach ridges, blocked tributary valleys, and abandoned meanderings; 3–7 ft above low-water level, probably less in tidal sectors.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
Whole of land system	150	Swamps	Young alluvial soils (8). Organic soils (peat soils, topsoil and peat soils, subsoil). Swamp inundated to 5 ft in wet season but water-tables 0–14 in. below surface in the dry season	Sago palm and *Phragmites* swamps; and woody river-bank succession	VIId

Population and Land Use.—Nil.

Assessment.—Although theoretically suitable for local paddy rice during the dry season there are no immediate large-scale development possibilities for this land system.

(36) Sanai Land System (150 sq miles)

Deep permanent swamp land. (Plate 7, Fig. 1; Plate 11, Fig. 2.)

Geology.—Alluvial silts and peat.

Physical Features.—Permanent swamps and lakes occupying lowest parts of back plain, blocked tributary valleys or abandoned meanders; 5 ft or less above low-water level.

Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	100	Deep swamps	Organic soils (peat soil, raw and organic muds). A very plastic clay underlies the permanent swamp with water up to 18 ft above ground level in the wet season and 3–10 ft during the dry season	Grass swamp	VIII
2	40	Shallow swamps	Young alluvial soils (8). Swampy with water 6 in. to 3 ft high in the dry season	Grass swamp	VIII
3	10	Swamp margins	Young alluvial soils (8), an observed alluvial black clay soil (Mungin), and an organic soil (peat soil, deep). Water-table in the dry season at or just below ground surface	*Phragmites* swamp	VIId

Population and Land Use.—Nil.

Assessment.—Permanent swamp with water-tables 1–10 ft above the ground even in the dry period makes this a land system with no potential.

PART IV. CLIMATE

By KAREN SHORT*

I. INTRODUCTION

(a) *Principal Climatic Features*

The greater part of the area falls within Köppen's (1931) tropical wet climate (Af) classification or Thornthwaite's (1931) perhumid tropical rain-forest type (AA'r). However, the northern coastal sector and the upper Ramu valley which are drier and possess greater rainfall seasonality classify as monsoonal (Am) or humid tropical (BA'w).

Mean annual rainfall varies from 71 in. at Dumpu in the upper Ramu valley to 224 in. at Aiome in the lower section of the same valley. Annual rainfall on the coast at Madang is 142 in. At all stations the wet season occurs between November and April followed by a dry season from May to October. The temperature regime is most equable, possessing a mean annual value of 80°F.

(b) *Climatic Controls*

The discussion of climatic controls presented here is based on that of Brookfield and Hart (1966) and Fitzpatrick *et al.* (1966). Throughout lowland New Guinea the major climatic controls are those of the seasonal latitudinal movements of two major air masses separated by a discontinuous intertropical convergence zone (ITCZ). The controls consist of a perturbation belt of westerly-moving vertical circulations to the north and the south-east trade wind belt to the south. The south-east trades which dominate from May to mid October consist of essentially shallow surface air masses overlain by dry zonal easterlies. Upper wind data for Lae indicate that the air masses of the perturbation belt season which dominate from December to March extend to higher altitudes than those of the south-east. Thus, in general, the zonal easterly and south-east trade air masses tend to have a lower capacity to produce heavy sustained rainfall than those of the perturbation belt, except where very strong orographic influences occur. This latter belt was referred to in previous literature as the north-west season.

The major local effect over these broader controls results from the presence of the inland Ramu valley trough which is aligned in the same direction as the main prevailing SE.–NW. winds. The lack of orographic barriers across this trough is the probable reason for the generally lower precipitation in the valley centre. However, the nearby presence of high mountains on each side of this trough and their associated orographic effect on rainfall results in a high rainfall gradient between the centre of the valley and these mountains.

* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

TABLE 1

MEAN MONTHLY AND ANNUAL RAINFALL (IN.)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Aiome (7/11)*	26·70	26·27	27·64	24·78	16·73	8·70	8·64	8·01	11·02	12·79	18·18	22·55	224·49
Awar (14/15)	8·30	8·45	8·93	10·28	6·40	4·19	3·36	2·48	2·90	6·37	8·26	12·08	82·30
Bogia (6/11)	10·28	9·56	10·95	9·38	6·13	3·88	2·65	1·65	3·25	5·75	8·31	11·89	84·34
Dumpu (5/7)	8·94	11·21	8·32	5·54	5·03	3·81	1·61	2·78	4·54	4·76	7·12	10·77	70·70
Gal (5/10)	12·15	10·76	12·50	15·53	11·66	8·05	8·32	7·78	7·46	10·61	16·21	12·88	125·89
Gusap (10/13)	8·43	10·28	11·11	7·58	4·10	2·26	1·06	2·68	5·29	5·77	7·45	7·71	74·95
Josephstaal (7/7)	14·89	11·30	13·10	11·37	7·42	4·10	3·93	5·11	4·91	6·14	9·61	13·70	105·58
Madang (20/21)	14·20	13·19	14·77	17·81	14·86	8·23	6·52	5·04	5·43	10·05	15·88	15·51	142·24
Saruga (10/11)	13·83	10·39	14·62	12·35	13·79	12·01	10·60	7·68	6·63	9·90	10·85	11·17	133·55
Wanuma (2/8)	13·91	12·93	14·94	12·65	9·76	5·30	6·07	6·28	8·08	11·14	11·85	15·83	127·34

* Indicates 11 years of record with only 7 years complete.

(c) *Climatic Records*

The length and quality of climatic records for the area are highly variable. Table 1 indicates both the number of years for which complete monthly data are available and the number of years for which rainfall records have been kept for stations with over 4 years of record. Unfortunately, daily rainfall records are even less satisfactory than monthly records.

The standard period selected is the 10 years from 1959 to 1968. This short standard period may be less of a handicap than might first appear as variability tests on stations with the longest records indicate low rainfall variability.

Climatic data other than rainfall data are available for Aiome, Bogia and Madang for 6, 6 and 11 years respectively. Although these records are short, the very low degree of monthly variability in such measures as temperature and relative humidity suggests that the results presented here are reasonably reliable. Unfortunately there are no records available, other than rainfall, for areas in the higher altitudinal zones.

II. General Climatic Characteristics

(a) *Rainfall*

Monthly and annual means for the various stations in and near the area are given in Table 1. Their spatial distribution is indicated by means of histograms in Fig. 5. The area of lowest annual rainfall occurs along the Ramu valley trough (71 in. at Dumpu to 105 in. at Josephstaal). At Awar, on the coast near the mouth of the Ramu, and at Bogia rainfall is also relatively low (82–84 in.); this may be caused by the absence of surrounding higher topography that would provide a triggering orographic rainfall effect. The station with the highest rainfall in the area, Aiome (224 in.), is situated on the mountain side of the Ramu valley cross-section rainfall gradient postulated in the previous section on climatic controls. Elsewhere the spatial range of mean annual rainfall is fairly limited (126–142 in.)

One of the major climatic features of the region is the seasonality of rainfall. Fitzpatrick *et al.* (1966) indicate the broad seasonality pattern of the area. The wet season occurs between October and May and the mean monthly rainfall data in Table 1 indicate that in general the wettest month has at least 3–4 times the rainfall of the driest month for stations with over 100 in. per annum rainfall and 5–10 times for drier stations.

Measures of monthly and annual variability of rainfall are presented in Table 2 for the standard period. The variability of annual rainfall (expressed by the standard deviation as a percentage of the mean) at Madang is 14%.

No direct measures of rainfall intensity are available. Table 3 presents the percentage frequency of rain days per quarter with rainfall within specified classes for the standard period. Falls of over 2 in. are more common in the wet season than in the dry season. The frequency of extreme daily rainfalls greater than 4 in. is most common at the wettest station, Aiome, and is not uncommon at Madang. From Table 3 it would appear that in general the high rainfalls characteristic of the area are not so much a result of any abnormal propensity for very heavy falls of limited duration as of the very frequent occurrence of falls of up to 1 in. per day.

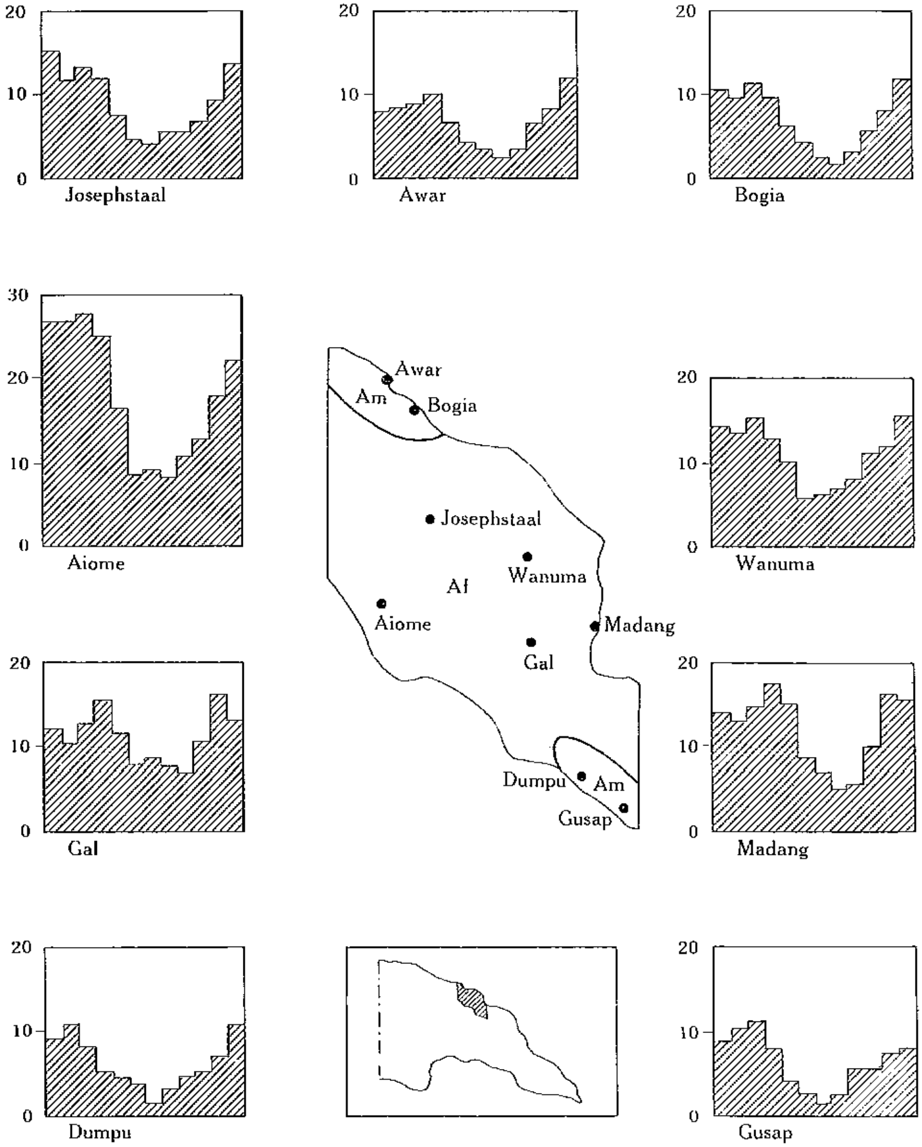


Fig. 5.—Annual and spatial distribution of rainfall (Jan.–Dec.). Histogram values in inches per month, with Köppen's climatic classification (Af, tropical wet climate; Am, tropical monsoonal climate).

TABLE 2

VARIABILITY OF MONTHLY RAINFALL (IN.) FOR THE STANDARD PERIOD

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Aiome													
Highest rainfall	40·81	37·11	45·69	30·11	25·12	12·67	13·47	15·13	23·17	18·23	31·60	35·38	253·53
Upper quartile	37·68	32·96	35·04	30·00	24·43	12·62	12·27	13·10	18·85	17·65	19·97	23·88	248·12
Median	23·02	32·63	28·63	26·35	19·85	7·75	11·78	8·29	11·89	14·53	18·34	22·19	217·53
Lower quartile	15·43	19·59	19·63	22·68	10·77	7·25	7·07	6·36	7·43	12·22	13·86	19·02	209·26
Lowest rainfall	10·99	14·42	16·86	19·33	7·97	4·77	1·97	5·66	7·08	10·09	11·80	16·97	204·55
Awar													
Highest rainfall	13·87	13·73	12·24	15·80	10·96	8·63	9·01	7·49	5·20	15·44	14·42	23·66	96·82
Upper quartile	11·86	10·77	10·30	13·10	9·00	5·90	5·99	3·15	3·54	8·09	9·93	14·97	96·63
Median	7·90	8·71	9·48	10·74	7·43	4·03	3·04	2·02	2·54	6·13	7·97	10·69	84·70
Lower quartile	5·92	6·59	8·62	6·68	4·80	3·37	1·71	1·09	2·02	4·23	6·20	8·78	78·75
Lowest rainfall	4·38	4·41	8·21	4·53	2·57	1·15	0·62	0·01	0·28	0·15	3·92	5·48	72·84
Gusap													
Highest rainfall	14·62	17·66	17·40	12·82	6·91	5·88	2·05	10·85	12·52	9·88	12·34	10·46	89·92
Upper quartile	11·45	14·56	14·87	8·91	5·44	3·89	1·07	4·38	4·99	7·93	9·25	8·42	86·40
Median	8·71	10·92	11·82	5·76	4·42	1·79	0·77	1·47	4·31	5·33	8·36	6·91	78·20
Lower quartile	5·57	6·14	5·67	4·03	3·35	0·59	0·39	0·58	2·08	4·66	4·84	5·71	64·42
Lowest rainfall	4·55	3·12	3·89	1·31	2·52	0·14	0·15	0·15	0·77	1·45	0·97	3·38	47·85
Madang													
Highest rainfall	21·85	19·47	19·33	30·32	23·02	13·93	17·16	11·89	7·97	20·18	26·00	26·98	175·81
Upper quartile	18·52	16·94	18·03	22·75	20·63	10·94	9·07	10·24	6·56	13·44	19·98	18·20	156·30
Median	15·17	11·00	13·70	20·06	13·80	7·63	7·08	6·40	4·19	11·90	13·34	16·42	146·89
Lower quartile	8·55	9·22	10·64	16·63	11·51	5·53	4·97	2·44	2·62	9·84	11·30	9·07	132·61
Lowest rainfall	6·22	3·46	8·66	8·38	7·88	4·60	1·04	0·93	0·52	0·65	8·81	8·69	122·08

TABLE 3

PERCENTAGE FREQUENCY OF RAIN DAYS PER QUARTER WITH RAINFALL WITHIN SPECIFIED CLASSES FOR THE STANDARD PERIOD

Station and quarter	Class (in./rain day) 0·01–0·24	0·25–0·99	1·00–1·99	2·00–3·99	4·00–5·99	≥6·00
Aiome						
JFM	27	38	17	13	3·3	0·7
AMJ	36	33	19	9	2·7	0·4
JAS	44	37	14	5	0·4	0
OND	33	37	18	10	1·4	0·2
Awar						
JFM	53	31	10	5	0·6	0
AMJ	50	34	10	5	0·7	0
JAS	63	29	6	3	0	0
OND	48	31	13	8	0·9	0
Gusap						
JFM	45	38	13	4	0	0
AMJ	53	35	9	4	0	0
JAS	58	29	11	3	0	0
OND	47	39	10	3	0·3	0·3
Madang						
JFM	45	32	12	9	1·6	0·2
AMJ	39	38	14	7	1·8	0·6
JAS	52	30	12	4	0·6	0·6
OND	39	34	15	10	2·5	0

TABLE 4

MEAN AND MAXIMUM LENGTH (DAYS) OF RAINY AND RAINLESS PERIODS PER QUARTER FOR THE STANDARD PERIOD

Station and quarter	Length of rainy period Mean	Max.	Percentage of rain days	Length of rainless period Mean	Max.	Percentage of rainless days
Aiome						
JFM	7·4	56	84·4	1·4	6	15·6
AMJ	3·2	23	61·2	2·0	11	38·8
JAS	2·5	14	50·5	2·5	13	49·5
OND	3·6	28	67·4	1·8	8	32·6
Awar						
JFM	2·7	16	59·3	1·8	10	40·7
AMJ	2·9	11	44·8	2·5	12	55·2
JAS	1·7	9	28·2	4·2	30	71·8
OND	2·1	11	48·2	2·2	26	51·8
Gusap						
JFM	3·2	20	62·6	1·9	11	37·4
AMJ	2·1	10	34·5	4·1	37	65·5
JAS	1·8	12	22·3	7·0	28	77·7
OND	2·3	12	43·8	2·9	16	56·2
Madang						
JFM	2·8	13	62·9	1·7	7	37·1
AMJ	2·9	20	58·6	2·2	10	41·4
JAS	1·9	13	38·6	3·1	18	61·4
OND	2·6	17	57·5	2·0	9	42·5

While Table 3 gives some impression of the relatively rainy nature of the climate this aspect is shown more clearly in Table 4 which gives the average and longest lengths in days per quarter of rainy and rainless periods as well as the percentage of rain days for the standard period. Again the seasonal difference in the measures is apparent, especially in terms of longest occurrences of rainy and rainless periods. The percentage of rain days is greatest in the first quarter and lowest in the third quarter of the year for all stations. Durations of rainy periods are longer in the wet season than in the dry season for the whole region but vary considerably in length from station to station. While durations of rainless periods show a seasonal trend the mean length of rainless periods ranges only from 1·4 to 4·2 days per quarter between stations.

(*b*) *Temperature*

Table 5 indicates the restricted range of mean monthly and other temperature characteristics. On the coast mean annual maximum is 87°F with a minimum of 73°. Inland these figures change to 89 and 71°, giving a slightly greater diurnal range inland. Monthly mean temperatures vary between 79 and 81°, giving a seasonal range of 2°F. The extreme maximum temperature on record is 97° and the extreme minimum is 61°, both at Aiome.

Information concerning the effect of altitude on temperature in this area is lacking; however, data from analogous areas in New Guinea (McAlpine 1972) indicate an approximate overall decrease in mean temperature of 3°F per 1000 ft.

(*c*) *Other Climatic Characteristics*

The monthly average indices of relative humidity together with estimates of evaporation are given in Table 6. Sunshine data for Madang are also presented in Table 6.

Humidity is high throughout the year, ranging between 85 and 89% for all stations, and shows little seasonal variation. Estimates of evaporation as related to an Australian standard tank have been derived from mean monthly maximum and minimum temperatures, vapour pressure and day length (Fitzpatrick 1963). Mean annual evaporation is about 56 in. throughout the lowlands and shows only slight seasonal variation at any station. Evaporation can be expected to decrease with altitude but probably does not fall below 45 in. in any populated area in the region.

Mean monthly total and low cloud cover for 0900 and 1500 hr, expressed as a percentage of sky covered, is given in Table 7. As shown by these mean data low cloud tends to increase while the total amount of cloud cover fluctuates only slightly during the day. The total amount of cloud coverage is 10–20% greater in the wet season than in the dry season. By contrast, low cloud cover does not exhibit a seasonal effect except at Bogia.

III. Soil Moisture

Estimates of soil moisture regimes presented here have been derived from a computer simulation of a simple water balance model (McAlpine 1970). Essentially the model is designed to give estimates of week-to-week changes in available soil

TABLE 5

MEAN MONTHLY TEMPERATURE CHARACTERISTICS (°F)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
					Aiome								
Extreme maximum	93·2	95·0	91·4	93·2	93·2	91·4	91·4	93·2	96·8	93·2	93·2	96·8	96·8
Mean maximum	88·5	87·8	88·0	88·3	89·1	88·2	87·3	89·1	90·0	89·4	89·1	87·6	88·5
Mean	80·0	79·5	80·0	80·0	80·1	79·2	78·6	79·6	80·5	80·2	80·1	79·4	79·8
Mean minimum	71·4	71·2	72·0	71·6	71·1	70·2	70·0	70·2	71·1	71·1	71·1	71·2	71·0
Extreme minimum	66·2	66·2	68·0	66·2	64·4	60·8	60·8	60·8	62·6	62·6	60·8	66·2	60·8
					Bogia								
Extreme maximum	91·4	91·4	91·4	91·4	89·6	89·6	89·6	89·6	89·6	89·6	91·4	91·4	91·4
Mean maximum	87·1	86·7	86·5	86·5	87·1	86·4	86·0	86·4	86·7	87·1	87·1	87·3	86·7
Mean	80·1	80·0	79·8	80·1	80·3	79·3	79·3	79·3	79·8	80·3	80·0	80·1	79·9
Mean minimum	73·0	73·2	73·0	73·6	73·6	72·3	72·7	72·3	72·9	73·6	72·9	73·0	73·0
Extreme minimum	66·2	69·8	68·0	69·8	69·8	69·8	68·0	66·2	69·8	69·8	66·2	68·0	66·2
					Madang								
Extreme maximum	91·4	91·4	91·4	91·4	89·6	89·6	89·6	89·6	91·4	89·6	91·4	91·4	91·4
Mean maximum	86·4	86·2	86·2	85·8	86·4	85·6	85·3	85·5	85·8	86·2	86·4	86·2	86·0
Mean	80·1	79·9	80·0	79·8	80·1	79·4	79·2	79·3	79·5	79·7	79·9	80·0	79·7
Mean minimum	73·8	73·6	73·8	73·8	73·9	73·2	73·0	73·2	73·2	73·2	73·4	73·8	73·5
Extreme minimum	69·8	69·8	69·8	69·8	68·0	66·2	68·0	66·2	69·8	68·0	68·0	66·2	66·2

TABLE 6

RELATIVE HUMIDITY AND EVAPORATION FOR CLIMATE STATIONS AND HOURS OF SUNSHINE FOR MADANG

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
					Aiome								
Average index of relative humidity (%)*	88	87	86	85	88	89	88	88	88	85	89	89	88
Evaporation (in.)†	4·8	4·7	4·7	4·9	4·6	4·3	4·2	4·5	4·6	5·2	5·1	4·8	56·4
					Bogia								
Average index of relative humidity (%)	86	86	87	87	87	86	86	88	87	86	89	87	87
Evaporation (in.)	4·9	4·9	4·5	4·2	4·4	4·3	4·2	4·3	4·7	4·7	4·8	4·9	54·8
					Madang								
Average index of relative humidity (%)	86	85	86	87	88	89	87	87	86	86	86	86	87
Evaporation (in.)	5·1	5·1	4·7	4·3	4·3	4·0	4·1	4·3	4·7	4·9	5·2	5·0	55·7
Mean sunshine (hr/day)	5·2	5·0	5·0	5·4	6·8	6·8	6·5	7·0	6·8	6·7	6·2	5·4	
Day-length (hr/day)‡	12·3	12·2	12·0	11·9	11·8	11·7	11·7	11·8	12·0	12·1	12·2	12·3	
Sunrise (hr)	0612	0624	0624	0618	0618	0624	0624	0624	0612	0554	0548	0600	
Sunset (hr)	1836	1842	1830	1818	1812	1812	1818	1824	1812	1812	1812	1824	

* The ratio of the average 9 a.m. vapour pressure to the saturation vapour pressure at the average mean temperature.
† Estimates based on method of Fitzpatrick (1963). ‡ Civil sunrise to civil sunset.

TABLE 7

CLOUD COVERAGE

Mean cloudiness (%)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
					Aiome								
Total amount 9 a.m.	82	80	82	70	66	60	65	60	62	66	79	75	71
Low amount 9 a.m.	28	25	28	28	21	20	25	20	22	22	29	25	24
Total amount 3 p.m.	85	82	82	75	66	66	75	69	62	69	81	81	75
Low amount 3 p.m.	29	30	32	34	29	31	35	29	22	22	44	38	31
					Bogia								
Total amount 9 a.m.	75	80	81	68	62	55	58	58	58	58	72	75	66
Low amount 9 a.m.	46	42	41	25	30	22	25	28	28	32	40	41	34
Total amount 3 p.m.	71	78	81	72	65	65	65	62	62	68	72	78	70
Low amount 3 p.m.	48	48	48	38	38	32	35	38	35	45	38	48	40
					Madang								
Total amount 9 a.m.	86	88	86	81	74	71	75	74	74	74	79	82	79
Low amount 9 a.m.	19	19	21	24	24	25	31	31	30	29	28	25	25
Total amount 3 p.m.	84	84	85	80	71	71	74	71	72	75	79	84	78
Low amount 3 p.m.	32	31	31	31	31	28	32	31	30	31	31	34	31

moisture using estimated evapotranspiration as withdrawals and weekly rainfall inputs. The assumed maximum soil moisture storage (field capacity) is 4·00 in.

The weekly changes in soil moisture level indicated by the application of this model have been averaged for the standard period and the results illustrated in Fig. 6. The curves indicate that a considerably higher level of soil moisture storage is experienced in the third quarter at Aiome than elsewhere.

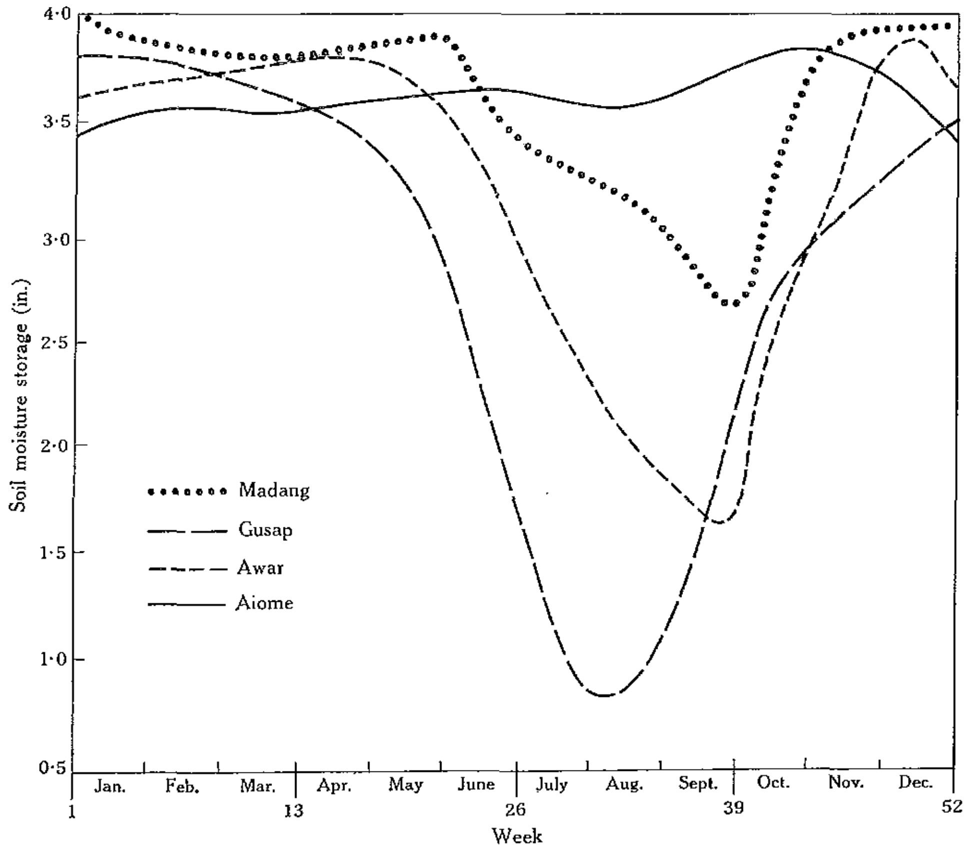


Fig. 6.—Average weekly soil moisture storage at four stations.

These curves represent only mean weekly conditions and do not in themselves portray the risk of serious soil water deficits that might influence plant growth and production. An indication of this facet is given in Table 8 where a frequency distribution showing the mean number of weeks per quarter for the standard period in which soil moisture was depleted to specified limits is presented. As would be expected, there is an increase in depletion to all stations in the dry season. This depletion is most marked at Awar, Gusap and Madang where instances of complete depletion have occurred. At Aiome depletions below 50% are rare. For the standard period adopted (1959–68) the longest uninterrupted sequence of complete soil moisture depletion is 3 weeks at Madang, 9 weeks at Awar and 7 weeks at Gusap, all occurred in 1965.

TABLE 8

MEAN NUMBER OF WEEKS WITH SOIL MOISTURE STORAGE AT SPECIFIED LEVELS PER QUARTER FOR THE STANDARD PERIOD

Station and quarter	Full	Storage levels 1–49% Depleted	50–99% Depleted	Empty
Aiome				
JFM	12·7	0·3	0	0
AMJ	10·7	2·3	0	0
JAS	8·5	4·4	0·1	0
OND	12·1	0·9	0	0
Awar				
JFM	9·0	3·6	0·4	0
AMJ	7·0	5·3	0·7	0
JAS	1·5	5·7	4·9	0·9
OND	6·9	4·7	0·9	0·5
Gusap				
JFM	9·1	3·7	0·2	0
AMJ	4·5	5·0	3·5	0
JAS	0·9	2·0	7·5	2·6
OND	5·1	6·0	1·1	0·8
Madang				
JFM	11·2	1·8	0	0
AMJ	10·8	2·2	0	0
JAS	6·0	4·3	2·7	0
OND	10·7	1·7	0·3	0·3

TABLE 9

MEAN NUMBER OF WEEKLY OCCURRENCES OF WATER SURPLUS PER QUARTER WITHIN SPECIFIED CLASSES (IN.) AND MEAN ANNUAL WATER SURPLUS FOR THE STANDARD PERIOD

Station and quarter	Nil	0·01–2·99	3·0–5·99	6·0–8·99	≥9·00	Mean annual water surplus (in.)
Aiome						152
JFM	0·3	3·4	4·8	2·8	1·7	
AMJ	2·3	5·9	3·4	0·7	0·7	
JAS	4·9	6·3	1·5	0·3	0	
OND	0·8	6·6	4·3	0·9	0·4	
Awar						45
JFM	4·0	7·5	1·4	0·1	0	
AMJ	6·0	5·6	1·4	0	0	
JAS	11·5	1·3	0·2	0	0	
OND	6·1	5·4	1·1	0·4	0	
Gusap						32
JFM	3·9	7·2	1·8	0·1	0	
AMJ	8·5	4·0	0·5	0	0	
JAS	12·1	0·8	0·1	0	0	
OND	8·1	4·4	0·3	0·2	0	
Madang						98
JFM	1·8	7·6	2·6	0·9	0·1	
AMJ	3·1	6·2	2·3	1·4	0	
JAS	7·2	4·7	1·0	0	0·1	
OND	2·4	6·6	3·0	0·7	0·3	

The residual term in the water balance model after evapotranspiration and soil moisture storage requirements have been met from weekly rainfall is water surplus. This may be regarded as an estimate of a combination of surface run-off and deep percolation. Table 9 gives the mean number of weekly occurrences of water surplus per quarter within specified classes. Both the frequency and magnitude of these surpluses are greatest at Aiome and least at Gusap. Mean annual water surplus is also given in Table 9 and varies from 32 in. at Gusap to 152 in. at Aiome.

IV. Acknowledgment

Climatic data were provided by the Commonwealth Bureau of Meteorology.

V. References

Brookfield, H. C., and Hart, D. (1966).—Rainfall in the tropical southwest Pacific. Aust. Natn. Univ. Dep. Geogr. Publ. G/3.

Fitzpatrick, E. A. (1963).—Estimates of pan evaporation from mean maximum temperature and vapor pressure. *J. Appl. Meteorol.* **2**, 780–92.

Fitzpatrick, E. A., Hart, D., and Brookfield, H. C. (1966).—Rainfall seasonality in the southwest Pacific. *Erdkunde* **20**, 181–94.

Köppen, W. (1931).—'Grundriss der Klimakunde.' (Walter de Gruyter Co.: Berlin.)

McAlpine, J. R. (1970).—Estimating pasture growth periods and droughts from simple water balance models. Proc. XIth Int. Grassl. Congr., pp. 484–7. (Univ. Qld. Press: Brisbane.)

McAlpine, J. R. (1972).—Climate of the Aitape–Ambunti area. CSIRO Aust. Land Res. Ser. No. 30, 60–72.

Thornthwaite, C. E. (1931).—The climate of North America according to a new classification. *Geogr. Rev.* **21**, 633–55.

PART V. GEOMORPHOLOGY

By E. Reiner* and J. A. Mabbutt†

I. Physical Regions

Five major physical regions have been recognized and are shown in Fig. 3. These are described below, from north to south.

(a) *Coastal Plains*

The coastline is 180 miles long with deep water inshore. This, combined with straight sectors parallel with structural trends in the coastal ranges, indicates a control by major faulting. The shoreline is emergent as shown by the raised coral reefs and few embayments (Plate 14, Fig. 1). The coastal plains covering some 260 sq miles are backed by steep hills. Continuous plains are found west of Hansa Bay and the Ramu north in the form of a series of low parallel sandy beach ridges 3 miles in width, but between Hansa Bay and Astrolabe Bay coastal plains are restricted to small alluvial flats at river outlets. The alluvial plain fringing Astrolabe Bay is a delta 5 miles wide consisting of the uplifted plain of the Gogol and Naru Rivers.

(b) *Hill Zone*

This zone occupies almost 3000 sq miles and can be subdivided into the northern extension of the Adelbert Range, the coastal foothills, the hilly continuation of the Finisterre Range and the central hills inland from the Adelbert Range.

The northern hills which cover 900 sq miles and extend into the Ramu plains are a zone of lesser uplift. They consist of closely dissected ridges and hills, steeper and narrow-crested in the higher central parts and lower and more rounded towards the margins. Apart from the smaller catchments on the margins, much of the region is drained south-eastwards by the Guam River which has captured an extensive area on the coastal side of the orographic axis.

Along the coast to the south are low rounded hills and branching ridges up to 300 ft high forming coastal foothills some 5 miles in width. Minor incised river valleys and narrow flood-plains traverse the zone. In the south altitudes may reach 800 ft.

The southern (Bagasin–Musak) hills which are a continuation of the Finisterre Mountains account for 500 sq miles and are short steep-sided ridges up to 1000 ft high aligned with the north-westerly regional strike. Altitudes attain 3000 ft above

* Formerly Division of Land Use Research, CSIRO, Canberra. Present address: Nieder Gelpe 13, 5251 Post Kalkkuhl Über Ingles-Kirchen, West Germany.

† Formerly Division of Land Use Research, CSIRO, Canberra. Present address: School of Geography, University of New South Wales, Kensington, N.S.W. 2033.

sea level in the central portion near Bagasin but are elsewhere below 2000 ft. There is a radial drainage pattern with outlet to the Sogeram River in the north-west, to the Gogol in the north and to the Ramu River in the south. The valleys are narrow in their upper sectors but widen downstream and develop discontinuous alluvial plains up to half a mile wide.

More than half the hill zone is taken up by the central hills, which cover some 1300 sq miles on the inland side of the Adelbert Range, together with the hills forming the divide between the Ramu and Sogeram Rivers. It consists of closely dissected steep-sided hills and short ridges up to 400 ft high and less than 800 ft above sea level. Altitude and relief generally decrease north-westwards towards the Ramu plain. The region is traversed by many large tributaries of the Ramu and Sogeram Rivers in flood-plains up to 1 mile wide. With this region are also included the physically similar Keram hills west of the lower Ramu River.

(*c*) *Mountain Ranges*

These account for 2600 sq miles and comprise the Adelbert Range, the Finisterre Range in its northernmost part and the lower slope of the Central Ranges.

The Adelbert Range is a low mountain range mainly below 4000 ft consisting of steep-sided ridges with minor upland areas of rounded hills but lacking prominent peaks. The drainage is complex with the longer rivers following the NW.–SE. geological structure and shorter transverse valleys draining the margins.

Only part of the Finisterre Mountains is included; there is a region of serrate steep-sided mountain ridges and peaks rising to 10 000 ft in the centre and with up to 3000 ft of relief. The drainage pattern is similar to that of the Adelberts in its combination of longer sectors with longitudinal upper catchments and shorter valleys on the flanks of the ranges. The main crest line lies north of the drainage divide and the main rivers turn south to cross it in steep gorges.

Only the north-eastern lowland slopes of the Central Ranges below 3000 ft are included in the survey area. Parts of both the Schrader and Bismarck Ranges are included. The ranges rise steeply and abruptly from the Ramu valley in a straight fault scarp with faceted spurs up to 3000 ft above sea level. Larger rivers indent the escarpment, particularly in the south, and the minor drainage consists of parallel narrow ravines.

(*d*) *The Ramu Valley*

The tectonic origin of the Ramu valley of some 900 sq miles is clearly reflected in its straight boundaries determined by north-west-trending faults. The average width of the valley in its lowland section is 6 miles and the altitude of the valley floor decreases therein from 1400 ft to 400 ft above sea level at Annanberg. Three sectors can be distinguished. The upper valley between the Finisterre and Bismarck Mountains is up to 5 miles wide including fans. The Ramu River here occupies a gravelly braiding flood-plain or river bed 1 mile wide along the south margin of the valley, which is also indented by tributary flood-plains. The northern margin is occupied by smaller undissected fans.

Near Usino the valley opens into an alluvial basin 14 miles wide and 20 miles long. Here the Ramu River meanders through a flood-plain 6 miles wide on the south side of the basin; tributary drainage entering from the north has formed flood-plains and flood-out swamps.

In the third sector the Ramu River enters a graben and its meandering channel is displaced to the north side by large alluvial fans from the Bismarck Mountains. These are now dissected and traversed by tributary flood-plains. The valley is now up to 6 miles wide and is swampy in places.

(*e*) *The Ramu Plain*

This region covers 1400 sq miles and begins at Annanberg where the Ramu River turns north and enters a wide plain which also extends into the valleys of the Guam and Sogeram Rivers, a deltaic region which finally merges with the Sepik River plains to the west. The meander belt of the Ramu River is up to 4 miles wide but the swampy back plains extend much further. Some low ridges and hills ranging from 20 to 100 ft high are found west of the Ramu River. North of these, part of the Bosman platform is seen as undulating low hills about 40 ft above the flood-plain. The plain north of this is swampy or gently undulating with wide meanders, oxbow lakes and cut-off river outlets.

II. Geological Outline

Acknowledgment is made here to Dr D. W. P. Corbett, a geologist of the Bureau of Mineral Resources, who participated in the lower Ramu survey. His reconnaissance was published (Corbett 1960). No geological map accompanies this report but reference may be made to the Bureau of Mineral Resources preliminary 1:1 000 000 map of the geology of Papua New Guinea (Anon. 1972). Reference should also be made to Bain *et al.* (1970).

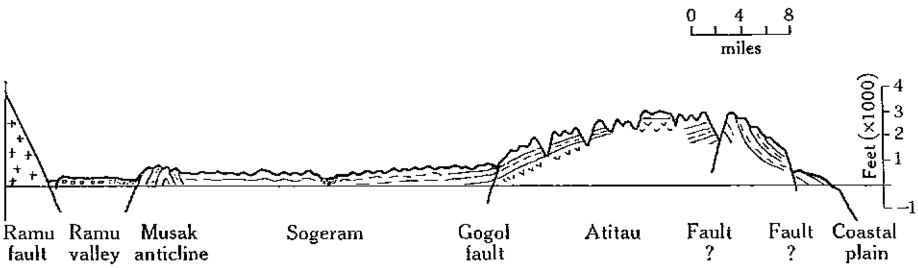


Fig. 7.—Generalized cross-section from the main ranges to the coast.

The pattern of physical regions just given corresponds to three tectonic divisions—the coastal ranges, central depression and the central mountains. Geologically the area is very young and most of its development took place in middle and late Tertiary and in Pleistocene times. A generalized cross-section is given in Fig. 7.

The oldest rocks are the schists of the Schrader and Bismarck Mountains which are correlated with the Goroka Formation of McMillan and Malone (1960). They are of Cretaceous to lower Tertiary age and were intruded in the Miocene by the massive Mt Wilhelm granodiorite batholith along the core of the present central mountains.

During most of the Tertiary era the area was part of the New Guinea Geosyncline in which were formed deposits extending in age from middle Miocene to Pliocene, beginning with limestone and passing into a varied sequence of sandstone, conglomerate and mudstone with associated volcanic rocks such as tuff and greywacke.

In the upper Miocene and lower Pliocene folding and uplift occurred in the main ranges and to a lesser degree in the growing geanticline of the coastal ranges which may then have been a chain of islands. In the upper Pliocene the area of continuing marine deposition was localized in the central depression where mudstone, siltstone and minor coral reefs were formed.

The main uplift of the area seems to have occurred in stages in the Pliocene and lower Pleistocene and was associated with block- and trough-faulting on NW. lines. The areas of greatest uplift were the main ranges outside the survey area where Tertiary marine sediments now occur at 9000 ft above sea level and in coastal ranges, particularly the Finisterres. The movements were throughout accompanied by vulcanism; the Finisterres received a thick cover of tuffs and ash with minor lava flows and small volcanic cones formed near the Adelbert Range. The coastline was demarcated by the uplift of the coastal ranges.

Surfaces of low relief were formed in the Adelberts during pauses in uplift and were in turn dissected as a result of further movements.

In the central depression, which remained relatively low-standing, the Ramu fault-trough was formed and became a zone of rapid alluvial deposition from the uplifted mountain blocks on either side.

The latest earth movements are directly expressed in the landscape, as in the spur facets of the Bismarck Range and the fault scarp between the Ramu valley and the central hills. Continuing uplift is indicated by seismic activity, particularly in the coastal ranges, and has resulted in upraised coral platforms and alluvial plains along the coast. Renewed graben-faulting has locally displaced older alluvial fans in the Ramu valley and the Bosman platform has been formed by the uplift of estuarine deposits.

Continuing earth movements have intensified the tendency to rapid erosion in higher areas and extensive alluviation in the lowlands.

III. Geomorphological History

The geomorphological history of the area is dominated by youthful faulting and strong differential uplift and no elements of the physical landscape predate the upper Tertiary.

The oldest surviving physiographic elements are probably the hilly upland surfaces with mature rounded outlines now restricted to scattered watershed areas mainly above 3000 ft above sea level in the Adelbert Range. It is possible, however, that the general accordance of higher crests which gives the Adelberts their characteristically even summit profiles may result from an even earlier planation. No equivalent survivals are recognized in the more strongly uplifted and dissected Finisterres.

The present relief of the coastal ranges indicates that the uplift which followed this postulated planation was greater in the Finisterres than in the Adelberts and that in both sectors it decreased from SE. to NW. The coastal ranges are commonly fault-bounded and block-faulting within the ranges has probably aided the development of the longitudinal valleys which characterize the inner parts of the Finisterres and Adelberts.

Uplift in the central depression has been greatest in continuation of the Finisterres, causing the strong relief of the southern (Bagasin–Musak) hills. Further north, uplift in two stages appears to have given rise to the higher and lower parts of the central hills. The former are generally about 200 ft higher with up to 250 ft greater relief than the lower hills where erosion has picked out a zone of softer mudstones. Renewed dissection of the hill lands of the central depression followed the down-faulting of the Ramu trough to form the present Ramu valley and the resultant rejuvenation of drainage in this area led to the capture by the Guam River of an extensive catchment in the northern hills.

Erosional levels formed during pauses in uplift may have given rise to the accordant crests at 300 ft and higher in the northern hills; the coastal foothills also show similar forms at 300 ft above sea level in the south.

The impressive fault scarp of the main ranges is also the result of spasmodic uplift, as shown by narrow benches above the faceted lower spurs, at between 2000 and 3000 ft above sea level.

Extensive gravel fans formed in the Ramu trough, flanking the mountain zones of strongest uplift. As a result the Ramu channel was displaced away from the Finisterres in its upper valley and forced to the north-east side of its valley by alluviation from the Bismarck Range further downstream.

At this stage the Ramu River entered a broad shallow embayment in the area of the present lower Ramu plain in which accumulated the estuarine muds of the Bosman platform.

The later stages of relief formation have probably resulted from continuing uplift and faulting combined with the Pleistocene eustatic shifts of sea level. Older alluvial fan deposits in the lower Ramu valley have been subjected to graben-faulting and have been severely dissected in stages, and renewed alluviation has given rise to alluvial terraces and the present flood-plains. The Bosman platform and the hills to the south have similarly resulted from the dissection of older alluvia. Deposition has occurred in all the larger valleys but the main area of alluviation has been the Ramu plain where considerable progradation of the shoreline has also occurred, as indicated by parallel-stranded beach ridges.

Coastal emergence is evidenced by numerous upraised coral reefs (Panzer 1933) and the slightly dissected alluvial plains at the head of Astrolabe Bay. A spectacular example of coastal emergence has been studied recently by Chappell (1974) along the northern seaboard of the Huon Peninsula east of the survey area. Here a flight of coral terraces rising to over 1800 ft provided a record of sea level changes in relation to the rising land going back to 220 000 years. The rate of uplift along the coast varied between 10 ft and 1 ft per 1000 years for this period. A slight drowning is indicated by the embayments at Madang and Alexishafen where the offshore coral islands may represent a former barrier reef, but in general the coast has retained its emergent fault-controlled character.

IV. Processes and Land Forms

(*a*) *Erosional Land Forms*

In this area, as elsewhere in New Guinea, land forms tend to evolve quickly in response to rapid rock weathering and mechanical erosion under the influence of a humid climate. This tendency is here accentuated by strong recent uplift. Hill slopes tend to be steep and valleys closely spaced with narrow divides, and river plains are subject to flooding of varying intensity and duration.

Available relief as determined by uplift is the most important factor in landscape evolution. With increasing relief erosion increases in severity, the drainage net tends to become closer, crests are more serrate and hill slopes steeper, whilst the valleys are increasingly narrow. For this reason relief has been used in the grouping of the land systems.

A secondary control over land forms is exercised by lithology. Since many land systems comprise several rock types lithology has not been employed in land system classification but certain generalizations can be made concerning the lithological control of erosional land forms.

(i) *Land Forms on Granodiorite.*—Granodiorite occurs only in the Bismarck Range where it is subject to strong erosion. It is a massive rock of moderate resistance and is subject to granular disintegration on weathering, so that hill-wash is effective on all steep slopes. It gives rise to strong and rugged relief with steep rectilinear slopes and narrowly rounded ridge crests. Drainage density is below average.

(ii) *Land Forms on Schists.*—Schists occur only in the Bismarck and Schrader Ranges in areas of strong relief energy. They weather rapidly and their fine cleavage and impermeable slope mantles give rise to rapid mechanical erosion and fairly closely spaced valleys. Landslides are common on the steep upper hill slopes and lower slopes tend to be irregular due to the resulting accumulation of colluvium.

(iii) *Land Forms on Sandstone with Mudstone.*—This rock is the most widespread in the survey area. The thin sandstone layers exercise a protective effect and give a stronger relief with more regular ridge-and-valley patterns and steeper hill slopes than does mudstone alone. Land forms in the lower parts of such areas, however, resemble those on mudstone.

(iv) *Land Forms on Mudstone.*—Mudstone is physically the least resistant of all the rock types in the area and breaks down readily on weathering. It tends to form lower relief of rounded hills and short ridges with somewhat gentler slopes. The thick impermeable weathering mantle results in a dense drainage pattern with particularly closely spaced short tributary valleys. Saturation of weathered mudstone leads to frequent mudflows and minor landslips which give benched or hummocky slope profiles and lead to the choking of minor valleys by colluvial fill.

(v) *Land Forms on Tuff and Greywacke.*—These are subject to very rapid chemical weathering followed by severe erosion in areas of strong relief. Their main occurrence is in the Finisterres where relief energy and erosion are at a maximum, and consequently they form a maze of narrow ridges and valleys with very steep or precipitous slopes.

(vi) *Land Forms on Limestone.*—The localized limestones consist mainly of porous impure coral limestone which weathers to a very heavy residual clay, but there are minor areas of more resistant massive siliceous limestone. They form ridges and cliffs with extensive rocky surfaces. These rocks are subject to surface solution and yield cavernous surfaces and there is local redeposition of secondary limestone on lower slopes.

(vii) *Land Forms on Dissected Old Alluvia.*—As a result of the latest fault movements older alluvia are being vigorously dissected in many parts of the Ramu valley. They consist mainly of former fan deposits of unsorted or bedded gravels and sands which are generally unweathered and relatively incoherent and subject to rapid channelling and slope collapse. In extreme cases they give rise to a maze of narrow ridges and steep-sided valleys.

(b) Depositional Land Forms

Rapid erosion in upland areas is associated with correspondingly active deposition in the river plains. Rapid mass movement of weathering mantles on steep slopes leads to a plentiful supply of colluvium and alluvium.

The tributary valleys are subject to frequent flash flooding when many high silt loads are transported. The texture of the alluvium varies with the source rocks; the volcanic rocks of the Finisterres yield a fine-textured alluvium whilst the granodiorite of the Bismarck Range gives a slightly coarser-textured sediment. Their narrow flood-plains are uneven and traversed by gravelly and sandy flood banks with intervening shallow depressions. They generally stand about 6 ft above the river bed which except during flooding is typically a braiding tract with gravelly or sandy banks and anastomosing minor channels. The narrow plains are flanked by colluvial fans which are subject to reworking by the river and its tributaries.

The main flood-plains are subject to general seasonal inundation but their meander belts also undergo short-lived local flooding during the dry season. They are generally areas of fine-textured sedimentation; an annual accretion of $2\frac{1}{2}$ in. has been measured but there are important local variations. Organic accretion as peat is also important.

The area of maximum deposition is the meander belt which in the Ramu plain is up to 4 miles wide. Discontinuous low levees of coarser-textured alluvium occur on outer banks and finer alluvium accumulates in the flood scrolls on river bends. The amplitude of the channel meanders increases down-valley; changes in course are indicated by the many oxbow lakes and the frequency of such changes is supported by map evidence (Stanley 1922). Deposition decreases away from the meander belt and the back plain is normally lower-lying and swampy.

Coastal processes are mainly aggradational, the steep coasts being largely protected from erosion by raised coral reefs. The tendency is for a smoothing of the coastline by the formation of sandy beaches. A seasonal north-westerly longshore drift is apparent in many deflected river mouths. The main area of sand beach formation is west of Hansa Bay, where there has been extensive progradation of the Ramu plain. It is notable that the delta is poorly developed at the Ramu mouth, this being attributed to deep water offshore.

V. References

Anon. (1972).—Geology of Papua New Guinea, 1:1 000 000 map. Prelim. ed. (Bur. Miner. Resour. Geol. Geophys. Aust.: Canberra.)

Bain, J. H. C., Mackenzie, D. E., and Ryburn, R. J. (1970).—Geology of the Kubor anticline—Central Highlands of New Guinea. Bur. Miner. Resour. Geol. Geophys. Aust. Rec. No. 1970/79.

Chappell, J. (1974).—Geology of the coral terraces, Huon Peninsula, New Guinea: a study of Quaternary tectonic movements and sea level changes. *Bull. Geol. Soc. Am.* **85**, 553–70.

Corbett, D. W. P. (1960).—Geological reconnaissance in the Ramu valley and adjacent areas, New Guinea. Bur. Miner. Resour. Geol. Geophys. Aust. Rec. No. 1962/32.

McMillan, N. J., and Malone, F. J. (1960).—Geology of the eastern Central Highlands of New Guinea. Bur. Miner. Resour. Geol. Geophys. Aust. Rep. No. 48.

Panzer, W. (1933).—Junge Küstenhebung im Bismarck Archipel und auf Neu Guinea. *Z. Ges. Erdk. Berl.*, Ergh. 5–6, pp. 175–90.

Stanley, E. R. (1922).—The salient geological features and natural resources of the New Guinea Territory. Rep. Leag. Natns on Admin. of T.N.G., 1921–22.

PART VI. THE SOIL FAMILIES

By H. A. Haantjens*

I. Introduction

Apart from recent alluvial soils some 49 soil families were recognized in the upper Ramu survey area. Two years later 20 of these were recognized as continuing into the lower Ramu area where, however, some 24 additional families were established. These new families, of course, reflected the prevailing delta conditions of the lower Ramu. Although a few minor modifications have been made the major task of the present combined report has been one of editing and the soils are described and presented much as they appeared in the two interim reports.

Detailed profile descriptions, sampled profiles and other analytical data remain in the interim reports and only brief profile descriptions are given here together with references to environmental conditions, vegetation, field pH, drainage status and fertility when available.

Because the field work was done some time ago there is no attempt to make a detailed soils classification other than the loose grouping shown in Table 10. Here the soils have been grouped mainly on profile characteristics into 11 major soil groups. Of these the first 10 deal with the more mature soils and comprise some 66 named soil families, mostly under a local name. The last group, comprising the young to recent alluvial soils, is arranged according to texture and stratification into 8 numbered families and represents a great simplification of the original complex of 24 series described in the interim reports.

The groups and their families are presented in alphabetical order to facilitate reference from the tabulated land systems.

No precise figures can be given for the actual areal extent of any of the soils named; a soil map was not prepared. Much of the pertinent soils information will be found on the tabulated land systems and indeed this Part must be regarded more as an appendix to these tabulations.

II. Description of the Soils

(a) *Alluvial Black Clay Soils*

These are very plastic heavy clay soils and with the exception of Surinam family are more than 4 ft deep. They have been grouped into four families on the variation of subsoil colour, presence or absence of gravel or concretions, and drainage differences. They mainly occur in Bumbu land system.

(i) *Bosman Family*.—This family is found extensively on flat to gently undulating uplands, consisting of old slightly uplifted marine deposits. The vegetation is mostly short grassland with local areas of lowland hill forest. The family has some

* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

TABLE 10

SOIL GROUPS AND FAMILIES AND THEIR OCCURRENCE IN LAND SYSTEMS

Soil group	Soil family	Land systems* in which soil occurs
Alluvial black clay soils	Bosman	20
	Kasamp	12, 15, 20, 24, 34
	Mungin	12, 21, 22, 24
	Sangkian	16
	Surinam	16
Immature brown residual soils	Banam	7, 9, 12
	Bopirompon	6
	Damanti	1
	Kalai	14, 20
	Karamsarik	2, 4, 7, 9, 11, 12, 13, 14
	Origa	12, 14
	Reinduk	14
	Sisimba	1
	Warwin	4, 7, 9, 11, 12, 13, 14, 24
Immature mottled residual soils	Aiha	7, 11, 12, 14
	Biwi	16
	Sirin	15
	Tebinsarik	11, 12, 14
Limestone soils	Mosia	6
	Opar	11, 12
	Rempi	22, 24
	Waguk	14, 24
Organic soils	Gomunu	1
	Jamenke	19
	Organic muds	36
	Peat soils (deep)	35
	Peat soils (raw)	28, 36
	Peat soils (subsoil)	23, 35
	Peat soils (topsoil)	25, 35
Poorly drained old alluvial soils	Ambana	24, 25
	Kabuk	25, 34
	Palipa	21, 22, 24, 32
	Tumunum	23, 25
Strongly weathered red and brown clay soils	Aimi	17
	Ainan	5
	Aiome	18, 19
	Autobak	3, 4
	Baia	5
	Kaove	4
	Korog	3, 4
	Koropa	4, 6, 12
	Mambu	18
	Sepu	18, 19, 26, 30
Undifferentiated residual soils	Lithosols	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 21, 22, 24
	Nininko	1
	Podago	10, 13, 15
	Slope soils (deep)	4, 18

TABLE 10 (*Continued*)

Soil group	Soil family	Land systems* in which soil occurs
	Slope soils (mudstone)	7, 11, 12
	Slope soils (shallow)	2, 4, 5, 7, 9
Weathered gleyed soils	Bibi	5
	Giri	12
	Hudini	14
	Mea	18
	Naupi	15
Well-drained old alluvial soils	Bembi	16, 21, 22, 29, 31
	Dumpu	16, 22, 23, 29
	Imbrum	30
	Kaian	24, 25
	Kaigulan	16
	Kausi	26
	Lanu	16, 22, 30
	Nubia	22, 24, 25
	Ouarara	16
	Sausi	16, 31
	Tumu	17
	Weisa	17, 19
Young alluvial soils	1	16, 21, 22, 25, 27, 28, 30, 31
	2	30
	3	21, 22, 24, 25, 26, 28, 29, 30, 31
	4	12, 21, 24, 26, 27, 28, 29, 30, 33, 36
	5	16, 21, 23, 26
	6	21, 23, 24, 25, 26, 27, 28, 29, 34
	7	7, 12, 14, 21, 24, 26, 27, 28, 29, 30, 32, 33, 34
	8	12, 23, 24, 26, 27, 29, 33, 35, 36

* Land systems are referred to by number. Names can be found in Part III where the land systems are arranged in numerical order.

affinity, including the presence of small iron concretions, to those in the weathered gleyed clay soils group.

More than 4 ft deep, a grey to olive-grey very plastic and sticky heavy clay subsoil is overlain by a 16–24-in. plastic heavy clay topsoil, black in the upper part and dark grey in the lower part. The topsoil is high in organic matter. The clay in the deeper subsoil is more olive-coloured and resembles plasticine. The soil is very slowly permeable. Run-off is nil to low and these soils are poorly drained.

(ii) *Kasamp Family*.—These soils occur locally on small alluvial flats surrounded by low hills and also in swamps near the coast. Vegetation is secondary alluvial forest and grassland to sago palm swamp.

This family consists of more than 4 ft of black to very dark grey, very plastic and sticky heavy clay soils, low to moderately high in organic matter. The soils are very slowly permeable. Run-off is nil to very low and the soils are poorly to very poorly drained. A water-table at 16 in. was found for one swamp profile.

(iii) *Mungin Family*.—This family occurs locally on alluvial flats between low hills in the delta area and high terraces of the coastal plain. The vegetation is often grassland, less frequently forest. Where poorly drained it may be sago palm swamp, phragmites swamp, or tall saccharum grassland. This soil is more than 4 ft deep with a dark grey to grey very plastic and sticky heavy clay subsoil overlain by 9–24-in. black to very dark grey very firm to plastic heavy clay topsoils. The organic matter values in the topsoil are low to moderately high. The pH is 6·5–7. The soils are slowly to very slowly permeable. Run-off is nil to medium and the soils are very poorly to imperfectly drained. Water-tables at between 13 and 38 in. were found in three of the profiles. The chemical fertility is probably moderately high.

(iv) *Sangkian Family*.—The soils are found on flat poorly drained surfaces of high alluvial fans with a cover of mid-height grasses.

The only profile observed is more than 4 ft deep and has plastic heavy clay subsoil with a 6-in. black slightly plastic clay topsoil. The subsoil is alternately black and very dark grey in colour. Calcium concretions, mostly in the shape of small tubes, occur throughout the profile but are most abundant in the topsoil. The pH varies from 7·5 to 8 through the profile. The soil is slowly permeable, poorly drained and has probably slow run-off. The chemical fertility is probably moderately high.

(v) *Surinam Family*.—This family is found only on the undulating higher part of Bumbu land system fan where the vegetation is short grassland.

These are 22–30 in. deep, very plastic heavy clay soils with 20–28-in. topsoils which are black in the upper part and very dark grey in the lower part and have moderate organic matter. The substratum consists of coarse gravelly clay which cannot be augered. One profile consisted of a shallow phase of 13-in. black topsoil directly overlying the gravel. The pH is 6·5 but may be 6 in the upper part of the topsoil. The soils are slowly permeable when moist and run-off is likely to be medium. They are imperfectly drained and chemical fertility is probably low.

(*b*) *Immature Brown Residual Soils*

The immaturity of these soils is apparent from the similarity between soil and parent rock textures, the dullness of the soil colours, the low degree of leaching and the relative shallowness of the profile. Most occur in the low mountains and hills on mudstone and siltstone. This group has been differentiated into nine families on texture, drainage differences, organic matter content and presence or absence of gravel.

(i) *Banam Family*.—These slope soils occur over steep and broken hilly country of sandstone and fine conglomerate. The vegetation is lowland hill forest and garden regrowth.

Approximately 2–3 ft deep, the subsoil consists of brown friable sandy clay to clay loam which contains much gravel. Topsoils are 3–12 in. thick, dark brown in colour and low to moderately high in organic matter. The soil is underlain by firm to soft weathered rock. The pH decreases from 6·5–7 in the topsoil to 6·5–5 in the subsoil. The soils are moderately to rapidly permeable, have medium to high run-off and are well to excessively drained. The chemical fertility is probably moderately low.

(ii) *Bopirompon Family*.—These soils are found on dissected low hilly foothills on the southern flanks of the Finisterre Range which are now in short grassland.

These shallow (14–20 in.) black friable to firm clay soils high in organic matter overlie a substratum of dark brown clay, sandy clay or weathered sandstone or siltstone. Increasing with depth are weathered stones and gravel. An eroded phase was recorded where the topsoil was very thin to completely absent. The pH is 6–6·5. The soils are well to excessively drained. The chemical fertility is probably moderately low.

(iii) *Damanti Family*.—This family is found on rugged mountainous country in the Finisterre Range and the vegetation is lowland hill forest with some gardens and grassland.

These soils are brown friable clay loams with a dark brown very friable loam topsoil and high organic matter. They are underlain by angularly broken grey-brown weathered volcanic tuff or clay loam containing large amounts of tuff fragments. They vary in depth from 12 to 46 in. The pH is approximately 6 in the topsoil, decreasing rapidly to 5·5 and 5 in the deeper subsoil. The soils are well drained and the chemical fertility is probably low.

(iv) *Kalai Family*.—This family is found mainly on old slightly uplifted beach deposits but also locally on low sandstone hills near the coast. It occurs mostly on slopes between 2 and 6°, more rarely on steeper slopes. The vegetation is lowland hill forest or secondary vegetation such as grassland, bamboo brake and coconut plantations.

A dark grey-brown to very dark grey rather plastic heavy clay topsoil moderately high in organic matter merges at 9–20 in. into a brown or grey-brown very plastic heavy 10–17-in. clay that is often somewhat mottled. The deeper subsoil consists of sandy clay merging into sandy clay loam or even sandy loam and is usually very compact. The soils are slowly permeable, have low to medium run-off and are imperfectly drained.

(v) *Karamsarik Family*.—This family is found extensively on steep hilly and low mountainous country where the rocks are mudstone and siltstone. It occurs on slopes ranging from 3 to 33°. The vegetation is lowland hill forest, garden regrowth and, locally, short grassland.

Approximately 2–3 ft deep, a brown firm clay subsoil is overlain by a 6–14-in. dark grey-brown firm clay topsoil low to moderately high in organic matter. The soils are underlain by compact weathered mudstone or mottled clay with increasing amounts of rock fragments. The pH increases from 6·5 to 7 in the subsoil. The soils are moderately permeable and have a high run-off. They are well to somewhat imperfectly drained. The chemical fertility is probably moderately high.

(vi) *Origa Family*.—This family is found on low hills of mudstone and sandstone where the vegetation is lowland hill forest, secondary forest and gardens with some small areas of short grassland.

These soils are shallow soils with 9–12 in. of very dark grey-brown friable or firm clay loam to clay topsoil with moderate organic matter, overlying mottled firm and plastic clay with rapidly increasing amounts of gravel which makes auger sampling below 20 in. impossible. The pH is approximately 6–6·5. The soils are imperfectly drained and have moderate permeability and slow run-off. The chemical fertility is probably moderately high.

(vii) *Reinduk Family*.—This family is found locally on low hills and broad crests in the coastal region on slopes up to 4–10°. Parent rock is mudstone, siltstone and, at Awar, volcanic rock. The vegetation is lowland hill forest and coconut plantation.

Approximately 2–3 ft deep, the subsoils vary from dark brown to grey-brown very plastic heavy clays commonly with some brown and black mottles. The topsoil is 14–20 in. thick and consists of very dark brown to very dark grey firm clay in the upper part and somewhat lighter-coloured plastic heavy clay in the lower part. The organic matter content is high. The soils are underlain by compact weathered rock. The soils are slowly permeable, have a low to medium run-off and are imperfectly drained.

(viii) *Sisimba Family*.—This is found only on a dissected hummocky old landslide in the Finisterre Range vegetated by *Casuarina* regrowth and gardens.

The only profile observed is a dark red-brown very friable loam to clay loam with a 19-in. dark brown very friable brown topsoil high in organic matter. Below 40 in. the subsoil becomes brown and gravelly, the gravel increasing with depth. The pH of the topsoil is 6 and of the subsoil 6·5. The soil is well drained and chemical fertility is probably moderately high.

(ix) *Warwin Family*.—This family occurs throughout low hilly to mountainous country on mudstone and siltstone. There was one occurrence on coralline deposits near the coast. It is usually found on moderate to gentle slopes; the vegetation is lowland hill forest with much gardening and regrowth including bamboo brake.

Usually 4 ft or more deep, a brown very plastic heavy clay subsoil which may be slightly grey mottled is overlain by a dark brown topsoil of varying thickness (4–21 in.). The latter usually consists of rather friable clay loam in the upper part and plastic clay in the lower part. The organic matter content ranges from low to high. The pH is 6–6·5 but 6·5–7 in the surface soil. The soils are slowly permeable, have high rapid run-off and are well to imperfectly drained. The chemical fertility is probably moderately high.

(*c*) *Immature Mottled Residual Soils*

These soils are found on mudstone and siltstone and are common in low hilly country. They occur only on small flatter areas in the steep higher hills. They are characterized by mottled subsoils, are clayey throughout and are usually less than 4 ft deep. Four families have been recognized on the basis of subsoil colour and drainage differences.

(i) *Aiha Family*.—The most mature of the group and mottled only in the subsoil, this family is found on mudstone and siltstone on gentle to moderate slopes in low hilly country with vegetation ranging from lowland hill forest to gardens and garden regrowth.

Usually about 4 ft deep, a brown plastic heavy clay subsoil strongly brown and grey mottled below 15–30 in. is overlain by a 6–14-in. topsoil consisting of dark brown friable to firm clay low to moderately high in organic matter. The pH fluctuates between 6 and 7 throughout the profile. Soils are slowly permeable, have low to medium run-off and are imperfectly drained. The chemical fertility is probably moderately high.

(ii) *Biwi Family*.—This is found on the undulating parts of the high fans from the southern flanks of the Finisterre Range now in short grassland.

These are firm and plastic dark brown to dark grey clay soils which are more or less strongly mottled. They have *c*. 18-in.-thick topsoils, black in the upper part, very dark brown or very dark grey in the lower part and high in organic matter. The upper part of the topsoil is friable, the lower part plastic. The soils are underlain at a depth of 25–40 in. by a very gravelly and stony substratum; pH is 6–6·5 increasing to 7 in the substratum. The soils are slowly permeable and have medium to slow run-off. The chemical fertility is difficult to assess but it is probably moderately low.

(iii) *Sirin Family*.—This family is found only on the short grasslands of Sirin land system. The parent material is siltstone and the soil occurs on gently concave more or less colluvial slopes of the low hills.

In these soils there is a 19–22-in. very dark grey very firm to very plastic heavy clay topsoil high in organic matter which merges into a 6–14-in. dark grey-brown very plastic heavy clay with many brown mottles of weathered rock fragments. This is underlain at about 30 in. by a dense mixture of grey clay and brown weathered rock. The soils are slowly permeable, have medium run-off and are imperfectly drained.

(iv) *Tebinsarik Family*.—This family is found on low hills, usually on gentle slopes and rarely at the foot or on flat tops of steep hills. The parent rock is mudstone or siltstone and the vegetation mostly grassland.

These are 2–4 ft deep strongly brown and grey mottled plastic clay soils overlain by 6–14 in. of very dark grey to dark grey-brown plastic clay to heavy clay topsoils moderately high in organic matter. The soils merge into a mottled dense and soft completely weathered rock. The pH is about 6·5 throughout the soil. Soils are very slowly permeable, have medium run-off and are poorly to very poorly drained. The chemical fertility is probably moderately high.

(*d*) *Limestone Soils*

These are usually shallow soils with coral limestone in the profile or substratum. Four families have been separated on the basis of texture, drainage and colour differences.

(i) *Mosia Family*.—These soils are found on the southern very dissected foothills of the Finisterre Range where the vegetation is mainly short grassland.

These are shallow clay soils on coral detritus with a 6–8-in. very dark red-brown friable light clay topsoil high in organic matter. This topsoil may rest directly on coral detritus or merge into a subsoil consisting of up to 20 in. of dark red-brown heavy clay passing abruptly to a very irregular surface of the coral detritus. The pH of the topsoil is 6·5 whilst in the subsoil it increases from 6 to 7 with depth. The soils are excessively drained and their chemical fertility is probably low.

(ii) *Opar Family*.—This family occurs rarely and is found on slopes up to 20° amidst scattered limestone blocks close to massive coral limestone outcrops in sedimentary hill landscapes. The dark heavy clays have probably come from a mixture of parent material of limestone and mudstone. Vegetation is remnants of lowland hill forest with short grassland.

These are very dark grey to very dark grey-brown firm to plastic heavy clay soils containing varying amounts of large limestone fragments. Below 20–24 in. either the amount of limestone increases considerably or the subsoil consists of completely weathered mudstone. The pH is 7–8. The soils are slowly to moderately permeable, have medium to high run-off and are well to imperfectly drained.

(iii) *Rempi Family*.—This family is found on gently undulating to almost flat slightly uplifted coral reefs and beach ridges along the coast. The parent material is coral detritus. The vegetation is coconut plantation and coastal regrowth.

These are shallow (6–8 in.) black to very dark brown very friable loam to clay loam soils, moderate to high in organic matter and overlying whitish coral sand and stone and shell fragments. The soil pH is 6·5–7 but may go up to 8. The soils are rapidly permeable, run-off is nil or very low and, depending on their depth, they are well to excessively drained. The chemical fertility is probably moderately high.

(iv) *Waguk Family*.—This family is found very locally on coral limestone on low hills and ridges near the coast. The vegetation is garden regrowth and secondary forest.

These are shallow dark grey-brown plastic clay soils with 3–4 in. of very dark grey-brown friable topsoils moderately high in organic matter. They are underlain at a depth of 10 in. by a mixture of brown very plastic clay and increasing amounts of coral detritus. The soils are moderately permeable, have high run-off and are well to excessively drained.

(*e*) *Organic Soils*

Except for Jamenke family, which is marginal to the poorly drained alluvial group, the remaining six families occur in swamps mostly in the vicinity of the coast. Recognition of families is based on the texture, the amount and degree of decomposition of the organic layers and where these layers occur in the profile.

(i) *Gomunu Family*.—The only profile observed is from a lake swamp resulting from a landslide blockage. It consists of 36 in. of dark organic mud overlying light grey sloppy clay with many plant remains. The water-table is very close to the surface.

(ii) *Jamenke Family*.—This is found in very slight depressions in the high alluvial fan surfaces of Aiome land system. The vegetation is moist *Ischaemum* grassland.

More than 4 ft deep, the soils consist of black very friable clay loam overlying very dark grey-brown firm clay which merges at 3–4 ft into grey and brown mottled plastic clay with gravel. The organic matter content is very high as the soils are of a semi-peaty nature. The soils are rapidly to moderately permeable, run-off is nil and they are poorly drained. A water-table at 43 in. was found in one profile.

(iii) *Organic Muds*.—These 'soils' consist of dark grey to very dark grey-brown very sloppy organic mud mixed with fine root material. This material builds up on the firm bottom of deep grass swamps and has no proper upper boundary as it becomes more and more suspended and merges into open water. Along the edges of swamps layers of denser grey clay may be embedded in the muds.

(iv) *Peat Soils* (*Deep*).—These soils occur locally in swamps in the delta area of the Ramu River. The vegetation is *Phragmites* or sago palm.

Approximately 4 ft deep or deeper, the soils are composed of layers of black to very dark grey-brown peaty clay and clayey peat. The soils are probably moderately permeable, swampy and run-off is nil. Water-tables are found at the surface and at 10 in.

(v) *Peat Soils* (*Raw*).—Raw peat occurs locally in small deep swamps such as cut-off meanders and has a mixed herbaceous swamp and aquatic vegetation.

Such 'soils' consist of more than 3 ft of raw peat with very open texture and full of dead and living roots. Some silt may be present in the deeper layers. The soils are swampy with water-tables at the surface.

(vi) *Peat Soils* (*Subsoil*).—These soils are found locally in the delta area of the Ramu River under more or less swampy conditions with a vegetation ranging from low palm forest to sago palm swamp.

In these soils a 24–34-in. layer of grey and brown mottled plastic clay overlies a very dark brown layer of well-decomposed peaty clay and clayey peat. The soils are slowly permeable, run-off is nil and they are very poorly drained to swampy. Water-tables were found at 14 and 42 in.

(vii) *Peat Soils* (*Topsoil*).—This soil was found only in a swale between beach ridges under a vegetation of *Phragmites* but probably occurs also in swamp land in the Ramu delta.

The profile observed had an 18-in. layer of black wet very friable and sticky well-decomposed peaty loam overlying a 7-in. layer of dark olive-grey and yellow-brown mottled, wet, slightly plastic and very sticky sandy clay, merging into sandy clay loam which in turn merges into dark grey loamy sand. The soil is swampy with water-tables between the surface and 10 in.

(*f*) *Poorly Drained Old Alluvial Soils*

These soils have deep black to very dark grey topsoils in contrast to the lighter colours of the young alluvial soils. They are found over many land systems mainly on low-lying but stable parts of beach ridges and alluvial plains in the vicinity of the coast. The four families are recognized on textural and drainage differences. Ambana is the most sandy, Tumunum has clayey topsoil and sand subsoil whilst Kabuk and Palipa are plastic clays and are at the same time the most poorly drained.

(i) *Ambana Family*.—This family occurs locally on flat low-lying beach ridges covered with grassland, coastal regrowth and coconut plantations.

These are grey and brown mottled soils with a texture ranging from sandy clay loam to sandy loam and, in the subsoil, commonly sand. The topsoil is 11–14 in. thick, black to very dark grey-brown in colour and high in organic matter. The soils are moderately permeable, run-off is nil and they are poorly to very poorly drained. Water-tables at 15 and 9 in. were observed in two profiles and the third profile was found in a plantation where drainage had been improved.

(ii) *Kabuk Family*.—This family was found on a narrow slight rise of an old beach ridge in a swamp and again at the landward edge of an old beach ridge. The vegetation is *Phragmites* swamp, tall *Saccharum* grassland and near Aiome *Campnosperma* swamp forest.

These soils consist of 10–12 in. of black to very dark grey-brown friable clay to clay loam separated from a strongly grey and brown mottled very plastic clay or heavy clay subsoil by a thin layer of brown rusty very friable loam or clay loam. The topsoils are rapidly permeable and the subsoils slowly permeable. Run-off is nil to very low and soils are poorly to very poorly drained. A water-table at 29 in. was found in one profile.

(iii) *Palipa Family*.—Soils of this family are found on sloping undulating alluvial coastal plains and flat depressions in the Usino basin. The vegetation is of alluvial well-drained and alluvial flood-plain forest through to tall *Saccharum* grassland.

There is more than 4 ft of grey-brown to grey strongly mottled heavy clay to clay soil that is plastic to extremely plastic from a depth of normally 5–15 in. The soils have 6–12-in. very dark grey-brown to dark brown clay loam to clay topsoils with moderate to low organic matter. The pH is 6–6·5 throughout the profile. The soils are poorly to very poorly drained, slowly permeable and have slow to medium run-off. The chemical fertility is probably high.

(iv) *Tumunum Family*.—This family is found on flat old beach ridges some distance inland. The vegetation is usually forest or grassland.

The soils consist of firm to very plastic clay to heavy clay to a depth of 19–29 in. Below this they become gradually more sandy, until they consist of sand below 28–37 in. The topsoils are 9–24 in. thick, black to very dark grey-brown in colour and moderately high to high in organic matter. The upper part of the soil is slowly permeable but the subsoil is rapidly permeable; run-off is nil to very low. The poor to imperfect drainage of these soils is due not so much to their low-lying situation with ensuing high water-tables as to the impermeability of the topsoils.

(g) *Strongly Weathered Red and Brown Clay Soils*

These soils are the most mature in the survey area. They are characterized by bright red and brown colours below the topsoil, clayey textures, strong leaching and deep profiles. Severe truncation of profiles is, however, often evident in mountain areas. Except for Koave and Koropa families these soils are relatively friable with regard to their high clay content. Ainan and Baia families are both rather shallow soils found locally on spur and foot slopes of the Schrader Range. The first occurs on volcanic material and the second on schists and shales. Autobak, Koave and Korog families all occur on the Adelbert Range volcanics while the plastic red soils of Koropa family have developed locally on mudstone and siltstone on the low ridges of Amaimon land system.

Aiome, Sepu, Mambu and Aimi families are often extensive on old alluvial fans from the Schrader Range with the brown soils of Aiome probably the youngest.

(i) *Aimi Family*.—This was found on a flat terrace of the Maria River where it traverses the Faita land system fan. The vegetation is mid-height grassland.

The only profile observed is more than 4 ft deep, dark red-brown friable clay to heavy clay with 11 in. of slightly darker friable clay loam topsoil high in organic matter. The pH decreases from 6 in the topsoil to 5·5 in the subsoil. The soil is well drained and the chemical fertility is probably moderately low.

(ii) *Ainan Family*.—This was found on lowland ridges of Bismarck land system covered with lowland hill forest.

The only profile observed consists of a 12-in. dark red-brown sandy clay topsoil with low organic matter and containing *c*. 30% stones, 8–16 in. in diameter, overlying more than 12 in. of red-brown sandy clay loam containing 40–50% stones. The soils are excessively drained and of low apparent fertility.

(iii) *Aiome Family*.—This family is found predominantly on flat upper surfaces of old alluvial fans at the foot of the Schrader Range. Slopes are up to 2° and the vegetation is mainly short grassland with forest remnants.

These soils are brown friable to firm clay soils, probably less mature than the red soils of Sepu family, with usually 14–20 in. of very dark brown very friable clay loam topsoils high in organic matter. Below 26–40 in. the soils are usually rather stony. They are moderately to rapidly permeable, well drained and have very low run-off.

(iv) *Autobak Family*.—This occurs in the Adelbert Range (Gal land system) nearly always on steep slopes of 20–30°. The vegetation is lowland hill forest with some garden regrowth.

Soils are rather shallow to rather deep brown to yellow-brown friable to firm clay soils with a normally 6–13-in. dark brown friable clay loam to clay topsoil with moderate organic matter. With depth there is a rather rapid transition to incompletely weathered tuffaceous rock. The pH increases with depth from 5 to 6 in the upper part and 5·5 to 6·5 in the lower. The soils are moderately permeable, have a high run-off, are well drained and are probably of moderate to low fertility.

(v) *Baia Family*.—This family has locally developed on shales and schists over the lower lowland spurs of the Schrader Range. It is found on gently sloping crests but also on steep foot slopes of up to 30°. The vegetation is lowland hill forest.

These soils have a 6–15-in. dark brown clay loam friable topsoil with moderate to low organic matter overlying 24–33 in. of red-brown to red friable clay which merges gradually into a brown to red-brown subsoil with slightly coarser texture and containing varying amounts of weathered rock fragments. The pH decreases gradually from 6 near the surface to 4·5 at lower depths. The soils are moderately permeable, have medium to high run-off, are well drained and appear to be of very low fertility.

(vi) *Kaove Family*.—This occurs very locally in the Adelbert Range on gently sloping broader crests or steep slopes close to the crest. Vegetation is lowland hill forest.

More than 4 ft of red, brown and greyish mottled plastic heavy clay soils are overlain by 5–8-in. dark brown firm clay topsoils moderately high in organic matter. The soils are slowly permeable, have low to medium run-off and are imperfectly drained.

(vii) *Korog Family*.—This family is found locally on igneous rocks up to 3000 ft high on crests and spurs in the Adelbert Range. Slopes may be as steep as 30°. The vegetation is lowland hill forest.

These are 3–4 ft deep and consist of a red-brown to red firm clay to heavy clay soil with 5–10-in. dark brown friable clay loam to clay topsoil. They are low to moderately high in organic matter. At depth there is a slightly coarser-textured firm subsoil with completely weathered rock fragments. The pH is 5·5–6. The soils are well drained, moderately permeable and apparently of low fertility. Run-off varies from low to high.

(viii) *Koropa Family*.—This family occurs locally on mudstone and siltstone on broad crests of the Adelbert Range with slopes 4–15° and again on the dissected fan of Romole land system. The vegetation is lowland hill forest and short grassland.

These soils are more than 4 ft deep and have a very firm to plastic heavy clay subsoil and usually 6–13-in. brown to dark brown friable clay to firm heavy clay topsoils low to moderately high in organic matter. The upper part of the subsoil is brown, the lower part red. The pH decreases with depth from 6 to 5·5. The soils are slowly permeable, have high run-off, are well drained and of low fertility.

(ix) *Mambu Family*.—This family is limited to flat fans in Panakatan land system with a vegetation of alluvial well-drained forest.

These are red-brown light clay to sandy clay soils with *c*. 1-ft-thick dark red-brown friable loam to clay topsoil high in organic matter. The deeper subsoil below *c*. 30 in. either contains many stones or consists of numerous layers of red-brown or yellow-red coarse sandy clay loam, gravelly sandy loam, sandy clay loam, etc. The pH decreases gradually from 6·5 near the surface to 5 at 4 ft. The soils are well drained. The chemical fertility is probably low.

(x) *Sepu Family*.—This occurs extensively on old high alluvial fans along the lower slopes of the Schrader Range. It is more prevalent than Aiome family on the dissected parts. The vegetation is lowland hill forest and grassland. Sepu family is also recorded on lower fans and river terraces where the forest is alluvial and there is tall *Saccharum* grassland.

More than 4 ft of red-brown to yellow-red firm clay to heavy clay soils are overlain by 6–10 in. of dark brown friable to firm clay loam topsoils in which organic matter is moderately high on flattish land but decreases on slopes. The subsoil is often very stony on steep slopes. The pH decreases from 6–6·5 near the surface to 5·5–4·5 at depth and the fertility is probably low to very low. The soils are moderately permeable, have very low to high run-off and are well drained.

(*h*) *Undifferentiated Residual Soils*

Six families have been distinguished on soil depth, degree of development of the topsoil, the nature of the parent material and the amount of gravel present.

Included here are some very shallow soils around the coast on hard sedimentary rocks and greywacke, and also shallow slope soils of the mountains, immature and colluvial in nature. Lithosols, less than 6 in. deep, occur in 15 different land systems but only as a minor category.

(i) *Lithosols Family*.—Lithosols occur in limited patches but have wide occurrence through steep hilly and mountainous areas especially on sharp crests and steep slopes. They are also common on grassland hills along the coast.

These are residual soils with only 6 in. or less of soil material overlying more or less weathered hard or dense parent rock. Pockets of deeper soil may occur and rock outcrops and fragments are very common. The soil material is mostly dark-coloured. Organic matter may be moderate when over limestone but is usually low. Drainage is excessive.

(ii) *Nininko Family*.—This family is found only on old landslip areas in the southern Finisterre Range where *Casuarina* trees have colonized and some gardens have been made.

These are brown, friable to firm light clay soils with a 3–9-in. dark brown loam to clay loam topsoil with moderate organic matter. In many cases the soil contains low to moderate amounts of gravel and stones and is underlain at a depth of between

18 and 35 in. by gravelly sandy clay loam or gravelly sandy clay. Surface stoniness varies widely. The pH is 6–6·5 throughout the profile and the soils are well drained. The chemical fertility is probably moderately high to high.

(iii) *Podago Family*.—This family is usually found on steep slopes, 15–30°, on siltstone, sandstone and greywacke in the coastal region. The vegetation is dominantly grassland with regrowth and forest remnants.

Very shallow (8–12 in.) black to very dark brown firm clay soils, high in organic matter, overlie dense soft to hard weathered siltstone or sandstone. The soils are rapidly permeable but the substratum appears to be slowly permeable. Run-off is high and the soils are excessively drained.

(iv) *Slope Soils* (*Deep*).—These soils occur locally on very steep slopes and under a lowland hill forest.

These are 3–4 ft deep, undifferentiated dark brown clay soils with poorly developed topsoils and containing varying amounts of weathered rock fragments at irregular depths. The soils are moderately permeable, have high run-off, are well drained and probably of low fertility.

(v) *Slope Soils* (*Mudstone*).—These soils occur locally on more or less broken and colluvial slopes, 10–20°, on mudstone and siltstone. The vegetation is lowland hill forest or garden regrowth.

Approximately 2–3 ft of dark grey-brown firm to plastic clay soils are overlain by poorly developed topsoils, low in organic matter. They contain unevenly distributed rock fragments which constitute a very large proportion of the soil below 2–3 ft. The soils are moderately to slowly permeable, have high run-off and are well drained.

(vi) *Slope Soils* (*Shallow*).—These soils occur extensively in all rugged mountain areas and on igneous, metamorphic and hard sedimentary rocks. Slopes may be very steep. Vegetation is lowland hill forest or garden regrowth.

Normally there is a 10–16-in. topsoil of very dark grey-brown friable to firm clay loam to clay overlying a somewhat lighter-textured subsoil with rock fragments. Weathered rock is commonly encountered between 15 and 30 in. The soils are rapidly permeable, have medium to high run-off, are well drained and probably low in fertility.

(*i*) *Weathered Gleyed Soils*

The presence of gleying and moderate to very high amounts of black or brown concretions in the upper and/or middle part of the profile is the binding factor of this group. The soils may differ rather strongly in other features. Bibi and Mea soils with dark topsoils and lighter subsoils containing black concretions occur along the lower slopes of the Bismarck Range while Giri and Hudini occur on broad mudstone and siltstone crests in the Amaimon hills. Subsoils here are red and grey mottled with only moderate amounts of concretions. Naupi family, found only on the grass hills of Sirin land system, on the other hand has strong concretions in a grey heavy subsoil.

(i) *Bibi Family*.—This is found along the lowland slopes of the central ranges under a lowland hill forest.

A shallow poorly drained soil with a dark organic loamy topsoil overlies more or less mottled red-brown clay containing many rock fragments and black iron concretions from a depth of 15–20 in. The pH is 5–5·6. The soils are poorly drained and of apparent low fertility.

(ii) *Giri Family*.—This family is found very locally on flat to gently undulating tops of low mudstone ridges. The vegetation is lowland hill forest, regrowth and grassland.

These soils are more than 4 ft deep. An 11–20-in. topsoil of very dark grey-brown firm clay in the upper part and dark grey plastic heavy clay in the lower part merges into a strongly red, brown and grey mottled very plastic heavy clay subsoil. Low to moderate amounts of iron concretions occur in the lower part of the topsoil, and sometimes also in the surface layer. The organic matter is moderately high. The soils are slowly permeable, have a low run-off and are poorly to imperfectly drained. A water-table was found in one profile at a depth of 38 in.

(iii) *Hudini Family*.—This family occurs on low hilly country of sedimentary material with lowland hill forest and some gardening.

The only profile observed is strongly eroded and this appears to be general. It is a red-brown heavy clay underlain at 8 in. by a strongly red and grey mottled subsoil of slightly coarser texture. The pH is 6 in the upper part and 5·5 in the lower part of the profile. The soil is slowly permeable and run-off is rapid. Chemical fertility is likely to be very low.

(iv) *Mea Family*.—This family occurs on flat fan slopes under forest.

The soils are very strongly red and grey mottled deep plastic clay soils with 8–14-in. very dark brown to black friable clay topsoils with moderate to high organic matter. Permeability is slow and the soils are poorly drained. The chemical fertility is probably low.

(v) *Naupi Family*.—This family was found only on broad low ridges south of coastal Bogia. Slopes are about 3° and the parent material is greywacke. The vegetation is open grassland or bamboo brake.

In these soils which are more than 4 ft deep a 12–14-in. very dark grey to very dark brown clay topsoil, high in organic matter and containing moderate amounts of iron concretions, merges into a 6–19-in. dark-coloured layer of iron concretions mixed with clay. This layer is underlain by grey very plastic heavy clay in which the iron concretions decrease and become softer with depth. The subsoils are slowly permeable; run-off is low to medium. Although the soils are poorly to imperfectly drained, they dry out quickly during the dry periods found in this area because of poor physical characteristics.

(*j*) *Well-drained Old Alluvial Soils*

These are usually deep soils with black to very dark grey-brown topsoils over gravelly subsoils in which they contrast with the young alluvial soils. With 12 families described they are the most varied of the major groups and are represented in most land systems. Around the coast they are found on the higher parts of beach ridges and coastal plains and are especially prominent on old river terraces and fans. Classified primarily from *sandy* to *clayey* they range from the almost pure sand of Nubia through Imbrum, Kaian, Kaigulan, Kausi, Weisa, Bembi, Lanu, Ouarara and Tumu families to Dumpu which is of uniform clay.

(i) *Bembi Family*.—These soils are found on undulating alluvial plains and flat higher river terraces. Vegetation is alluvial forest and tall *Saccharum* grassland.

These are brown friable soils more than 4 ft deep and the texture merges from clay or clay loam to sandy clay loam or loam below 20–36 in. and in a few cases to fine sandy loam below 36 in. Topsoils are usually 12–19 in. thick, black to very dark grey-brown and high in organic matter. The pH is 6–6·5 and soils are well drained and moderately permeable. Run-off is nil or very low.

(ii) *Dumpu Family*.—This family is found on undulating fans and alluvial plains as well as high river terraces. Vegetation is mainly alluvial forest with some tall *Saccharum* grassland.

These are at least 4 ft deep, dark brown to olive-brown firm clay to sandy clay soils with normally 13–20-in. very dark grey-brown topsoils with moderate to high organic matter. The pH is 6–6·5 through the profile. The soils are moderately permeable. Run-off is nil or very low and the soils are well drained and probably of high fertility.

(iii) *Imbrum Family*.—On river flood-outs the vegetation comprises grass and mixed herbaceous successions.

These are more than 4 ft deep, very sandy or coarse sandy soils with 9–14-in. black very friable sandy loam or loam topsoils, high in organic matter. The pH is 5·5–6. The soils are excessively drained and must be rated low in chemical fertility.

(iv) *Kaian Family*.—These are found locally on high beach ridges, mostly on the inland slopes. The vegetation is grassland, regrowth or coconuts.

These are friable loam to light clay soils merging with depth into sandy loam and, between 24 and 31 in., into loose sand. The topsoils are 14–26 in. thick, very dark brown in colour and high in organic matter. The soils are well drained and rapidly to moderately permeable; run-off is nil.

(v) *Kaigulan Family*.—This family occurs on fan and terrace surfaces in Bumbu land system in which the vegetation is a short grass cover.

These soils are 24–26 in. deep, of varying texture (clay loam, sandy clay, clay, and rarely loam in the top part, and sandy clay, gravelly sandy clay, gravelly sandy clay loam, or clay in the lower part) overlying an extremely gravelly and stony substrate. The soils are high in organic matter, usually black in the upper part and very dark brown in the lower part. The pH is approximately 6–6·5 throughout the profile. The soils are well drained and the chemical fertility is probably high.

(vi) *Kausi Family*.—This family is found on sloping alluvial fans where the vegetation is alluvial forest and tall *Saccharum* grassland.

These are at least 4 ft deep, dark brown to red-brown very friable loam to sandy clay loam soils with moderate organic matter. Low to moderate amounts of stones occur below 12 in. The pH is 6–6·5 and the soils are well drained with a moderate chemical fertility rating.

(vii) *Lanu Family*.—These soils are found on flat to undulating parts of Bumbu land system as well as alluvial plains and flood-outs and lower river terraces of Imbrum land system. The vegetation is mainly short grassland but also some tall *Saccharum* grassland.

These are shallow, 12–15-in. black soils, high in organic matter and overlying an extremely gravelly and stony substrate. Two phases are recognized—Lanu sandy loam to loam which is very friable and excessively drained, and Lanu clay loam to clay which is firm to friable and well to excessively drained. The pH is 6 throughout the profile. The soils are locally stony and the chemical fertility is probably high to moderately high.

(viii) *Nubia Family*.—This family occurs extensively on relatively high beach ridges, on flat to gently sloping land. The vegetation consists of grassland, gardens and garden regrowth and coconut plantations.

More than 4 ft deep, loose very sandy soils are overlain by 8–20-in. very dark brown very friable sandy loam topsoils moderately high in organic matter. The soils are rapidly permeable, well to excessively drained and run-off is nil.

(ix) *Ouarara Family*.—These soils are found on the undulating Bumbu land system under a short grass cover.

These are very shallow (6–9 in.) black very friable loams high in organic matter and with low to high amounts of gravel and overlying extremely gravelly substrate. The pH is about 6. The soils are excessively drained. The chemical fertility of the topsoil is moderately high.

(x) *Sausi Family*.—This family occurs on undulating fans and alluvial plains with short grassland and some tall *Saccharum* grassland.

These are more than 4 ft deep, brown soils with 15–17-in. black to very dark brown friable to firm topsoils high in organic matter. The texture of the subsoil is sandy clay loam merging into sandy loam at 24–26 in. and loamy sand at greater depth. There is also a plastic subsoil phase. The pH is 6 in the topsoil and 6–6·5 in the subsoil. The typical soils are well drained and rapidly permeable and have very low run-off. Chemical fertility is probably moderately high.

(xi) *Tumu Family*.—This family occurs on alluvial fan surfaces with alluvial forest and tall *Saccharum* grassland.

These are dark brown soils with irregular textural profiles. They have a 3–14-in. very dark brown very friable loam topsoil with high organic content overlying a loam or clay loam or clay which becomes gravelly at 14–19 in. Gravelly layers may alternate with loamy layers in the deeper subsoil. In one instance the soil was 23 in. of loam with a gravelly subsoil appearing at 42 in. The pH is 6–6·5 and the soil is well drained to excessively drained while chemical fertility is probably moderately high.

(xii) *Weisa Family*.—These soils occur on flat fans and terraces with forest and grassland cover.

The soils are *c.* 30 in. deep and overlie a gravelly substrate. The topsoil is black sandy loam or loam, merging into very dark grey-brown loam or clay loam at 10–14 in. The soils are high in organic matter. The pH is 6 throughout and the soils are well drained to moderately drained due to ground water. The chemical fertility is probably moderately high.

(*k*) *Young Alluvial Soils*

These are the soils of recent alluvial deposits. They show no profile development other than some darkening of the topsoil by organic matter and mottling due to poor drainage. The well-drained aspects are dark grey-brown to dark yellow-brown or dark olive-brown in colour although lighter colours also occur. Topsoils 4–16 in. thick are commonly very dark brown to very dark grey. Various shades of grey with varying amounts of brown mottling occur in poorly drained soils. The pH tends to be between 6 and 7 but may be as high as 8 or as low as 5·5.

Occurring on unconsolidated materials, the recent alluvial soils can be considered as deep soils. Their subdivision here is based upon texture and texture changes reflecting the stratified nature of the sediments. Some stratification is seen even in soils with a uniform texture. Due to differences in topographic situation, water-table and permeability the drainage conditions vary enormously and range from well drained to swampy; in general the finer the texture the poorer the drainage. On the basis of their texture, the young alluvial soils have been grouped into eight numbered families.

(1) *Coarse-textured Young Alluvial Soils.*—These soils consist of loose to very friable (sand) loamy (fine) sand and very gravelly materials. Commonly topsoils are (fine) sandy loam or (gravelly) loam, 2–12 in. thick.

(2) *Coarse-textured over Medium-textured Young Alluvial Soils.*—Loose to very friable loamy (fine) sand, fine sand or gravelly sandy loam, 15–29 in. thick, overlies a friable to very friable silt loam or (silty) clay loam.

(3) *Medium-textured over Coarse-textured Young Alluvial Soils.*—Friable (silt) loam, (silty) clay loam or sandy clay loam, 8–36 in. thick, overlies and merges into loose to very friable (loamy) (fine) sand, gravelly (loamy) sand or gravelly (silt) loam.

(4) *Medium-textured Young Alluvial Soils.*—These soils consist of friable (fine) sandy loam, (silt) loam, (silty) clay loam or sandy clay loam, commonly stratified.

(5) *Coarse- to Medium-textured over Fine-textured Young Alluvial Soils.*—These are very friable to friable, in cases loose, sandy clay loam, (silt) loam, (fine) sandy loam or (loamy fine) sand, 8–32 in. thick, overlying firm to plastic or very firm (silty) clay, sandy clay, with instances of heavy clay.

(6) *Fine-textured over Coarse- to Medium-textured Young Alluvial Soils.*—Friable to firm, in cases very firm, light to heavy clay, silty clay or sandy clay, 12–40 in. thick, overlies or merges into friable to loose sandy clay loam to sand or very gravelly loam.

(7) *Fine-textured Young Alluvial Soils.*—These are firm to very firm, firm to plastic and in some cases friable (light) clay, (silty) clay, sometimes with thin sandier or heavy clay layers.

(8) *Very Fine-textured Young Alluvial Soils.*—These are very firm to very plastic heavy clay with some (silty) clay and sandy clay layers. Included is one profile overlying coral detritus.

PART VII. VEGETATION AND ECOLOGY

By R. G. ROBBINS,* J. C. SAUNDERS† and R. PULLEN†‡

I. INTRODUCTION

This Part represents an updating of the vegetation accounts presented in the provisional reports on the Ramu valley. In the Gogol–Upper Ramu survey J. C. Saunders was both forest botanist and plant ecologist, but a preliminary plant-collecting trip had been made the year before by R. D. Hoogland, then taxonomist with the Division. In the lower Ramu–Atitau survey J. C. Saunders was again forest botanist while R. G. Robbins was plant ecologist and R. Pullen botanical collector.

The present classification and description of the vegetation are based upon ground traverses in the field; the collections of some 1500 plant specimens and over 700 wood samples, all deposited with the Herbarium Australiense, CSIRO, Canberra; and a detailed air-photo study and interpretation.

A forest resources map only is presented and thus some vegetation types are not depicted, but fall into the category 'Other Areas'. Even some areas of forest are excluded by the minimum stocking rate defined in Part VIII. The general location and extent of the excluded types may be gleaned from a study of the tabulated land systems and the land system map or in less detail from the text.

Although altitudes range from sea level to over 10 000 ft in the survey area, and rainfall from 71 to 224 in., the major climax vegetation on well-drained sites is a tropical evergreen rain forest. Several formations are included. From sea level to 3000 ft, i.e. within the humid tropical lowlands, the optimum is a three-tree-layered rain forest which includes hill and alluvial plain aspects. Much of this lowland forest shows the impact of a scattered but long-term history of shifting agriculture.

From 3000 ft upwards the cooler uplands are marked by the beginning of a lower montane forest formation where the structural optimum is reduced to two tree layers. Most of this can be described as a mixed 'oak–laurel' mid-mountain forest but in places it is dominated by pure groves of *Castanopsis* (oaks) or *Nothofagus* (beeches). Locally tall emergent *Araucaria* (pines) may be present.

A few summit ridges above 9000 ft in the Finisterre Range have a true montane forest of stunted moss-covered trees.

Open grasslands, which appear to be invariably man-induced, are more prevalent in low-rainfall localities and the larger tracts are found in the upper Ramu valley and again along the north coast inland from Bogia. Along this coast a narrow zone of strand vegetation is briefly interrupted by mangroves lining the river estuaries.

* Formerly Division of Land Use Research. Present address: Department of Applied Plant Sciences, University of Nairobi, Kenya.

† Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

‡ Present address: Division of Plant Industry, CSIRO, P.O. Box 1600, Canberra City, A.C.T. 2601.

Swamp vegetation, ranging from flood-plain palm forests through sago palm and phragmites reed swamp, and floating grass swamp to open lakes of aquatic plants, occurs over the vast Ramu River plain. Such permanent and fluctuating swamps are controlled by the annual floods which occur during the wet season. Fig. 8 gives a vegetational cross-section of the Ramu flood-plain.

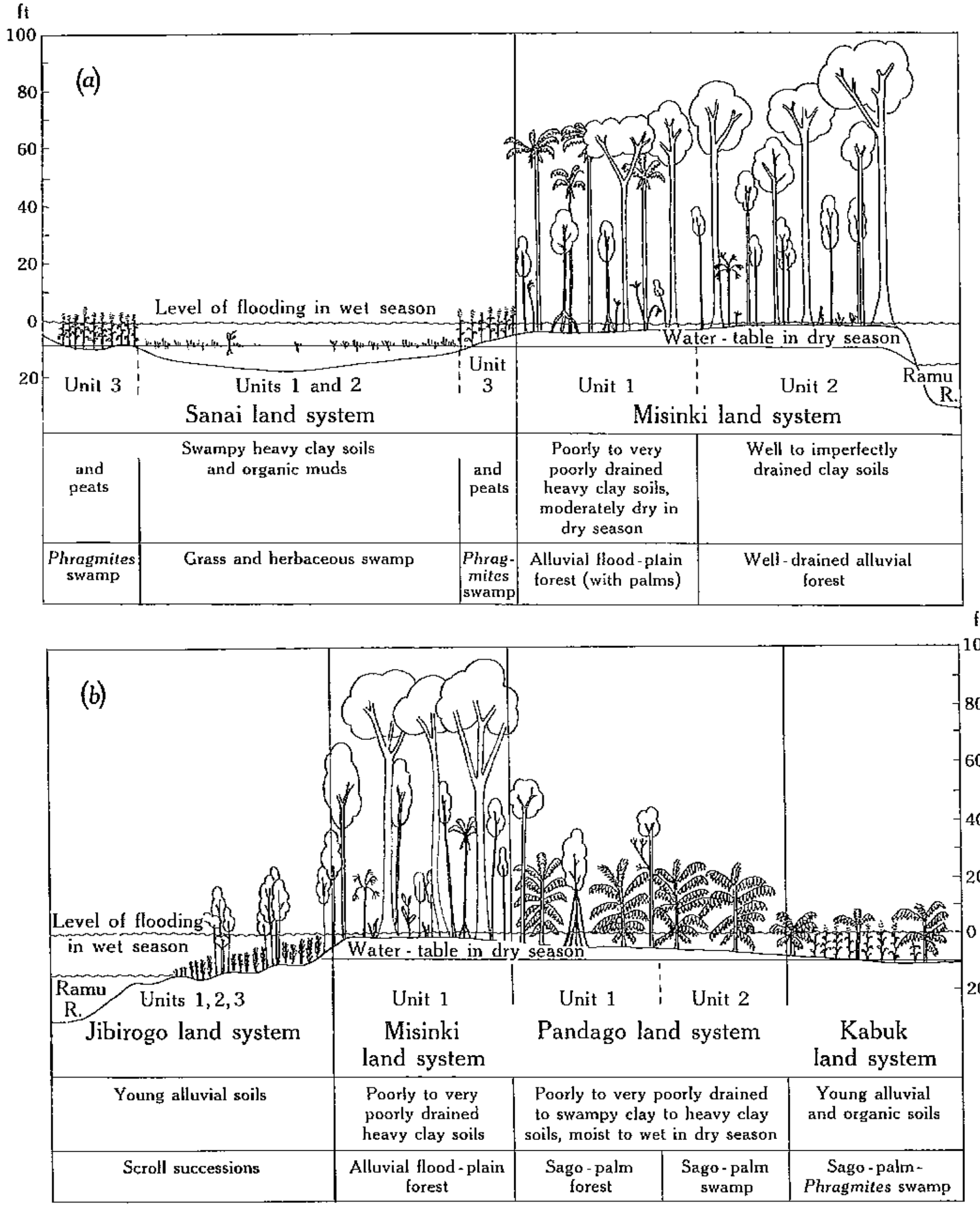


Fig. 8.—Cross-section of the Ramu flood-plain showing land systems and vegetation types and their relationship to the flood regime. The location of the transect is shown on the vegetation map.

II. Description of the Plant Communities

(*a*) *Tall Forest Vegetation*

The lowland rain forests of New Guinea have proved to be very rich in species, e.g. some 200 different species of tall trees over 20 in. in diameter have been recorded in the area. Floristic associations are commonly only of local importance. It is even difficult to assign characteristic genera or species to such broad categories as 'hill forest' or 'alluvial forest'. Such timber trees as *Intsia bijuga* may at one time be characteristic of hill forest but yet have local stands on the alluvial plains and even occur in swamp forest. Hence, while no one species may be definitive of a forest type, its greater quantitative abundance may well be diagnostic. There is also no doubt that further taxonomic studies will resolve species preferences especially among associate and subordinate trees. The floristic lists given here in no way imply that such species are exclusive to the forest type in which they are mentioned. Common trees ranging throughout the mixed lowland rain forest include species of *Celtis, Intsia, Alstonia, Terminalia, Canarium, Dysoxylum, Artocarpus, Albizia, Syzygium, Calophyllum, Dracontomelum, Ficus, Elaeocarpus, Sloanea, Pometia, Nauclea, Pimeleodendron, Garuga, Spondias, Chrysophyllum*, to mention a few almost at random.

(i) *Lowland Hill Forest*.—These forests (Plate 1, Fig. 2; Plate 7, Fig. 2; Plate 8, Fig. 1) cover all the steep lower mountains and hilly uplands below 3000 ft with generally well-drained but immature, often shallow soils, and also the dissected parts of the alluvial fans with deeper red soils.

Structurally the forest is of three-tree strata above a shrub and ground layer. The upper canopy trees may average 120 ft with occasional emergents to 150 ft. The subcanopy is about 80 ft and is followed by a more spaced lower tree layer ranging from 20 to 60 ft. In addition to the three tree layers there are shrubs below 20 ft and a field layer of ground herbs, ferns and forest seedlings (Fig. 9).

In the lowland hill forest common canopy trees will include *Intsia bijuga, Celtis philippinensis, C. nymanii, C. latifolia, Canarium acutifolium, C. indicum, Buchanania macrocarpa, Cryptocarya depressa, Dillenia papuana, Duabanga moluccana, Elaeocarpus amplifolius, Garuga floribunda, Hernandia papuana, Horsfieldia polyantha, Maranthes corymbosa, Euodia, Palaquium, Pouteria maclayana, Serianthes kanehirae, Spondias cytherea, Trichadenia philippinensis* and *Tristiropsis canarioides*.

Second-stratum trees likely to be found are *Anthocephalus cadamba, Aglaia, Chrysophyllum lanceolatum, Eriandra fragrans, Garcinia, Gonystylus, Gonocaryum litorale, Solenospermum torricellense, Petraeovitex, Syzygium lauterbachianum* and *Vatica papuana*.

The lowermost tree layer includes *Casearia, Cupaniopsis, Neuburgia, Ficus congesta, F. ampelas, F. bernaysii, F. gul, Gnetum gnemon, Harpullia, Horsfieldia subtilis, Myristica globosa, Microcos, Oreocnide, Picrasma javanica, Macaranga punctata, Syzygium malaccense*, and the palms *Ptychococcus* and *Ptychosperma hollrungii*.

Shrubs are *Archidendron, Aphania cuspidata, Aphanamixis, Aporusa, Cyrtandra, Ervatamia, Ixora, Medinilla, Poikilogyne, Pittosporum sinuatum* and *Villebrunea*.

The ground layer is often sparse but these herbs occur: *Alpinia, Boehmeria, Curculigo, Cyathula prostrata, Colocasia, Dianella nemorosa, Elatostema, Heliconia* *bihai*, *Hemigraphis reptans*, *Impatiens*, *Laportea decumana*, *Lindernia antipoda*, *Oldenlandia*, *Peperomia* and the track edge grasses *Paspalum conjugatum*, *Oplismenus hirtellus* and *Pseudochinolaena polystachya*.

Epiphytes and climbers include the ferns *Ctenopteris*, *Antrophyum plantagineum* and *Trichomanes aphlebioides* as well as *Cissus discolor*, *Piper caninum*, *Freycinetia*, *Schefflera* and the rattans *Calamus* and *Korthalsia*.

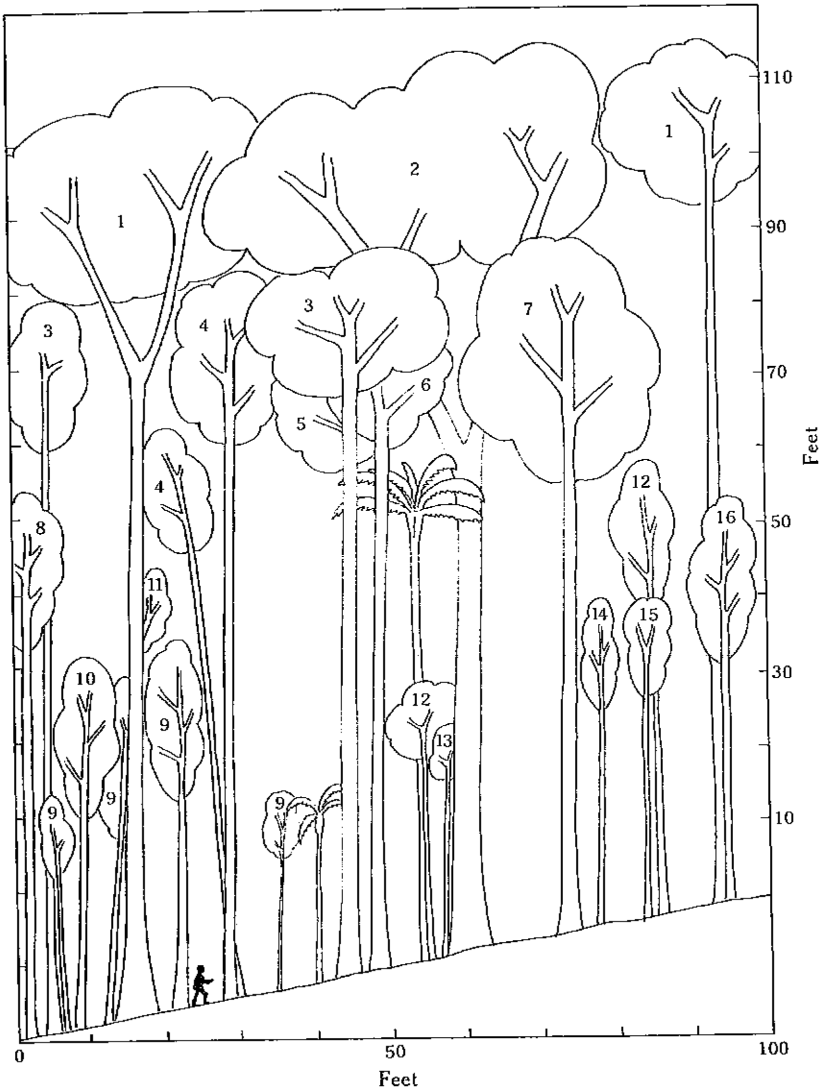


Fig. 9.—Lowland hill forest. The profile represents an actual transect of the forest, 100 × 25 ft, drawn to scale on location. Only the three tree layers are depicted; shrubs and ground plants are not drawn in. The trees are: 1, *Tristiropsis*; 2, *Intsia bijuga*; 3, *Pimeleodendron amboinicum*; 4, *Canarium*; 5, *Pometia pinnata*; 6, *Maniltoa*; 7, *Laportea*; 8, *Myristica*; 9, *Litsea*; 10, *Syzygium*; 11, *Homalium*; 12, *Diospyros*; 13, *Ficus*; 14, *Gonocaryum*; 15, *Microcos*; 16, Annonaceae.

Population density is high over the hilly uplands and the long practice of shifting cultivation has resulted in a mosaic pattern of gardens, regrowth and advanced secondary forest (Plate 5, Fig. 1). In making a new garden plot in the forest the undergrowth is first cleared; most of the tall trees are then felled by axe and the resulting debris is left to dry out. After firing, tubers, cuttings and seed are planted without any further preparation of the soil by means of a pointed dibble stick into any bare patch between the fallen logs which still litter the plot (Plate 4, Fig. 2; Plate 12, Fig. 1).

Little or no weeding is done and after the initial crop the plot is abandoned to weed grasses, hardy ferns, wild ginger and other weeds such as *Moghania strobilifera*, *Ludwigia*, *Solanum*, *Coleus* and the woody shrubs, *Pipturus*, *Triumfetta* and *Breynia*. Bamboo and regrowth trees now rapidly enter the sequence forming a close thicket of *Abroma augusta*, *Antidesma*, *Claoxylon*, *Colona scabra*, *Cordia dichotoma*, *Commersonia bartramia*, *Diospyros papuana*, *Eupomatia laurina*, *Ehretia*, *Ficus pungens*, *Geunsia cumingiana*, *Hibiscus tiliaceus*, *Homonoia javensis*, *Kleinhovia hospita*, *Leea indica*, *Melochia umbellata*, *Macaranga tanarius*, *M. aleuritoides*, *M. densiflorus* and *Protium macgregorii*.

(ii) *Alluvial Well-drained Forest*.—This forest (Plate 6, Fig. 2; Plate 9, Fig. 1; Plate 11, Fig. 1) covers the higher parts of the flat lowland alluvial plains and river levees and terraces. At the most these are only briefly flooded during the wet season. Soils throughout are young alluvial clays in which the water-table may fall to 10 ft below the surface during the dry season (Figs 8, 10).

There are minor structural and physiognomic differences with hill forest. The range of girth sizes of the canopy trees is more variable and there are widely spaced large-girth individuals with spreading crowns and few emergents. The subcanopy layer is more dispersed and does not follow as closely upon the upper canopy as in hill forest although the same general three-height groups of trees are present. Flange buttresses are a feature and palms may dominate locally. Large stilt-rooted *Pandanus* (screw pines) are common.

Floristic composition remains extremely rich and mixed. Trees belonging to the families Meliaceae, Sapindaceae, Burseraceae, Annonaceae and Myristicaceae are frequent. *Pometia pinnata* or 'taun' and *Vitex cofassus*, 'garamut', are characteristic while deciduous species within Sterculiaceae and Combretaceae are often conspicuous, showing up on air photos taken in the dry season. Huge 'strangler' figs may occupy several square chains of crown space and have an immense girder work of fusing trunks. Other tall trees include *Alstonia scholaris*, *Aphanamixis*, *Ailanthus integrifolius*, *Celtis luzonensis*, *Calophyllum soulattri*, *Chisocheton*, *Endospermum medullosum*, *Gigasiphon schlechteri*, *Canarium kaniense*, *Mastixiodendron pachyclados*, *Dysoxylum*, *Planchonella*, *Pterocymbium beccarii*, *Pterocarpus indicus*, *Dracontomelum*, *Kingiodendron alternifolium*, *Sloanea*, *Polyalthia*, *Octomeles sumatrana*, *Lagerstroemia*, *Teysmaniodendron bogoriense*, *Terminalia kaernbachii*, *Spondias dulcis*, *Syzygium buettnerianum*, *Tetrameles nudiflora*, *Uranda umbellata* and *Xanthophyllum papuanum*.

The second layer is almost as rich in species and includes *Antiaropsis decipiens*, *Aglaia subargentea*, *Buchanania*, *Bridelia subnuda*, *Cananga odorata*, *Cerbera floribunda*, *Cordia dichotoma*, *Dictyoneura*, *Elaeocarpus sphaericus*, *Euroschinus papuanus*, *Erythrospermum candidum*, *Maniltoa schefferi*, *Myristica hollrungii*, *Nauclea* and *Neonauclea*, *Parartocarpus venenosus*, *Parastemon versteeghii* and *Palaquium supfianum*.

The lowermost tree stratum, essentially below 50 ft, is made up of *Aporusa*, *Dysoxylum alatum*, *Diospyros*, *Endospermum labios*, *Guioa*, *Helicia*, *Litsea*, *Maniltoa plurijuga*, *Ochrosia*, *Platea latifolia*, *Phyllanthus*, *Pisonia umbellifera*, *Syzygium alatum* and *S. acroanthum*.

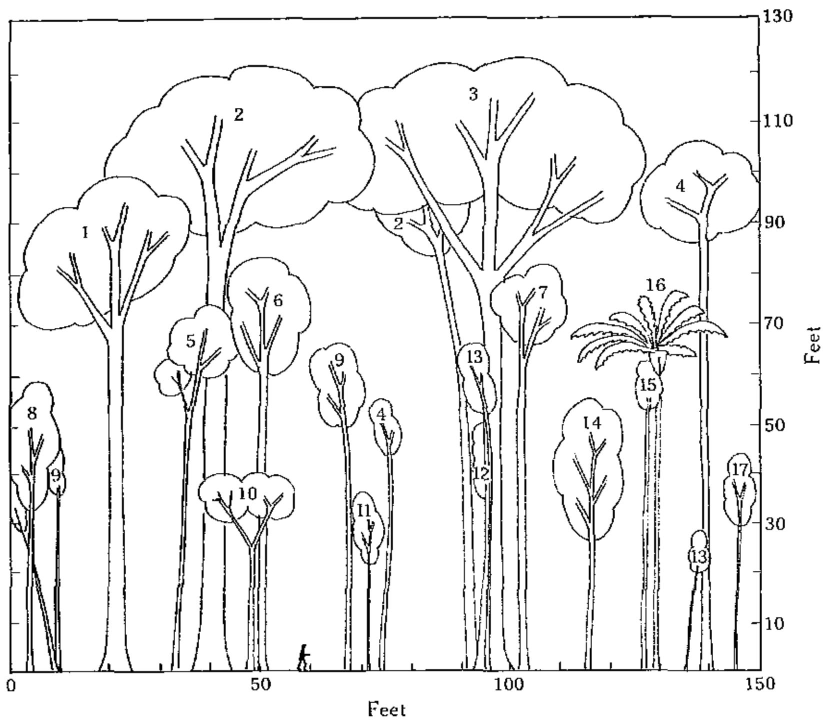


Fig. 10.—Alluvial well-drained forest. The profile represents an actual transect of the forest, 150 × 25 ft, drawn to scale on location. Only the three tree layers are depicted; shrubs and ground plants are not drawn in. The trees are: 1, *Litsea*; 2, *Celtis* sp.; 3, *C. philippinensis*; 4, *Alstonia scholaris*; 5, *Sterculia*; 6, *Vitex cofassus*; 7, *Chrysophyllum lanceolatum*; 8, *Aporosa*; 9, *Gnetum gnemon*; 10, *Pisonia*; 11, *Stemonurus*; 12, *Gynotroches axillaris*; 13, *Dysoxylum*; 14, *Myristica*; 15, *Melanolepis*; 16, palm (*Caryota*); 17, *Platea*.

Among the many shrubs members of the Rubiaceae are prominent with *Tarenna*, *Randia*, *Ixora*, *Gardenia*, *Pavetta*, *Lasianthus* and *Psychotria*. Others are *Aphania cuspidata*, *Casearia clutiifolia*, *Syzygium*, *Ervatamia orientalis*, *Maniltoa rosea*, *Scleropyrum aurantiacum*, *Guettardia*, *Medusanthera laxifolia*, *Macaranga subpeltata*, *Ryparosa javanica*, *Semecarpus magnifica*, *Tabernaemontana aurantiaca*, *Stemonurus*, *Mischocarpus* and *Voacanga papuana*. Small palms such as *Pinanga*, *Licuala lauterbachiana*, *Hydriastele macrospadix* and *Arenga microcarpa* are common as are the palm-like *Cordyline*, *Dracaena angustifolia* and *Pandanus* spp.

In addition to most of the ground herbs given for the hill forests there are *Curcuma longa*, *Cyrtosperma*, *Donax canniformis*, *Alocasia*, *Costus speciosus*, *Calanthe*, *Forrestia*, *Pilea*, *Pseuderantherum*, *Selaginella*, *Stachyphrinum*, *Tapeinochilus*, and the ferns *Athyrium*, *Microlepia* and *Helminthostachys*. Forest grasses are *Centotheca latifolia* and *Leptaspis urceolata*.

Climbers include rattans, club mosses, ferns, aroids and peppers as well as the cucurbit *Alsomitria macrocarpa* with its cannonball fruits on the highest crowns releasing hundreds of membranous winged seeds.

Garden regrowth in initial stages has the weeds *Achyranthes bidentata, Acalypha, Ageratum conyzoides, Amaranthus dubius, Borreria, Crassocephalum crepidioides, Echinochloa crus-galli, Euphorbia hirta, Galearia, Leptochloa, Mollugo pentaphylla, Physalis minima* and *Synedrella nodiflora.* Ferns are *Hornstedtia* and *Blechnum.* Woody species enter and soon form a closed canopy of poles and saplings 30 ft or more high. Most of the species found in the regrowth phases of hill forest are present together with *Alphitonia incana, Aridisia, Althoffia tripyxis, Artocarpus altilis, Euodia anisodora, Macaranga densiflora, Phaleria, Sterculia, Timonius, Astronia, Boerlagiodendron, Elaeocarpus comatus, Glochidion, Ficus calopilina, Goniothalamus, Micromelum minutum, Myristica subalulata, Premna integrifolia, Pisonia, Phylacium, Melanolepis multiglandulosa* and *Tephrosia.*

(iii) *Alluvial Flood-plain Forest.*—This forest (Plate 7, Fig. 1; Plate 9, Fig. 1; Plate 10, Fig. 1) is a wet aspect of alluvial forest and occurs on the lower terraces and higher parts of the back plains. Inundation occurs during the wet season but the heavy clay soils may dry out rather severely in the dry season when water-tables can drop to 6–8 ft below the surface. The full relationship of the alluvial forests and swamp communities is shown in Fig. 8. Some aspects of the alluvial flood-plain forest can be termed a palm marsh forest with structure reduced to two tree layers and tall palms to 90 ft high dominating the canopy and belonging to the genera *Gulubia, Orania* and *Ptychococcus.* At lower levels stilt-rooted *Garcinia subtilininervis, Gynotroches axillaris* and *Myristica cylindrocarpa* are frequent. There are quantitative shifts in species composition from the alluvial well-drained forest and *Octomeles, Terminalia, Nauclea, Campnosperma brevipetiolata, Firmiana papuana, Planchonia papuana, Prunus schlechteri, Bischofia javanica, Dillenia castaneifolia* and *Baccaurea papuana* may all be said to be characteristic. Shrubs and ground layer plants are much the same as for the alluvial well-drained forest while garden regrowth is rare within the flood-plain forest.

(iv) *Lower Montane Forest.*—Such forest (Plate 1, Fig. 2) occurs only above 3000 ft and is found along a few crests of the Adelbert Range and within the Finisterre land system on the Finisterre Range. Structurally, lower montane forest has an optimum of two tree layers. The uniform compact canopy is between 60 and 90 ft to be closely followed by the subcanopy. Pure stands of New Guinea oaks (*Castanopsis acuminatissima, Lithocarpus celebicus* and *L. molucca*) have been mapped on the Adelbert Range and may represent advanced secondary forest areas. On the upper slopes of the Finisterre Range occur stands of the southern beech (*Nothofagus* spp.) in which tall *Pandanus, Bambusa forbesii* and the climbing bamboo *Nastus* sp. are characteristic (Figs 11, 12).

A shift in floristic composition from the humid lowland involves these new tree records: *Ackama, Alstonia brassii, Cinnamomum, Cryptocarya* spp. and *Litsea, Planchonella macropoda, Dillenia schlechteri, Elaeocarpus* spp., *Elmerillia papuana, Ficus porphyrochaete, Flindersia, Pullea, Opocunonia, Weinmannia, Schizomeria, Turpinia* and *Galbulimima.*

Shrubs are not abundant but may include *Amaracarpus*, *Bubbia*, *Lasianthus*, *Sphenostemon*, *Sericolea*, *Saurauia*, *Olea* and several species of tree ferns. Trunk buttresses, woody lianes, and palms are generally less evident. Terrestrial herbs, mosses, liverworts, and ferns are more profuse and include *Begonia*, *Ophiorrhiza*, *Selaginella*, *Lophatherum gracile* and *Athyrium cordifolium*.

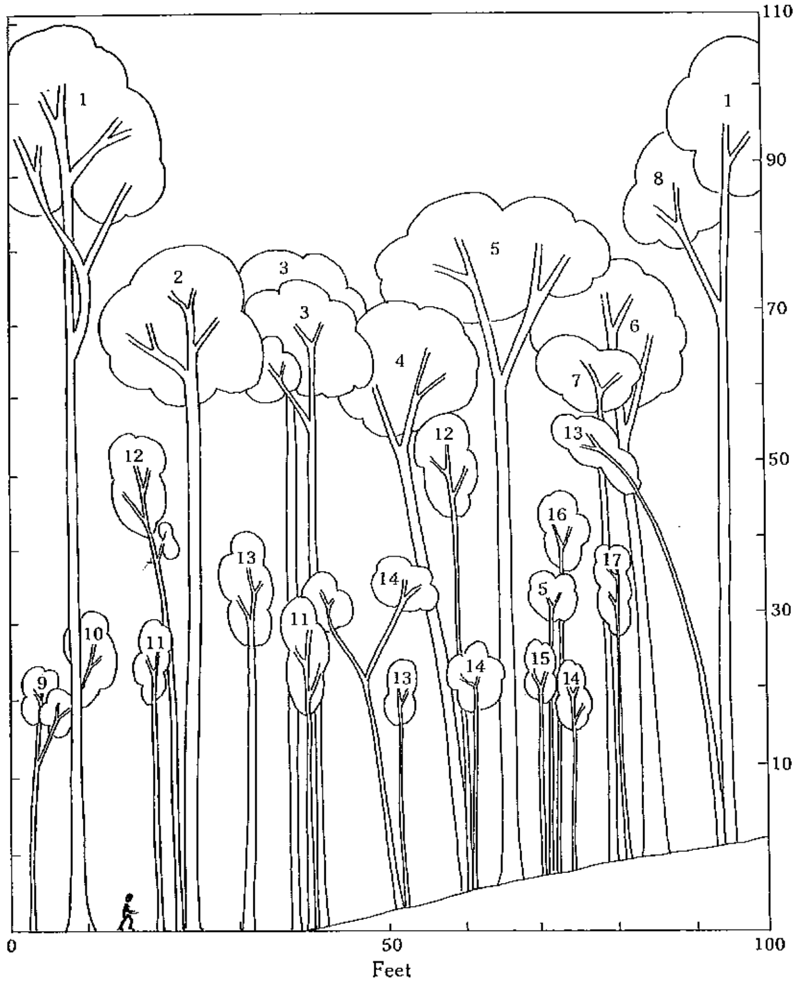


Fig. 11.—Mixed lower montane forest at 7300 ft on the Schrader Range. The profile represents an actual transect, 100 × 25 ft, drawn to scale on location. Only the two tree layers have been depicted; shrubs and ground plants are not drawn in. The trees are: 1, oak (*Lithocarpus moluccana*); 2, *Opocunonia*; 3, *Planchonella macropoda*; 4, *Haplolobus*; 5, *Platea*; 6, *Pygeum*; 7, *Mallotus*; 8, *Timonius belensis*; 9, *Levieria*; 10, *Astronia*; 11, *Elaeocarpus*; 12, *Cryptocarya*; 13, *Ficus* sp.; 14, *Ficus* sp.; 15, *Syzygium*; 16, *Lepidopetalum*; 17, *Euodia*.

In the southern valleys lower montane forest has been cleared for gardens and the regrowth includes tall cane grasses such as *Polytoca macrophylla*, sword grass (*Miscanthus floridulus*), the wild relative of the sugar-cane *Saccharum spontaneum*, and *Thysanolaena maxima*, together with wild bananas and gingers. Woody regrowth has *Macaranga* spp., *Leucosyke*, *Pipturus*, *Boehmeria*, *Grevillea*, *Schuurmansia henningsii*, *Wendlandia paniculata*, *Omalanthus*, *Decaspermum* and *Albizia*.

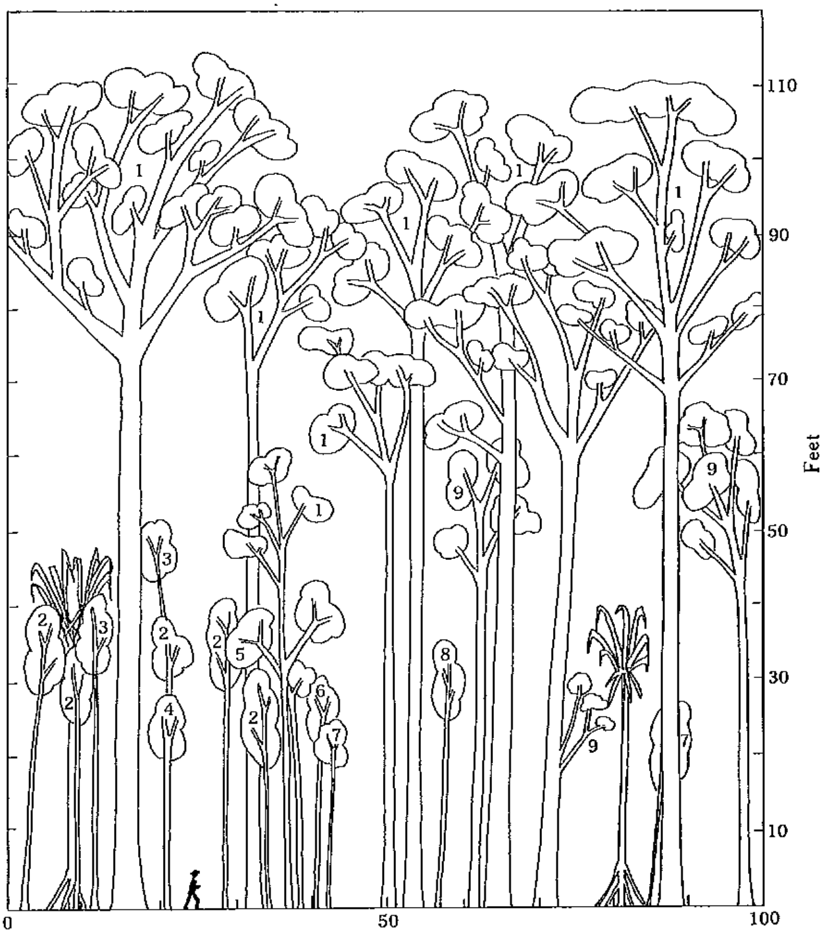


Fig. 12.—Lower montane beech forest. In this two-tree-layered forest the dominant tree (1) is *Nothofagus carrii*. Note the associated *Pandanus*. For other details see Fig. 11.

(v) *Montane Forest*.—Occurring only along the higher crests of the mist-shrouded Finisterre Range above 9000 ft, true montane forest finds very limited expression in the survey area. Here optimum forest development is a single-tree-layered forest of frequently gnarled and stunted trees up to 40 ft high. Mosses and liverworts clothe branches, twigs, trunks and the hummocky forest floor, giving rise to the popular term 'mossy forest'. Once again a floristic shift is evident in the preponderance of *Rhododendron* spp., *Vaccinium* spp., *Rapanea*, *Quintinia*, *Dimorphanthera*, *Drimys*, *Olearia* and many small Rubiaceae and Myrtaceae.

(*b*) *Coastal Vegetation*

(i) *Strand Woodland.*—A narrow strip of strand woodland (Plate 14, Fig. 2) is almost continuous along the sandy beach ridges of the 180-mile coastline. A pioneer zone of sand binders and halophytes is first seen above the tide line with trailing swordbean, *Canavalia maritima,* and beach convolvulus, *Ipomoea pes-caprae.* The coastal grasses *Thuarea involuta* and *Ischaemum muticum* and the sedges *Cyperus javanicus* and *C. pedunculatus* are present with the spider lily *Crinum asiaticum.*

Inland is a hedge of small shrubs tolerant to the salt-laden winds and including *Scaevola taccada, Morinda citrifolia, Acanthus, Justicia, Callicarpa, Clerodendron inerme* and *Pandanus.*

This seaward front is continuous with the strand woodland of trees 50–60 ft high, among which are *Barringtonia asiatica, Calophyllum inophyllum, Cerbera manghas, Hibiscus tiliaceus, Inocarpus fagiferus, Macaranga, Pongamia pinnata, Thespesia populnea,* the coastal nutmeg *Myristica schleinitzii* and the sea almond *Terminalia catappa.* Beneath the wind-shorn canopy a few shrubs of *Ardisia, Excoecaria agallocha, Gonocaryum litorale, Maniltoa schefferi* and *Picrasma javanica* find shelter with the climbers *Hoya diversifolia* and *Tristellateia australasiae.* Such vegetation is typical of the whole New Guinea coast and indeed is panpacific in distribution. In places where clay banks form the sea front over steeply shelving beaches, gnarled massive *Calophyllum* trees overhang the sea at high tide. Dense stands of the coastal she-oak (*Casuarina equisetifolia*) are found on the aggrading sand banks of river mouths.

(ii) *Mangrove Forest and Woodland.*—While a few mangroves may line the banks of tidal creeks and lagoons along the coast they only form mappable units in the Madang and Alexishafen areas and again at Bot-Bot and Borai near the Ramu mouth. The stands are nowhere extensive and little zonation of species can be observed. The community is a mixed one of small-girth trees reaching to 70 ft when well developed but more often it is merely a low woodland. Species are *Rhizophora apiculata, Heritiera littoralis, Aegiceras corniculatum, Sonneratia caseolaris, Bruguiera gymnorrhiza, B. parviflora* and *Avicennia marina.* Stilt roots and pneumatophores (breathing roots) are characteristic. The upper reaches of most mangrove swamps are lined with *Nypa fruticans* palms with 30-ft fronds.

(*c*) *Swamp Vegetation*

(i) Campnosperma *Swamp Forest.*—Small occurrences of this forest (Fig. 9) which is often very extensive in swampy terrain elsewhere in New Guinea are mappable from the air photos. The canopy at 60–70 ft is dominated by large-leaved *Campnosperma brevipetiolata* usually in pure stands over a ground layer of sago palms. Very small areas may be occupied by a more mixed swamp woodland where groves of slender trees with exposed flange roots enclosing water-filled hollows grow closely together. Recorded here are *Calophyllum, Garcinia, Myristica, Bischofia, Terminalia, Palaquium, Erythrina, Uranda, Brownlowia, Planchonella, Barringtonia* and *Teysmanniodendron.*

(ii) *Sago Palm Forest.*—This is a seasonal swamp community of mixed trees and sago palms. *Metroxylon sagu* may constitute up to 60% of the community and form a dense under-layer of spreading fronds up to 30 ft high but with more mature trunked individual palms emergent above this. The woody tree element is of scattered emergent trees 60–70 ft high forming a very irregular and open canopy. Climbing rattans are rampant on the crowns of these trees while the boles are enveloped with masses of thin-stemmed climbing ferns, especially the stiff serrate-leaved *Stenochlaena palustris.* Rain forest trees, tolerant to wet conditions, found here are *Alstonia, Canarium, Octomeles, Planchonia, Bischofia, Dillenia, Ficus, Palaquium, Syzygium, Nauclea* and *Myristica,* while *Carallia brachiata, Erythrina indica, Dolichandrone spathacea, Hibiscus tiliaceus* and *Garcinia subtilininervis* are diagnostic.

(iii) *Sago Palm Swamp.*—In this community (Plate 8, Fig. 2) only sago palms occur; it constitutes the wettest of the seasonal or fluctuating swamps. Owing to their suckering habit the palms grow in small round clumps of 3–5 palms. Over-arching fronds form a dense canopy at 20–30 ft and on the floor covered with a litter of fallen fronds lie pools of water drying out to soft mud in the dry period. Occasionally a mature flowering palm is seen. From the pith of such individuals sago starch or 'sac sac' is obtained, an important staple diet of the flood-plain dwellers (Plate 9, Fig. 2).

(iv) Pandanus *Swamp.*—Mapped only in the Usino basin but found in small pockets in oxbow cut-offs throughout the Ramu plain, *Pandanus* swamp appears to be a natural forest regeneration phase. *Pandanus* spp. form a single layer 20–40 ft high with a rather open canopy and swamp conditions appear to be almost permanent and subject to sudden flood-outs.

(v) *Sago Palm*–Phragmites *Swamp.*—This is a permanent swamp where the water-table remains just above ground level in the dry season. The community no doubt represents an ecotone or transition between sago palm swamp and *Phragmites* swamp and occurs at the gradient between seasonally fluctuating and permanent swamp. Its wide occurrence in the lower Ramu flood-plain is the basis of the Kabuk land system. The sago palms are usually very dwarfed and occur in round circular groves 40 ft across, probably indicating marginally higher ground. They are set in a dense cover of *Phragmites karka.* Other grasses such as *Saccharum robustum* and *Leersia hexandra* and swamp ferns may be present.

(vi) Phragmites *Swamp.*—Found mainly in the lower Ramu flood-plain near the mouth of the Ramu River, this is a permanent swamp community of tall dense *Phragmites karka* (reed) up to 15 ft high.

(vii) *Grass Swamp.*—Typically this is a dense mass of floating swamp grasses (Plate 11, Fig. 2) covering water up to 10 ft deep and anchored by long roots to the organic mud below. *Panicum paludosum* and *Hymenachne acutigluma,* both with long trailing stems, are dominant while rice grass, *Leersia hexandra, Isachne* and *Oryza* sp. are also present. Even in the dry season the water may be 2 ft deep over the heavy grey waterlogged clays which, however, dry out briefly around the periphery where *Ischaemum polystachyum, Panicum paludosum, Coix gigantea, Echinochloa stagnina, Apluda mutica* and other wet grasses grow together with *Ipomoea aquatica, Polygonum* and other weeds.

On the other hand, with still deeper water and in lakes formed by cut-off meanders there is a mixed swamp of herbaceous plants including the fleshy *Hanguana malayana* and *Monochoria hastata*; sedges such as *Thoracostachyum sumatranum,* *Scirpodendron, Scirpus, Fuirena umbellata, Eleocharis* and *Gahnia*, and aquatic plants, *Limnanthemum, Nymphaea* and *Nelumbium*, the last two forming water-lily pads on open lakes (Plate 13, Fig. 1).

(*d*) *River-bank Successions*

(i) *Herbaceous Succession.*—The habitat (Plate 10, Fig. 1) here is the low sand banks and stony rises of braided stream beds as well as shelving mud banks and scrolls of the river meanders. On such scrolls the herbaceous succession is found in the lows or swales and consists of dense stands of the wild sugar-cane *Saccharum robustum* growing to 20 ft high but giving way to *Phragmites* in the wetter troughs. Grasses are *Apluda mutica, Chloris barbata, Eleusine indica, Echinochloa crus-galli, Eragrostis elongata, Pennisetum macrostachyum* and *Ischaemum polystachyum*. Herbs include *Cassia alata, Crotalaria apiculata* and *Floscopa scandens*.

(ii) *Woody Succession.*—On the meander scrolls small trees commonly occupy the rises and show up as curving parallel lines on the air photos. Small *Ficus* spp., *Macaranga, Endospermum, Sterculia, Timonius, Artocarpus, Leea, Euodia, Hibiscus, Nauclea, Pipturus* and *Albizia* are all pioneers while the seral climax may be dense stands of *Casuarina* or *Octomeles*.

(*e*) *Grassland*

(i) *Tall* Saccharum *Grassland.*—*Saccharum spontaneum*, a wild sugar-cane growing to 5 ft, dominates this vegetation which is found typically on flat alluvial plains near the coast. The black clays, wet to moist in the wet season, dry out to a firm hard surface in the dry period. Associated grasses are *Imperata, Apluda, Sorghum, Ophiuros, Ischaemum* and scattered *Phragmites*.

(ii) Ischaemum *Grassland.*—Another grassland (Plate 12, Fig. 2) with moist affinities is often found in wetter depressions adjacent to dry grassland. There is an almost pure stand of *Ischaemum polystachyum* and *I. barbatum* and the site is often shared with the grasses *Apluda mutica, Dimeria, Paspalum orbiculare, Sporobolus elongatus, Panicum, Setaria pallidofuscua, Chrysopogon acicularis* and the sedges *Fimbristylis dichotoma, Rhynchospora rubra* and *Cyperus odoratus*.

(iii) Ophiuros–Imperata *Grassland.*—This community (Plate 12, Fig. 2) is a medium-height grassland and probably reflects more favourable sites such as areas of deeper soils and where biotic interference has been less intense. It is widely distributed in the Ramu area. Kunai grass, *Imperata cylindrica*, forms a dense cover of closely growing tussocks up to 6 ft high. Dispersed throughout is the tall *Ophiuros tongcalingii* (syn. *O. exaltatus*) with its long whip-like flowering culms.

Common associates are the tall *Coelorachis rottboellioides, Themeda intermedia* and *Sorghum nitidum*, while smaller grasses are *Alloteropsis semialata, Eulalia leptostachys, E. trispicata, Paspalum longifolium* and the sedges *Cyperus* and *Scleria* spp. The tuberous aroid *Amorphophallus campanulatus* is frequent, while small trees of *Albizia procera, Nauclea coadunata* (syn. *N. orientalis*), *Antidesma ghaesembila, Glochidion, Timonius timon* and the low palm-like *Cycas media* are all common.

(iv) Themeda–Arundinella *Grassland.*—This is the more frequent disclimax grassland for the area (Plate 2; Plate 13, Fig. 2). It is a short grassland of drier sites and is representative of steeper slopes, crests and shallower soils. As with the other grasslands, it is frequently burnt over in the dry season. It grades into the *Ophiuros–Imperata* grassland and includes most of the associate grasses as well as the scattered fire-tolerant trees listed for that community. *Themeda australis*, kangaroo grass, is usually dominant, growing to 2–4 ft. However, both *Arundinella setosa* and in the upper Ramu valley *Alloteropsis semialata* may be codominant.

III. Ecology

(*a*) *Coastal Environment*

The coastline bounding the area in the north is mainly of curving sandy beaches and coral headlands (Plate 13, Fig. 2; Plate 14). Coastal sand plants and strand shrubs and trees form a narrow seaward front which may be no more than 50 yd wide. Back swales to beach ridges are often brackish swamp, with sago palms and *Phragmites* common. Small salt marshes dominated by the golden swamp fern, *Acrostichum aureum*, occur. Tidal estuaries with mangroves and nypa palms are sources of fuel, tannin and thatching for the nearby villages. Population is relatively dense along the coast and much vegetation has been cleared for coconuts so that regrowth vegetation and grassland predominate.

(*b*) *Swamp Environment*

Swamp lands cover some 700 sq miles or one-third of the alluvial region in the Ramu–Madang area.

The broad ecological factors governing the swamp regions are the seasonal alternation between wet and dry periods; and these are linked to the actual duration, depth and flow of the floodwaters and residual water-table relations (Plate 9; Plate 11, Fig. 2; Plate 13, Fig. 1).

Within the Ramu flood-plain the complex pattern of swamp forest, sago palm swamp, river-bank successions and herbaceous swamp lands reflects the influence of this seasonal flood cycle. A mosaic of fluctuating and permanent swamps is found in the various stages of silting up of oxbows and cut-off meanders which are a feature of the lower Ramu plain. Fig. 8 shows a transect near Misinki village. Seasonal or fluctuating swamp is defined as those communities where the water-table falls to below ground level in the dry season, the typical vegetation being sago palm forest and sago palm swamp. Permanent swamp, on the other hand, has water over the surface throughout the year but the actual depths may vary and fluctuate by 10 ft or more. In this category are the *Phragmites*, the grass and the herbaceous swamps.

(*c*) *Environment of the Alluvial Fans, Terraces and Plains*

Lowland alluvial forests (Plate 2; Plate 7, Fig. 1; Plate 10, Fig. 1) account for more than 1000 sq miles mainly in the lower Ramu River and its tributaries, the Guam and Sogeram Rivers. Smaller areas are the terraces of the Gogol River and the plains of the Usino basin. Although for the greater part the alluvial forests are subject to only occasional and brief inundations, they are only sparsely inhabited. They represent one of the largest regions of such forest in New Guinea and have a fairly high potential, but access is very difficult.

(*d*) *Hill and Mountain Environment*

Lowland hill forest (Plate 1, Fig. 2; Plate 4; Plate 5, Fig. 1) covers some 4800 sq miles or more than half the survey area. It predominates over the extensive northern, coastal and central hills as well as the Adelbert Range. Even in the closed forest ancient *Ficus* and breadfruit trees, *Artocarpus*, indicate past interference. Such trees are commonly spared during the making of garden plots and thus in many places could be relicts of the primary forest. There is no doubt that the hill forest has a long history of nomadic shifting agriculture and this would account for the large areas of non-commercial forest, the extent of which can be readily seen by a comparative study of the vegetation described in the land systems and on the forest resources map.

Coinciding with the climatic change from the humid lowlands to the cooler uplands is the lower montane forest formation. There is a shift to more temperate species and a reduction in the optimum forest structure. While this zone is excellent for settlement it is somewhat limited within the survey area and only the inland slopes of the Finisterre Range have any number of villages sited within the lower montane zone. The montane forests, above 9000 ft, are visited only by hunters.

(*e*) *Grassland Environment*

Tracts of grassland are frequent throughout the area and total some 560 sq miles (Plate 2; Plate 12, Fig. 2). They are more continuous in the areas of drier climate where soils are generally shallow or drying winds prevail. Almost invariably such grasslands are the result of man's clearing of the original forest. The grassland disclimax once established is maintained by annual firing. In the local economy the grasslands are under-utilized; their potential uses include cattle grazing and reafforestation. In 1956 a cattle project was started at Gusap, and grazing has since been extended to the upper Ramu valley.

PART VIII. FOREST RESOURCES

By J. C. Saunders*

I. Introduction

The aim of this Part and its associated map is to indicate the general location and extent of the commercial forest types in the Ramu–Madang area and assign an estimated average stocking rate to each type. The land has also been classified into categories based on indexes of accessibility.

Commercial forests contain at least 3000 super ft/ac of standing timber from trees having a minimum girth of 5 ft at breast height (or above the buttresses). The same nomenclature is used for these forests as for those described in Part VII, to facilitate cross-reference with the general descriptions. However, because of the girth and volume limitations imposed in this Part there is a shift in the relative importance of some species, and areas of forest types are generally smaller.

Commercial forest (referred to as forest) covers slightly less than 50% of the area, occurring from sea level to approximately 10 000 ft in a wide range of environments. The forest is mainly confined to the rugged mountainous terrain of the Adelbert, Finisterre and Central Ranges and the gentler terrain of the central hills and the middle Ramu valley.† Accessible forest is virtually restricted to the last two regions where stocking rates are generally depressed. Consequently, the overall forest potential of the area is moderate to low.

Over most of the rugged mountainous terrain forests play an invaluable role in watershed protection. These forests should be left in their natural state as a barrier to prevent accelerated erosion and consequent destruction of the environment.

The potential for minor forest products is low, except perhaps for exploiting rattan which abounds in the alluvial flood-plain forests. Only existing forest resources have been studied and no attempt has been made to assess the potential for re-afforestation, although much of the information embodied in the whole report might be useful in such a study.

Since the original field work for this report was completed several detailed forest assessments by the Department of Forests, Papua New Guinea, have been carried out in the Ramu, Gogol and inland Madang areas (Director of Forests, personal communication) with a view to expanding the timber industry of the area.

According to R. Kent Wilson (Ward and Lea 1970), milling operations in the area are very limited, the daily log input being *c.* 3500 super ft, and virtually confined to Madang.

* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

† The regions referred to in this Part are identical with the physical regions described in Part V (see Fig. 3).

Madang, in fact, imports sawn timber from the Sepik area. However, at the time of writing this report (1973), plans for a vast expansion of the timber industry of the area are well advanced.

II. Assessment Methods

During the Gogol–Upper Ramu survey, no detailed plot assessments were made in the field. Visual estimates of stocking rates were made during ecological investigations. However, in the previous year a 2-ac plot, near Faita on the foothills of the Central Ranges, was clear-felled and detailed measurements taken for an investigation into the structure of the forest.

Forests of the Lower Ramu–Atitau survey were sampled by using a slight modification of the 'point-centred quarter method' of Cottam and Curtis (1956). Sampling points were selected at 100-yd intervals within each forest type and at each point the distance from the point to the nearest 'commercial timber tree', i.e. a tree of at least 5 ft girth at breast height (or above buttresses), in each quadrant of a circle about the point was measured.

Data recorded for all such trees included girth over bark, merchantable length, total height, botanical name and local name in Amele (Madang) language. Each tree was also classed on form and external symptoms of defects as suitable or likely to be unsuitable as a potential saw log. Girth measurements were made by girth tape in 1-ft classes and merchantable length in 5-ft classes by a Haga altimeter. Where the botanical name of a tree was in doubt, a wood sample (and where possible a herbarium specimen) was collected. Wood samples were later compared with woods supported by herbarium collections in Canberra, and in the Forest Products Laboratory, CSIRO, Melbourne, by Mr H. D. Ingle.

The herbarium specimens have been lodged in the Herbarium Australiense in Canberra and duplicates distributed to Lae herbarium.

The above information was augmented by visual observations and estimates while walking between sample areas, and by the observations of the plant ecologist. Volume figures were based on a form factor of 0·5, with no bark allowance.

From the qualitative and quantitative data collected on each plot an appraisal of each plot's value as a representative sample of the forest type was made using air photos, and estimated stocking rates were assigned to each type. The assigned stocking rates are a very approximate indication of timber volume and must be used with extreme caution as the sampling percentage is extremely low. They should be regarded as an indication of which forest types warrant more detailed investigation to assess accurate volume figures.

III. Classification and Mapping of Forests

The forests are divided into four major groups based on environment: forest on alluvium, swamp forest, lowland hill forest and lower montane forest.

Forests on alluvium are further subdivided into two types, alluvial well-drained forest and alluvial flood-plain forest, mainly on structural characteristics exhibited in the air-photo pattern. The latter forest type has a more open canopy and often shows palms in the understorey.

TABLE 11

TREES RECORDED AND THEIR FREQUENCY OF OCCURRENCE IN FOREST TYPES

P, predominant, >80%; D, dominant, 50–80%; S, subdominant, 20–50%; F, frequent, 15–20%; C, common, 10–15%; O, occasional, 5–10%; R, rare, <5%; ( ), locally

Botanical name	Alluvial well-drained forest	Alluvial flood-plain forest	*Campnosperma* forest	Lowland hill forest (high stocking)	Lowland hill forest (low stocking)	Lower montane forest	*Castanopsis* forest	*Nothofagus* forest
Ackama						R		
Adenanthera pavonina					R			
Adinandra				R				
Aglaia spp.	R	R		O	R			
Ailanthus	R			R				
Albizia falcataria	R	R			(D)			
Alseodaphne	R							
Alstonia scholaris	O	R		O	O			
A. spp.		R			R	R		
Althoffia pleiostigma		R			R			
Anthocephalus cadamba	R	O		R				
Aphanamyxis	R							
Araucaria hunsteinii				(O)				
Archidendron	R			R	R			
Artocarpus spp.	R	O(C)		R	R			
Baccaurea papuana		R						
Barringtonia spp.	R	R	R					
Bischofia javanica	R	O	O					
Boerlagiodendron	R	R			R			
Buchanania spp.	R	R		R	R			
Calophyllum spp.	R		R	R	R			
Campnosperma brevipetiolata	R	O	P					
Cananga odorata	R	R						
Canarium spp.	R	R		O	R			
Casearia				R				
Castanopsis acuminatissima				(P)	(P)	O	P	
Cedrela					(O)			

Celtis spp. (hard)	C	C		C	C		
C. spp. (soft)	O	O		O	O		
Cerbera floribunda	R	R		R	R		
Chisocheton spp.	O	R		R	R		
Chrysophyllum	R	R		R			
Cinnamomum spp.	R	R		R		R	R
Cordia	R	R					
Cryptocarya spp.	R	R		O	R	O	R
Dillenia spp.	R	R		R	R	R	
Diospyros spp.	R			R			
Dracontomelum spp.	R	R		R	R		
Duabanga moluccana					R		
Dysoxylum spp.	O	R		O	O		
Elaeocarpus spp.	R	R		R	R	R	R
Elmerrillia papuana				R		O	R
Endospermum spp.	R	R			R		
Erythrina			R				
Erythrospermum candidum	R			R			
Erythroxylon ecarinatum				R	R		
Euodia spp.	R	R		R	R	R	
Euroschinus papuanus		R					
Eurya					R	R	
Fagraea						R	
Ficus spp.	O	C		O	O	R	
Firmiana papuana	R	R					
Flindersia spp.				R	R	R	
Galbulimima belgraveana						R	R
Garcinia spp.	R	R	R	R			
Garuga floribunda	R	R		R	R(O)		
Gigasiphon schlechteri	R	R		R			
Glochidion						R	
Gonocaryum				R	R		
Gossampinus	R				R		
Gymnacranthera	R	R		R			
Gynotroches axillaris	R	R					

TABLE 11 (*Continued*)

Botanical name	Alluvial well-drained forest	Alluvial flood-plain forest	*Campnosperma* forest	Lowland hill forest (high stocking)	Lowland hill forest (low stocking)	Lower montane forest	*Castanopsis* forest	*Nothofagus* forest
Gyrocarpus					R			
Harpullia spp.		R						
Helicia						R		
Hernandia	R	R		R	O			
Homalium	R	R		R	R			
Homonoia javensis				R				
Horsfieldia spp.	R	O		R	R			
Inocarpus fagiferus		R		R	R			
Intsia bijuga	O	R		C	C			
Kingiodendron alternifolium	R	R						
Kleinhovia hospita	R	R(C)						
Lagerstroemia	R	R						
Laportea spp.		R(C)						
Linociera				R	R			
Lithocarpus spp.						R	(P)	
Litsea spp.	R	R		R	R	R	R	
Macaranga spp.	R	R			R			
Mangifera spp.	R			R	R			
Maniltoa spp.	R	R		R	R			
Maranthes corymbosa		R		O	R			
Mastixiodendron pachyclados	O	R		R	O			
Meliosma				R	R			
Microcos spp.	R	R		R	R			
Myristica spp.	R	O	R	R	R			
Nauclea	R	O						
Neonauclea spp.	O	R		O	O			
Neoscortechinia	R							
Neuburgia	R	R		R				
Nothofagus spp.								P
Octomeles sumatrana	O	O(F)			R			

Opocunonia nymanii							
Palaquium spp.	R	R	R	R			
Pangium edule	R	R		R	R	C	
Parartocarpus venenosus		R		R	R		
Pimeleodendron amboinicum	O	R		R	R		
Pisonia	R	R					
Planchonella spp.	R	R	R	O	R	O	R
Planchonia papuana	R	O					
Platea	R	R		R			
Podocarpus spp.				R		R	R
Polyalthia spp.	R	R		R	R		
Polyosma						R	
Pometia pinnata	F	C		C	C		
Pometia tomentosa				C			
Prunus spp.	R	R		R	R		
Pterocarpus indicus	R	R		R	R		
Pterocymbium beccarii	R			R	O		
Pullea						O	R
Quintinia						R	
Randia				R			
Rhus taitensis					R		
Saurauia spp.						R	
Schizomeria spp.						O	R
Serianthes					R		
Sloanea spp.	R	O		R	R	R	R
Solenospermum torricellense				R	R		
Spondias cytherea	R	R		R	O		
Steganthera				R			
Sterculia spp.	R	C		R	O		
Syzygium spp.	R	R		O	R	O	R
Terminalia spp.	C	C	O	O	C		
Tetrameles nudiflora	R	R					
Teysmanniodendron bogoriense	O	O	R	O	O		
Thespesia	R			R	R		
Timonius		R					

TABLE 11 (*Continued*)

Botanical name	Alluvial well-drained forest	Alluvial flood-plain forest	*Campnosperma* forest	Lowland hill forest (high stocking)	Lowland hill forest (low stocking)	Lower montane forest	*Castanopsis* forest	*Nothofagus* forest
Trichadenia	R	R		R	R			
Tristiropsis spp.	R	R		O	R			
Turpinia						R	R	
Urandra umbellata	R	R	R					
Vatica papuana	R	R			R			
Vitex cofassus	O	O		R	O			
Weinmannia						R		
Wrightia	R			R	R			
Xanthophyllum papuanum	R	R		R	R			
Xylopia	R	R		R	R			

Swamp forest in the area is restricted to one type only, *Campnosperma* forest, which exhibits a distinctive air-photo pattern determined by crown shape, evenness of canopy and its single (or almost so) species composition.

Generally the forests of the area have been classified and mapped to approximate forest types of the Wewak–Lower Sepik area (Saunders 1968).

Lowland hill forests include all forests on upland areas (including older fans) below *c.* 3000 ft above sea level and are subdivided into two forest types, lowland hill forest (high stocking) and lowland hill forest (low stocking).

The lower montane forests occur above 3000 ft above sea level and are subdivided on floristic dominance into three types: lower montane forest, which has a mixed species composition, *Castanopsis* (oak) forest and *Nothofagus* forest.

Thus nine forest types appear on the accompanying map at a scale of 1:500 000. Areas for each forest type were calculated using a dot grid (1 dot = 0·6 sq mile) overlay on a 1:250 000 map.

IV. Description of Forest Types

(*a*) *Introductory Remarks*

To avoid repetition these general descriptions are restricted to points of forestry interest and are designed to complement the descriptions given in Part VII. In each description only the most frequently occurring trees are listed. A complete list of species recorded in each forest type is found in Table 11.

(*b*) *Alluvial Well-drained Forest*

This forest type has a high stocking rate and covers 480 sq miles (Plate 6, Fig. 2; Plate 9, Fig. 1). Species composition is mixed, the most frequent being *Pometia pinnata*. Other noteworthy trees contributing to the timber volume are *Celtis* spp., *Terminalia* spp., *Teysmanniodendron bogoriense*, *Neonauclea* spp., *Intsia bijuga*, *Ficus* spp., *Dysoxylum* spp., *Mastixiodendron pachyclados* and *Vitex cofassus*.

Girths are variable but generally range up to 12 ft. Boles range up to 80 ft with the modal class at 50–60 ft. Bole form is extremely variable. The twisted short boles of *Pterocarpus indicus*, *Vitex cofassus* and to a lesser extent *Pometia pinnata* tend to lower the stocking rates, but the remaining trees generally have straight, cylindrical to slightly fluted, long boles. The estimated stocking rate is 10 000 super ft/ac.

The forest grows on higher parts of alluvial plains and on the levees and terraces. It is generally confined to the upper and middle reaches of the Ramu, Gogol and Sogeram River systems. Access within the forest is very good.

(*c*) *Alluvial Flood-plain Forest*

The forest has a low stocking rate and covers 620 sq miles (Plate 11, Fig. 1). The main species contributing to the timber volume are *Terminalia* spp., *Ficus* spp., *Pometia pinnata*, *Sterculia* spp., *Celtis* spp., *Planchonia papuana*, *Anthocephalus cadamba*, *Nauclea* sp., *Teysmanniodendron bogoriense*, *Sloanea* spp. and *Vitex cofassus*.

Girths are variable, but generally do not exceed 12 ft. Boles are generally shorter than those of the well-drained forest, the modal class being 40–50 ft. Bole form is generally similar to the well-drained forest but there is a much lower overall density of trees. The estimated stocking rate is 3500 super ft/ac.

The stocking rate is extremely variable throughout the forest. Locally, relatively dense stands of *Octomeles sumatrana* may boost stocking rates to abnormally high figures; one recorded plot is 20 000 super ft/ac. However, these stands are generally small and relatively rare. For the most part there is a gradual decrease in stocking rate with increasing wetness.

The forest is found on back plains of the middle and lower courses of most of the larger river systems in the area. The major occurrences are on the lower Ramu plain (Plate 7, Fig. 1), the middle Ramu valley, the Usino basin and the coastal plain in Astrolabe land system. Access varies from moderate to poor with increasing wetness.

(*d*) Campnosperma *Swamp Forest*

The forest has a low stocking rate and covers only 5 sq miles. It is a pure or almost pure stand of *Campnosperma brevipetiolata*. Girths rarely exceed 6 ft and boles are generally short and straight, rarely exceeding 30 ft. As the density of the forest varies greatly so does the stocking rate, with figures as high as 8000 super ft/ac ranging down to 3000 super ft/ac. The estimated overall stocking rate is 3500 super ft/ac.

Small stands of the forest are found in the Usino basin and the middle Ramu valley. Access is very poor. The water-table, which is near the soil surface during most of the dry season, may be up to 4 ft above the surface for the remainder of the year.

(*e*) *Lowland Hill Forest* (*High Stocking*)

The forest has a moderate stocking rate and covers 820 sq miles. The major contributors to timber volume are *Pometia tomentosa* and *P. pinnata*, *Intsia bijuga*, *Celtis* spp., *Ficus* spp., *Canarium* spp., *Aglaia* spp., *Cryptocarya* spp., *Dysoxylum* spp., *Syzygium* spp., *Maranthes corymbosa*, *Tristiropsis* spp., *Planchonella* spp. and *Neonauclea* sp. Locally, along the Central Ranges, scattered emergents of *Araucaria hunsteinii* are found.

Girths are generally smaller than those of the alluvial forests but fall within the same range of 5–12 ft. Boles are generally straight and long, the modal class being 50–60 ft. The estimated stocking rate is 7000 super ft/ac but is often much higher on gentle terrain.

The forest, predominantly composed of evergreen trees, is confined to the high-rainfall areas associated with the Central Ranges, the Adelbert Range and the Finisterre Range. Access is generally very poor to nil because of the rugged terrain except for small areas such as the fans near Aiome (Plate 6, Fig. 2) at the foot of the Central Ranges.

(*f*) *Lowland Hill Forest* (*Low Stocking*)

This low stocking rate forest is by far the major type in the area, covering 1850 sq miles. The heterogeneity of its floristic composition from place to place is determined mainly by water stress and human interference. These factors are depicted in the greater proportional representation of deciduous trees, on the one hand, and of secondary species, e.g. *Pometia pinnata*, on the other. Consequently, it is impossible to describe the forest adequately. From plot observations these trees appear to contribute most to the timber volume: *Intsia bijuga*, *Celtis* spp., *Pometia pinnata*, *Terminalia* spp., *Pterocymbium beccarii*, *Garuga floribunda*, *Spondias cytherea*, *Ficus* spp., *Hernandia* sp., *Neonauclea* sp., *Mastixiodendron pachyclados* and *Sterculia* spp. *Albizia falcataria* dominates a large area of the forest to the north of Josephstaal.

Girths range up to 12 ft, the larger ones generally being remnant trees belonging to a previous vegetation. Boles, too, are variable in length and form. The estimated average stocking rate is 4000 super ft/ac.

The forest is found throughout the area, particularly in the central hills region, on gentle hills to rugged mountainous terrain (Plate 1, Fig. 2). Access ranges from very good to very poor but is moderate to poor in most areas.

(*g*) *Lower Montane Forest*

This forest has a low stocking rate and covers 280 sq miles. Inadequate sampling of this forest type precludes any detailed description but these recorded trees all contribute significantly to the timber volume: *Opocunonia* sp., *Pullea* sp., *Schizomeria* sp., *Planchonella macropoda*, *Sloanea* sp., *Elaeocarpus* sp., *Syzygium* spp., *Elmerrillia papuana*, *Cinnamomum* sp., *Cryptocarya* sp., *Galbulimima belgraveana* and *Podocarpus* spp.

Girths are generally small (5–8 ft) and boles short, up to 50 ft and generally 30–40 ft. Tree density is high relative to the lowland forests and the estimated stocking rate is 4000 super ft/ac.

Situated on the higher parts of the rugged Finisterre and Adelbert Ranges, this forest is considered to be inaccessible.

(*h*) Castanopsis *Forest*

This low stocking rate forest covers 22 sq miles. It is dominated by *Castanopsis acuminatissima* on the ridge crests and upper slopes but carries a mixed lower montane forest in the gullies. Where it occurs below 3000 ft above sea level the gully forest is of the lowland hill forest type. *Lithocarpus* spp. may be associated with the *Castanopsis* but may also become dominant in certain situations.

Girths are generally small (5–7 ft) and boles are short, usually less than 30 ft. The estimated stocking rate is 3000 super ft/ac.

It occurs on the Adelbert Range often on plateaux where, although access may be moderate within the forest, the surrounding terrain is inaccessible.

(*i*) Nothofagus *Forest*

This moderate stocking rate forest covers 13 sq miles. Although not visited in the Finisterre Range, the only occurrence in this area, a comparable site in the Central Ranges is used for descriptive purposes. The forest is predominantly *Nothofagus* spp. Girths are generally in the 5–8 ft range and boles are generally straight, ranging up to 50 ft. The estimated average stocking rate is 7000 super ft/ac, decreasing with increasing altitude.

It occurs in the upper part of the lower montane zone and thus is inaccessible in this area.

V. Access

(a) *General*

Access is dependent on the following environmental factors: slope steepness and relief, precipitation, soil drainage and inundation, and river flooding.* Indexes have been calculated to express the degree of access hazard attributable to each of these factors separately or in combination. They are based on the number of days per year that the land affected will be inaccessible to conventional wheeled vehicles. Weighted factors for slope represent a 'degree of difficulty' of access.

Table 12

DURATION OF INACCESSIBILITY DUE TO WETNESS HAZARDS AND WEIGHT FACTOR FOR CALCULATING INDEXES

Nature and class of hazard		Estimated max. duration of inaccessibility (days/yr)	Weight factor for calculating soil drainage/inundation index
Soil drainage/inundation			
Well drained	(W0)	0	0
Imperfectly drained or short inundation	(W1)	45	0·12
Poorly drained or moderate inundation	(W2)	120	0·33
Very poorly drained or long inundation	(W3)	180	0·50
Swampy or very long inundation	(W4)	270	0·75
Permanently inundated	(W5)	365	1·00
River flooding			
Nil		0	0
Once in 6–10 years		3	0·01
Once in 2–5 years		8	0·02
Once every year		15	0·04
More than once every year		>30	0·08

(i) *Soil Drainage/Inundation* (*DI*) *Index*.—This index indicates the limiting effect of soil wetness and overflow.

It is assumed that due to precipitation alone almost all land is inaccessible for a certain length of time each year, even under optimum drainage conditions. The time of inaccessibility is estimated from the period during which soil moisture rises above field capacity and is calculated from the results of the application of the water balance model discussed in Part IV. Above field capacity, conditions are assumed to occur in those weeks when soil moisture storage has reached the maximum level (4 in.) and more than 3 in. of run-off occurs. The length of the period ranges from 21 days per year at Gusap, through 29 days at Awar, 66 days at Wanuma, 86 days at Madang, to 151 days at Aiome.† These periods are used in assessing the DI index, after subjective adjustment for interaction with soil drainage/inundation factors. For example, the period is ignored in areas of permanent swamp.

* Defined here as a short-term inundation ($\leqslant$15 days).

† Length of records: standard 10-yr period, all stations.

The DI index is calculated for each land system using the descriptions in Part III in respect to soil drainage, water-table, precipitation and river flooding. It is the sum of the products of percentage area of the land system affected by a particular hazard or group of hazards and a weighting factor for the maximum expected number of days per year the particular hazard(s) could render the land inaccessible as set out in Table 12.

Thus:

DI = $(0 \cdot 0 + C + F) \times$ % area in W0 + $(0 \cdot 12 + C + F) \times$ % area in W1 + $(0 \cdot 33 + C + F) \times$ % area in W2 + $(0 \cdot 5 + C + F) \times$ % area in W3 + $(0 \cdot 75 + C + F) \times$ % area in W4 + $1 \cdot 0 \times$ % area in W5, where W0, W1, . . . W5 are the drainage/inundation hazards, C is the adjusted weighting factor for the precipitation/water balance hazard and F is the river flooding hazard.

(ii) *Slope(s) Index*.—This index is calculated for each land system from S = $0 \cdot 0 \times$ (% slopes < 10°) + $0 \cdot 33 \times$ (% slopes 10–16°) + $0 \cdot 66 \times$ (% slopes 17–29°) + $1 \cdot 0 \times$ (% slopes > 29°).

(iii) *Access* (*A*) *Index*.—Although all the environmental factors interact, their effects are often additive; e.g. imperfectly drained soils may occur on moderately steep slopes in high-rainfall areas. For this reason the access index is calculated as the sum of the slope index and the soil drainage/inundation index for each land system, subtracted from 100. A = 100 − (S + DI).

For general description, access index classes are: nil, 0–5; very poor, 6–20; poor, 21–40; moderate, 41–60; good, 61–80; very good, >80.

The access index shows the accessibility of any land system relative to other land systems and has no absolute value.

(*b*) *Terrain Access Categories*

On the basis of the indexes described above, the land systems are grouped into nine broad categories described below, listed in Table 13 and shown on Fig. 13.

The land systems are first divided into four groups on the basis of the slope index (S0, 0–25; S1, 26–50; S2, 51–75; S3, >75) which gives an assessment of the proportion of accessible slope in one land system relative to another. Some of the steeper land systems are placed in a better terrain access category where very low or low relief may increase their accessibility.

Land systems with soil drainage and/or inundation hazards are subdivided on their drainage/inundation indexes (W1, 21–40; W2, 41–70; W3, >70), presenting increasingly difficult access.

Those land systems that are subject to minor flooding once or more than once per year over more than 20% of their area are given an extra symbol, F.

Terrain access category S0 land consists mainly of well-drained areas on fans and plains or gently undulating surfaces that have characteristic slopes less than 10° and have nil to very low relief (Plate 3, Fig. 2). It presents no internal access problems except for minor areas of imperfect to poor drainage and minor areas of steep slopes, typically along incised streams. It is found along the Ramu valley and on the coastal plains.

Terrain access category S1 land consists mainly of low hilly terrain. Slopes are generally moderate and relief is moderate to very low. Some areas of steep slopes and

TABLE 13

ACCESS CATEGORIES AND INDEXES OF LAND SYSTEMS

Access category	Area (sq miles)	Indexes S	Indexes DI	Indexes A	Accessibility	Land systems
S0	270	0–10	10–20	81–87	Very good	Bumbu (16), Faita (17), Aiome (19), Madang (24)
S1	670	26	20	45	Moderate	Amaimon (12)
S2	1480	55–73	10–20	17–31	Poor to very poor	Atitau (3), Morumu (11), Sangan (13), Amele (14), Sirin (15), Panakatan (18)
S3	3080	76–100	10–16	0–10	Very poor to nil	Finisterre (1), Kubari (2), Gal (4), Bismarck (5), Romele (6), Bagasin (7), Otaki (8), Musak (9), Wanabutu (10)
S0W1	125	0–6	33–38	61–62	Good	Bosman (20), Nubia (25)
S0W2	710	0	49–67	33–51	Moderate to poor	Astrolabe (21), Boriva (23), Misinki (27), Jibirogo (28)
S0W3	700	0	80–100	0–20	Very poor to nil	Eli (33), Pandago (34), Kabuk (35), Sanai (36)
S0F	40	0	18	82	Very good	Kabenau (22)
S0W1F	825	0–3	25–40	59–75	Good to moderate	Ramu (26), Papul (29), Inbrum (30), Sausi (31), Usino (32)

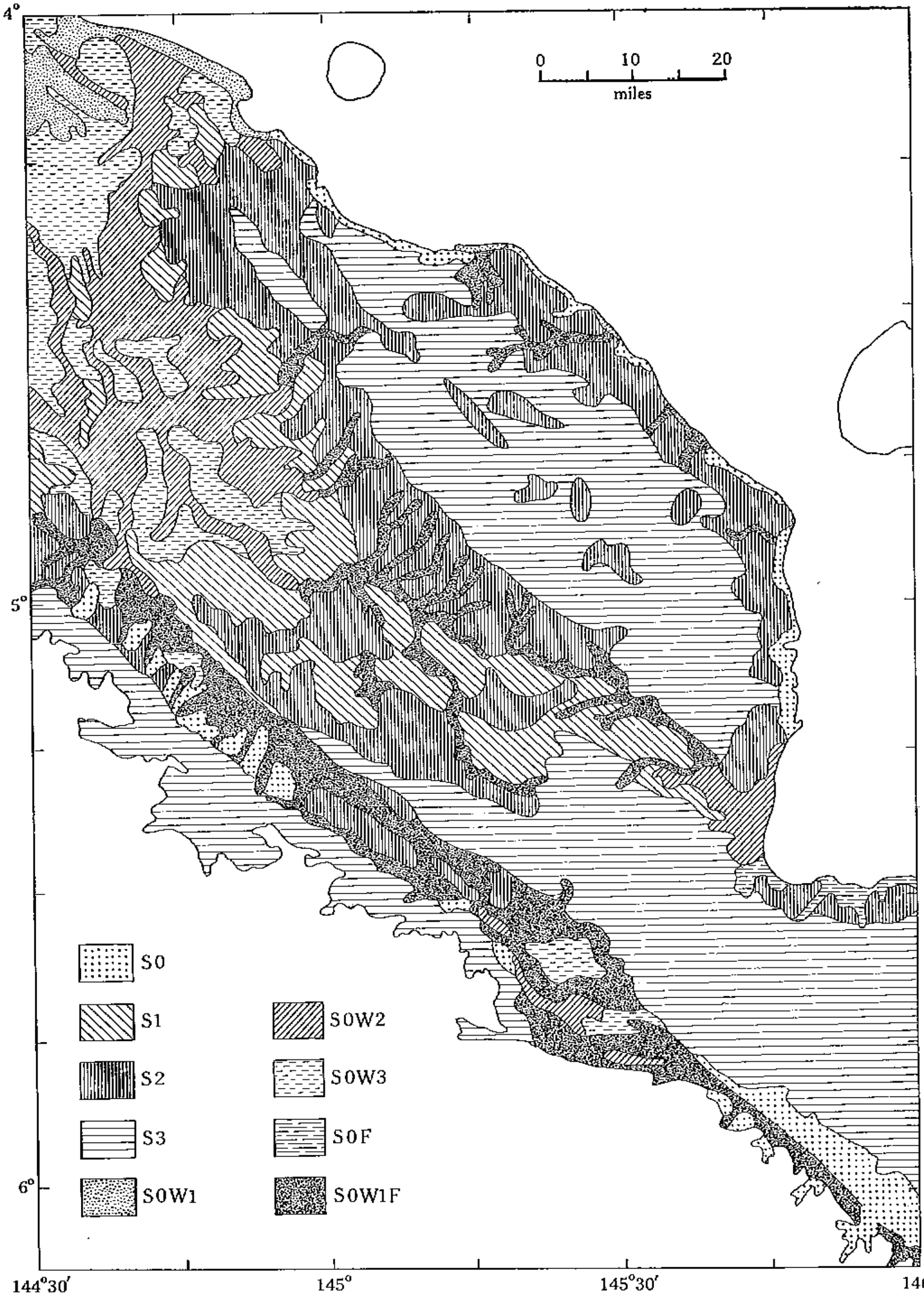


Fig. 13.—Terrain access categories.

minor areas of imperfect to poor drainage occur but are easily avoided. It occurs mainly in the central hills but small occurrences are scattered throughout the area.

Terrain access category S2 land consists mainly of high hilly terrain or strongly dissected low hills with steep slopes. Access difficulties are caused by steep slopes and minor areas of poor drainage, as in valley floors. It is found throughout the area.

Terrain access category S3 land consists mainly of very high hilly and mountainous terrain with very steep slopes and relief ranging from low to very high. Generally, slopes are too steep for road-building and forested areas are best left as watershed protection. However, some of the foothill zones are less rugged and more similar to category S2. This S3 category covers three-eighths of the area and is confined to the Central, Finisterre and Adelbert Ranges and the southern hills (Plate 5).

Terrain access category S0W1 land consists of flat to gently undulating plains and the beach ridge complex of the coastal plain. Much of the land is well to imperfectly drained but some parts may be poorly to very poorly drained and minor areas may be inundated for up to 3 months per year. As a whole the category provides good access. It is found near the mouth of the Ramu River.

Terrain access category S0W2 land consists of poorly drained plains (Plate 10, Fig. 1) . Slope and relief are negligible. Because of inundation and poor drainage, large areas may be inaccessible for up to 5 months per year and minor areas for longer periods. However, by carefully selecting road routes and building causeways where necessary, access may be possible to large areas for much of the year. This category is typical of the back plains of the lower Ramu and lower Gogol Rivers, but does occur along the Ramu valley above Annanberg.

Terrain access category S0W3 consists of swamps (Plate 11, Fig. 2), both freshwater and saline. It comprises land systems which are inundated or very poorly drained for 5 months or longer per year. However, some small areas may be accessible for brief periods during the dry season. This category is typical of the back swamps of the alluvial plains and is abundant in the lower Ramu River flood-plain.

Terrain access category S0F is similar to S0 except that it receives damaging floods at least once per year over 30% of its area. It comprises the Kabenau land system.

Terrain access category S0W1F is similar to S0W1, except that it receives floods at least once per year over at least 20% of the land. It comprises the alluvial plains along the upper courses of most of the rivers in the area, the largest occurrence being along the Ramu River above Annanberg.

(c) *General Conclusions*

The most accessible land is in the upper Ramu valley and on the coastal plain. The Usino basin and the middle Ramu valley (Plate 6, Fig. 2) generally provide moderate to good access. However, in the above regions many streams cross the logical road routes. By contrast the lower Ramu plain (Plate 7, Fig. 1) generally provides poor to very poor access, comprising for the most part back plains and back swamps. Limited access may be possible during the dry season by utilizing levees and higher parts of the back plains.

Of the uplands, the central hills provide moderate access, and the northern and coastal hills moderate to poor access. The southern hills together with the Central Ranges, the Adelbert Range and the Finisterre Range (Plate 1, Fig. 2) provide very poor to nil access except, in some cases, along their foothill zone.

Existing road access is limited to a coastal road linking Awar and Madang. This road then continues up the Gogol River valley to Utu. Several short lengths of road branch off this system. A second road in the upper Ramu valley extends from Koropa through Gusap to link up with the Highlands highway and Lae.

Madang is the major port in the area but the coast is served by small ships. Air transport serves the remainder of the area.

The lower Ramu River is generally navigable by smaller craft and may provide a possible outlet for timber in that region.

VI. References

Cottam, G., and Curtis, J. T. (1956).—The use of distance measures in phytosociological sampling. *Ecology* 37, 451–60.

Saunders, J. C. (1968).—Forest resources of the Wewak–Lower Sepik area. CSIRO Aust. Land Res. Ser. No. 22, 125–32.

Ward, R. G., and Lea, D. A. M. (1970).—'An Atlas of Papua and New Guinea.' (Dep. Geography, Univ. of Papua New Guinea and Collins Longman.)

PART IX. LAND USE CAPABILITY

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 distributional pattern of the many types. As a result the land systems, although each has its characteristic dominant land type 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. The resulting generalized distribution of land capability is presented in Fig. 14.

Readers interested in the land use potential of particular land systems rather than that of the whole area should refer to the land class column as well as the assessment notes of the land system tabular descriptions in Part III.

Some additional aspects of land use capability will, of course, be contained in Parts IV and VI dealing with climate and soils.

II. Land Use Capability Categories

All land has been grouped into four categories which have been subdivided into 12 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 used by the United States Conservation Service and fully detailed in Part III. The suitability for development has been assessed under Papua New Guinea conditions on the basis of five general purposes: arable crops; tree crops, i.e. coffee, coconuts, cacao, oil palms, rubber, etc.; wet rice growing; grazing; and forestry. Special management and possible reclamation measures have been taken into consideration where necessary.

A summary of the land use capability in the survey area is given in Table 14. This will help in assessing such land in relation to the land system map.

* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

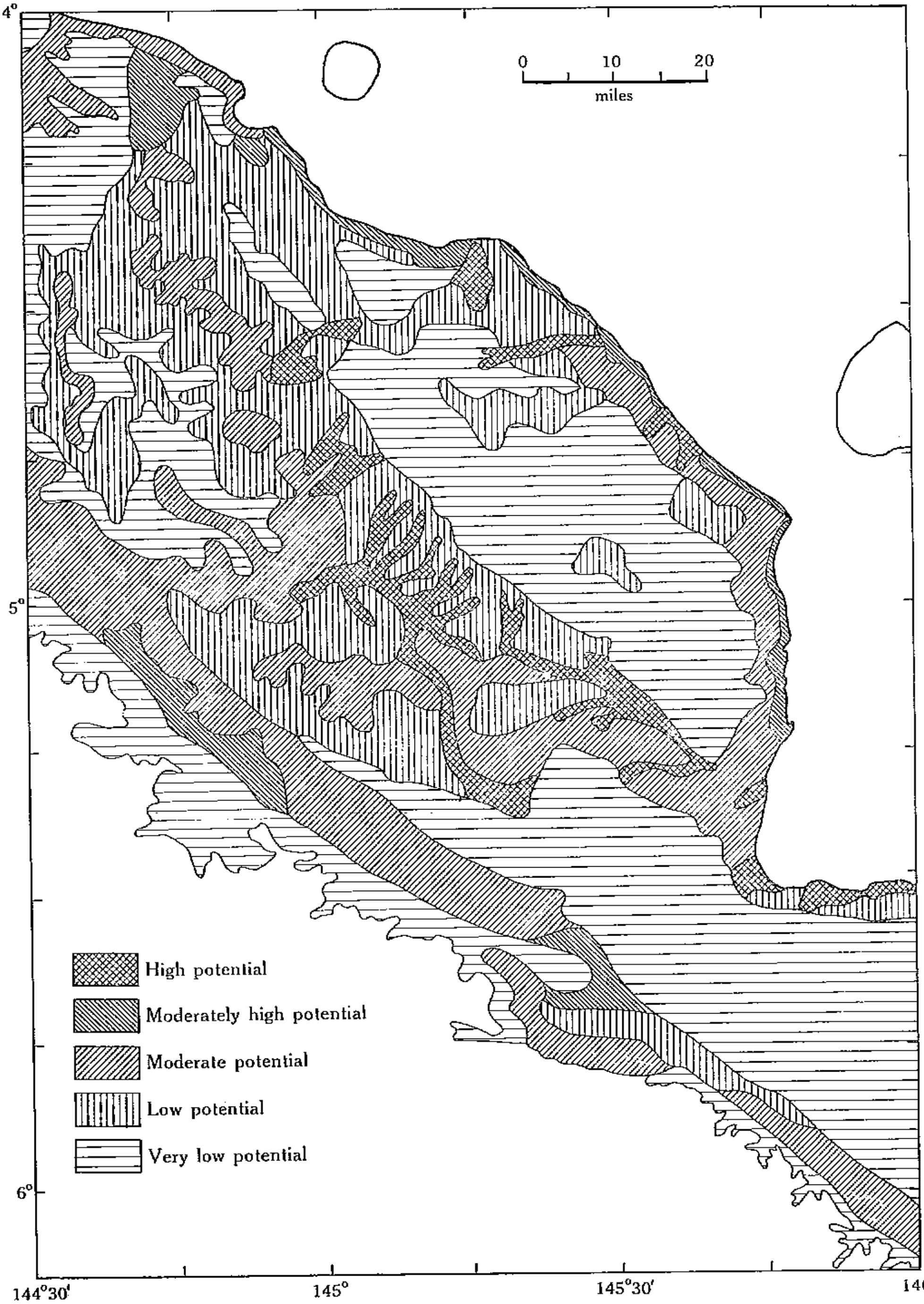


Fig. 14.—Generalized land use potential.

TABLE 14

DISTRIBUTION AND NATURE OF LAND USE CAPABILITY CATEGORIES AND SUBDIVISIONS

Land use capability category	Land system and units in which it occurs	Estimated area (sq miles)
Land without or with only slight physical limitations for agricultural development		550
First-class level land	Papul (29), 1	135
	Astrolabe (21), 1, 2, 3	31
	Boriva (23), 1	30
	Ramu (26), 1	26
	Sausi (31), 1, 3	22
	Bumbu (16), 1, 2	17
	Madang (24), 2, 4	16
	Kabenau (22), 1	12
	Nubia (25), 1, 3	6
	Faita (17), 1	14
	Bagasin (7), 4	2
	Usino (32), 3	1
Total		312
Level land with easily rectified drainage problems	Nubia (25), 2, 3	24
	Borivla (23), 1, 2	20
	Astroabe (21), 1	10
	Ramu (26), 1	10
	Papul (29), 1	10
	Madang (24), 2	9
	Aiome (19), 3	7
	Usino (32), 2	3
	Panakatan (18), 2	2
Total		95
Level land with leached soils	Aiome (19), 1, 2, 3	60
	Panakatan (18), 2, 3	14
	Ramu (26), 3	8
Total		82
Level land with mildly droughty soils	Madang (24), 1, 3	32
	Kabenau (22), 1, 5	9
	Nubia (25), 1	9
	Ramu (26), 3	7
	Faita (17), 1	4
Total		61
Land with moderate limitations for agricultural development		1804
Poorly drained level land, difficult to improve	Astrolabe (21), 1, 2, 3	62
	Papul (29), 2	40
	Bosman (20), 1	35
	Boriva (23), 2	20
	Madang (24), 1	11
	Nubia (25), 3	6
	Kabenau (22), 2	5
	Sirin (15), 3	3
	Morumu (11), 3	3
	Amele (14), 3	2
	Bumbu (16), 6	1
Total		188
Level land subject to mild flooding	Misinki (27), 1, 2, 3	450

TABLE 14 (*Continued*)

Land use capability category	Land system and units in which it occurs	Estimated area (sq miles)
	Ramu (26), 1, 2	285
	Papul (29), 2	70
	Sausi (31), 1, 2	30
	Usino (32), 1, 2, 3	28
	Amaimon (12), 4	15
	Astrolabe (21), 1	7
	Madang (24), 4	4
	Kabenau (22), 3	7
Total		896
Low hilly land with gentle to moderate slopes	Amaimon (12), 1, 2, 3	568
	Amele (14), 2	93
	Bosman (20), 1, 2	40
	Bumbu (16), 3	15
	Sirin (15), 2	4
Total		720
Land with serious limitations for agricultural development		1752
Level land with seriously droughty soils	Bumbu (16), 1, 2, 4, 5	37
	Imbrum (30), 2	22
	Faita (17), 1, 2	13
	Astrolabe (21), 2, 3	2
Total		74
Rugged hilly land	Morumu (11), 1, 2, 3	962
	Amaimon (12), 1	233
	Amele (14), 1, 4	105
	Sangan (13), 1	102
	Panakatan (18), 1, 4	76
	Musak (9), 1, 2	60
	Romole (6), 1, 2	51
	Gal (4), 3	50
	Kubari (2)	34
	Sirin (15), 1	5
Total		1678
Land without or with extremely limited possibilities for agricultural development		3730
Rugged mountainous land	Gal (4), 1, 2	931
	Bagasin (7)	586
	Bismarck (5), 5, 6	498
	Kubari (2)	398
	Finisterre (1)	288
	Musak (9), 1, 2, 3	106
	Wanabutu (10)	20
	Otaki (8)	9
Total		2836
Swampy land	Pandago (34)	380
	Sanai (36)	154
	Kabuk (35)	150
	Eli (33), 1, 3	13
	Nubia (25), 4, 5	3
	Kubari (2)	3
	Madang (24), 4	2
Total		705

TABLE 14 (*Continued*)

Land use capability category	Land system and units in which it occurs	Estimated area (sq miles)
Severely flooded land	Jibirogo (28)	123
	Imbrum (30), 13	54
	Kabenau (22), 4	7
	Eli (33), 2	4
	Bumbu (16), 4	1
Total		189

(*a*) *Land without or with only Slight Physical Limitations for Agricultural Development*

(i) *First-class Level Land.*—This land category comprises generally level, non-flooded land with well-drained deep productive soils. It is therefore very suitable for arable crops, as well as for tree crops and grazing. In some parts such as Bumbu, Faita, Sausi and Astrolabe land systems, it may be gently sloping and simple conservation measures are necessary to prevent erosion with arable cropping. A disadvantage of this land is that it is of scattered occurrence, often poorly accessible and usually covered with tall forest, although some parts have grasslands.

Present agricultural occupation is surprisingly sparse and restricted to local gardens and some plantations in coastal areas where access is better. A large part of Bumbu land system is held as pastoral lease.

Because of the small proportion of this high-quality land and its scattered distribution, its most logical utilization would be as a nucleus of intensive permanent arable agriculture from which surrounding land of lower value could be utilized for tree crops and grazing.

The chemical soil fertility is high: pH 6·5–7·5; high exchange capacity; high percentage of base saturation, dominated by Ca; moderate to high available P; moderate to high exchangeable K. It probably includes the most fertile soils in the area.

(ii) *Level Land with Easily Rectified Drainage Problems.*—Apart from the fact that initial development will be more costly because of the necessity to improve land drainage by means of drainage ditches, the potential of this land is very similar to that of category (i) with which it commonly forms a complex. It is probably slightly less suitable for tree crops and more dominantly suitable for arable crops.

The chemical soil fertility is high and similar to that of land category (i). It is still largely forested and sparsely inhabited.

(iii) *Level Land with Leached Soils.*—This category has been separated because it has acid-leached red soils where fertility problems are likely to arise if the land is used for continuous cultivation. As it is important to preserve the organic matter in the topsoils as much as possible, and as the soils are physically of good quality, this land is probably best used for tree crops. Much of it is covered with grassland, thus simplifying land clearing. Locally, mainly in Ramu land system, the land is stony and has moderate erosion hazards. It is sparsely inhabited and at present poorly accessible.

The chemical soil fertility is low to moderate: pH 5–5·6; low exchange capacity; low percentage of base saturation, commonly dominated by Mg; low to moderate available P; moderate exchangeable K.

(iv) *Level Land with Mildly Droughty Soils.*—This land with its shallow soils on coral or gravel, or deep but very sandy soils, should not be used for cropping during the dry season. As it is important to maintain a high level of organic matter in these soils, the land is best kept under perennial vegetation, preferably tree crops which are best able to utilize fully the limited moisture of the deeper subsoils. Much of this land is already in use for coconut plantation, whilst cocoa is grown successfully on the best soils in this land category.

The chemical soil fertility is moderate to high: pH 6·5–8; moderate exchange capacity; high percentage of saturation, dominated by Ca; low to high available P; moderate exchangeable K.

It is densely inhabited only along the coast.

(*b*) *Land with Moderate Limitations for Agricultural Development*

(i) *Poorly Drained Level Land, Difficult to Improve.*—Except for several coconut plantations on Madang land system, there is very little land use in this category. Large areas are covered with poor forest and other large areas with grassland. Much is quite accessible.

The poor drainage is due to the impermeability of heavy clay soils and, more rarely, to the low topographic position as well. It is doubtful that drainage can be improved sufficiently to make this land suitable for other than a few types of arable and tree crops. Even the highly adaptable coconut palm grows poorly but it should be possible to improve surface drainage enough to use this land for grazing purposes.

The soils appear to be very suitable for wet rice growing. Topographically this form of land use appears to be most promising in Astrolable land system, on the large area of this land south of the Gogol River, and where the necessary irrigation would be generally possible. In other areas such as Bosman land system ponding would have to depend on rain water. Natural inundation is most common in Boriva and Nubia land systems.

The chemical soil fertility is low to moderate: pH 6–7; high exchange capacity; high percentage saturation, dominated by Ca; generally low available P; strongly variable exchangeable K. In Bosman land system P and K are particularly low.

(ii) *Level Land Subject to Mild Flooding.*—This vast area of almost uninhabited land, covered with mostly poor forest, deserves special attention. Most of this land is at present poorly accessible. It is useful to distinguish between areas where flood control is and is not possible.

To the first group belong the large areas of Sausi, Madang, Usino and Misinki land systems. In its simplest form flooding may be controlled by improving the discharge of surface water by means of a system of drainage channels. This applies to land with a sufficient gradient and lying well away from large rivers, i.e. along the foot of the hilly country. In wide low-lying flood-plains individual areas may be protected against flooding by large rivers by surrounding them with levee banks. Although the fertile soils of these areas are commonly of very fine texture and somewhat impermeable, it should be possible to establish systems of arable agriculture on them, or certain tree crops such as oil palms. The most permeable soils are likely to be very suitable for wet rice only.

Flood control appears to be almost impossible on land of this category in Amaimon, Kabenau, Astrolabe, Ramu and Papul land systems. However, in these areas flooding is usually of short duration and confined to the wet season. The soils are commonly less clayey and are very suitable for tree crops and arable crops. Investigations are required to decide whether growing of tree crops would be possible under conditions of temporary flooding, whether arable cropping during flood-free periods would be profitable or whether grazing would be the best form of land use. It is quite possible that a combination of these forms of agriculture as mixed farming would be best. One question arising from the opening up of this country would be its distance to places of settlement. Obviously people cannot live on the flooded land, but as the flooded areas are commonly narrow, this problem is not likely to be serious. Also, important points are the effect of flooding on roads, land partitions and drainage ditches and the effect of forest clearing on the flood regime and stability of rivers, especially along their banks. With regard to the first point it is encouraging that silt loads and velocity of the flood water appear to be generally low. Forest clearing along the river, while eliminating much of the snag problem, might increase erosion of the banks, although this is not at all certain. It has not occurred where minor clearing has already taken place.

The chemical soil fertility is high: pH 6–7·5; high exchange capacity; high percentage base saturation, dominated by Ca; generally moderate to high available P (with a few notable low exceptions); moderate to high exchangeable K.

(iii) *Low Hilly Land with Gentle to Moderate Slopes.*—Apart from small pockets, this land category is too steep and broken for permanent cultivation of arable crops. The soils are generally too impermeable or shallow for tree crops, although there may be limited scope here in Amaimon and Amele land systems.

Grazing appears to be the most promising form of land use in most of this country as much of the land is already covered with grass or low regrowth. It would be worth while to investigate possibilities of pasture improvement and methods of pasture management as this land category may be capable of supporting a rather intensive cattle industry.

Several areas of Amaimon and Amele land systems are intensively used for shifting cultivation, but the land is generally not particularly suitable for this form of agriculture as the forest vegetation is soon converted into grassland because of the unfavourable soil conditions.

The chemical soil fertility is moderate: pH 6–7; high exchange capacity; high percentage of base saturation, dominated by Ca; low available P; moderate to high exchangeable K.

(*c*) *Land with Serious Limitations for Agricultural Development*

(i) *Level Land with Seriously Droughty Soils.*—This sparsely inhabited grass-covered land has very shallow soils in gravel and stone deposits and occurs in a dry part of the survey area, the upper Ramu valley. It is suitable only for more or less extensive grazing, but the stocking capacity may be considerably increased by pasture improvement. There is little information on the chemical soil fertility of this land and it is likely to vary greatly from place to place.

(ii) *Rugged Hilly Land.*—Although this land includes catchment areas of the second order only, it would be unwise to promote any agricultural development that might lead to substantial increase in run-off, already naturally high in areas of impermeable mudstone.

Sparse shifting cultivation causes no harm but where the land becomes densely occupied, as a result of population increase or the introduction of cash crops into the rotation, run-off may be dangerously increased and soil erosion initiated. In many areas, notably in Bagasin, Musak, Amaimon and Morumu land systems, it is evident that over-cultivation is already leading to soil deterioration and grassland encroachment. This process has reached an advanced stage on the grass-covered hills of Romole, Sangan and Sirin land systems, which are now only marginal or totally unsuitable even for shifting cultivation and where land use potential appears now restricted to extensive grazing or reforestation. Elsewhere in this land category agricultural development is virtually limited to tree crops.

The chemical soil fertility is moderate: pH 5·5–7; high exchange capacity; high to moderate percentage of base saturation, slightly dominated by Ca; low available P; moderate exchangeable K.

Access for inland areas is at present nil.

(*d*) *Land without or with Extremely Limited Possibilities for Agricultural Development*

(i) *Rugged Mountainous Land.*—Most of these lands are very important catchment areas in which natural forest vegetation should be disturbed as little as possible, although sparse shifting cultivation can continue. Because of the extremely steep long slopes and common landslides the introduction of tree crops in shifting cultivation would be only locally possible. Any large-scale agricultural development would in any case be hampered by the lack of communications.

The chemical fertility of the soils is low: variable but generally low pH; low to moderate exchange capacity; low to moderate percentage of base saturation, dominated by Ca; low available P; moderate to high exchangeable K.

(ii) *Severely Flooded Land.*—Flooding of this land is too severe and frequent to allow permanent agricultural development. Commonly the soils are very gravelly or stony, which makes this land virtually useless. Where soil conditions are favourable as in parts of Imbrum and Jibirogo land systems, this land may be used for quick-growing 'catch' crops such as tobacco, corn, tomatoes, grown in the short flood-free period.

There is no information on the chemical soil fertility but this is likely to be high in the better soils.

INDEX TO LAND SYSTEMS

Fig. 1.—Looking across the shallow snag-filled Ramu River from Faita to the northernmost extension of the Finisterre Range. Mt Kubari, under cloud cover, is just below 6000 ft.

Fig. 2.—The rugged Finisterre and Kubari land systems. Looking up the Surinam River valley just south of Dumpu. Lowland hill forest and lower montane forest on crests.

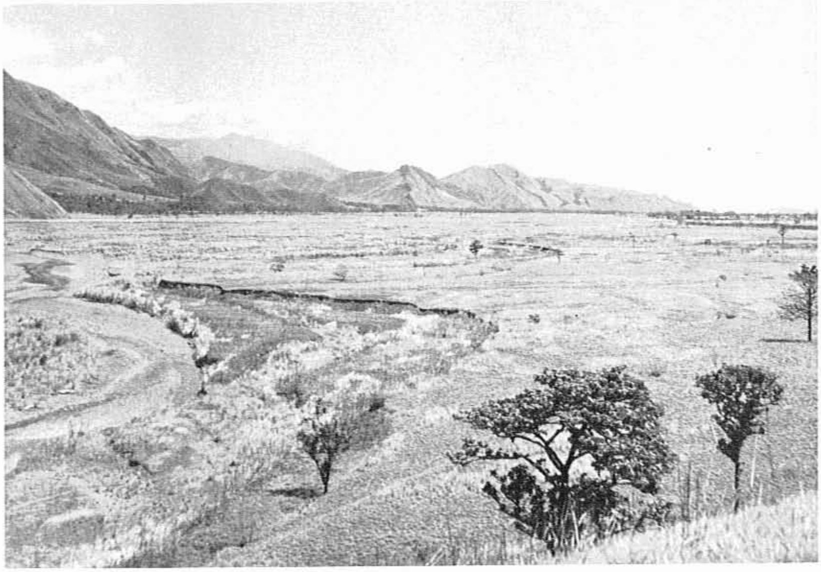


Fig. 1.—A view downstream from near Gusap overlooking the gently sloping alluvial fan of Bumbu land system traversed by incised through-going streams, one of which is seen on the left. On the extreme left the Ramu River skirts the foothills of the Central Ranges. In the middle background the hogback form of the limestone Otaki land system can be seen. The vegetation is short dry grassland of *Themeda–Arundinella*. The trees are *Nauclea coadunata*.

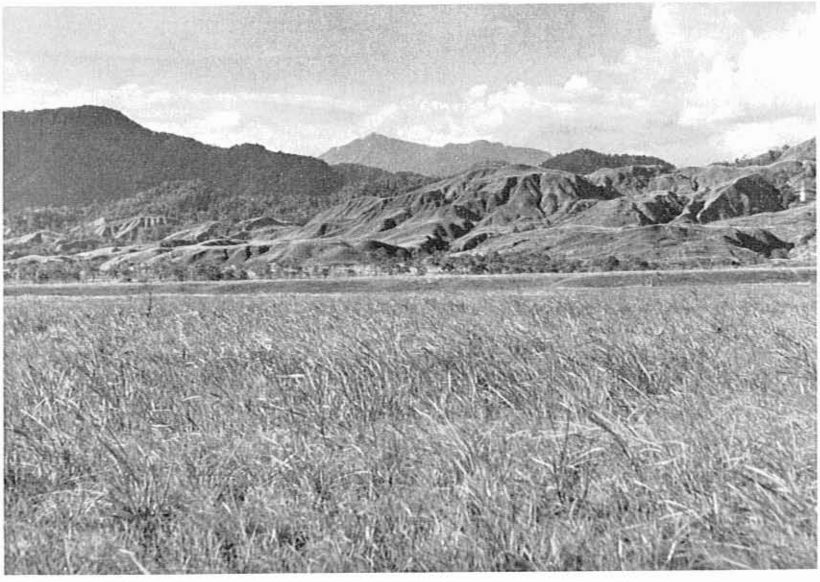


Fig. 2.—A view over the Bumbu fan near Dumpu to the much-dissected Romole land system which comprises the steep southern foothills of the Finisterre Range rising in the background.

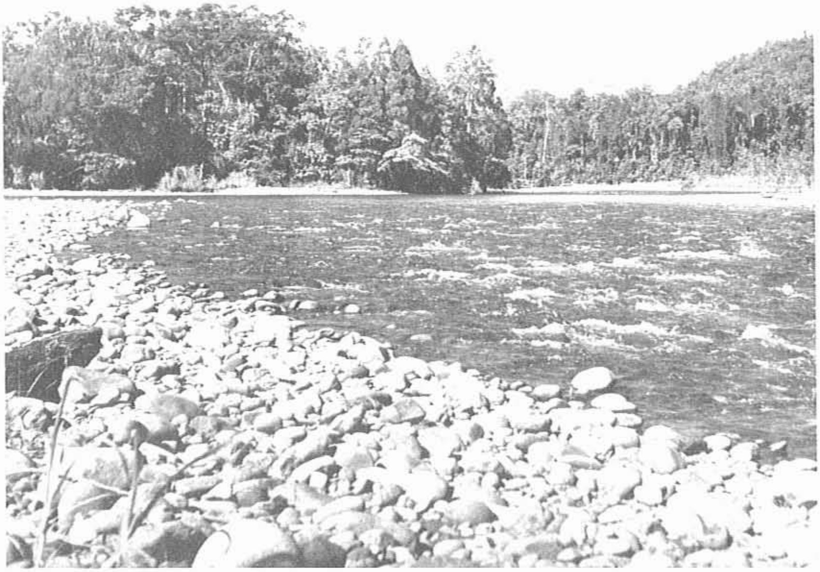


Fig. 1.—The stony bed of the Ongan River where it leaves the Central Ranges. This is typical of the fast-flowing mountain tributaries of the Ramu River where they emerge from the Central Ranges into the upper valley (Imbrum land system). The alluvial forest edge includes *Octomeles* and *Casuarina*.

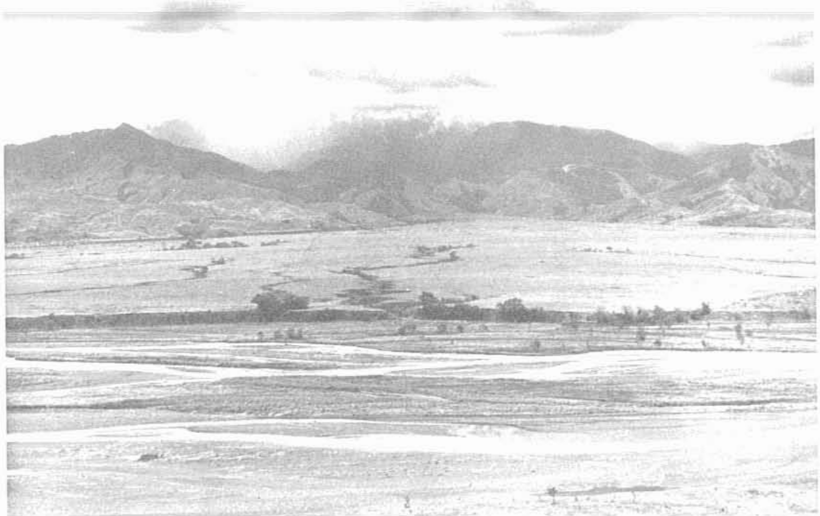


Fig. 2.—Looking across the braided stream bed of the Ramu River (Imbrum land system) to the fan of Bumbu land system showing its river escarpment and traversing streams. The fan rises gently to the forest-cleared foothills and slopes of Kubari land system and the higher misted Finisterre land system behind.

Fig. 1.—Jobso, a typical hill village in Kubari land system on the lower inland slopes of the Finisterre Range. Coconuts are planted within the village but the gardens based on shifting agriculture may be some distance away within the lowland hill forest.

Fig. 2.—A garden plot with the lowland hill forest felled, fired and ready for planting in the foothills of the Central Ranges (Bismarck land system).

Meroi, a typical ridge-top village of the hills of Bagasin land system. Every phase of current gardens, garden regrowth and incipient grassland may be seen.

Fig. 1.—A panorama of the Usino basin from the Faita hills. Here the upper Ramu River and its northern tributaries the Peka, Mea and Nopu Rivers meander to form a flood-plain comprising Sausi, Usino, Eli and part of Pandago land systems.

Fig. 2.—Looking down from Tugum during a gathering rainstorm on the Central Ranges above Aiome over Aiome land system (mainly fan grassland areas) and merging into Ramu land system on the extreme left. Lowland hill forest and alluvial well-drained forest.

Fig. 1.—The alluvial flood-plain of the lower Ramu River from near Misinki. The meandering river with its scrolls, levees, back-plains and oxbows includes land systems such as Jibirogo, Sanai, Kabuk, Pandago and Misinki.

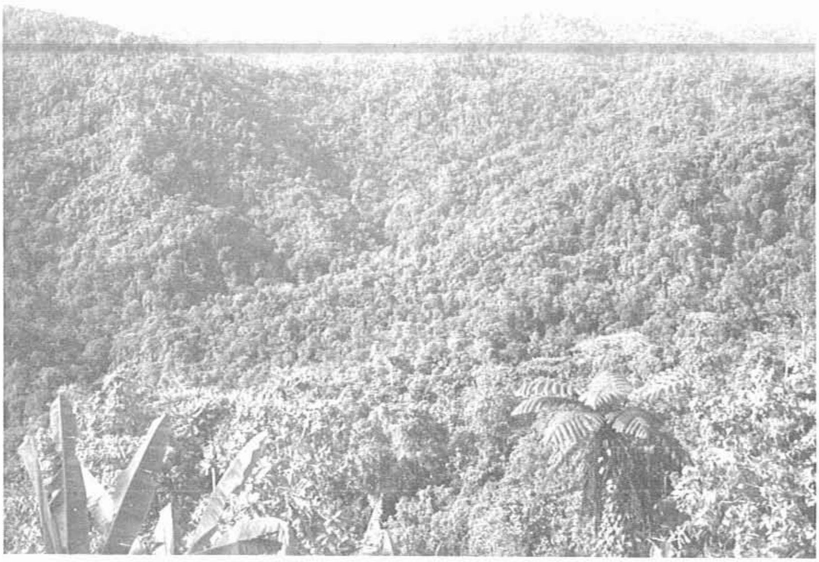


Fig. 2.—Contrasting with the alluvial flats is the rugged topography of the mountainous Gal land system. Here the steep slopes of the Adelbert Range are covered with mixed lowland hill forest. Scattered villages occur along crests.

Fig. 1.—Government forest track from Mirap to Dimir through lowland hill forest in the Adelbert Range foothills (Amele land system).

Fig. 2.—Sago-palm swamp in Pandago land system. This is a fluctuating swamp with the water-table falling to just below the surface in the dry season. The water here is a drainage channel. The trunk of a mature sago palm from which the starchy 'sac sac' is obtained may be just seen on the right.

Fig. 1.—Interior of the alluvial well-drained forest near Aiome in Ramu land system. Note the large flange-buttressed trunk of the tall *Terminalia* tree with lianes and climbing plants.

Fig. 2.—Chiselling the starchy pith from the mature trunk of a sago palm at Gamai village near the Ramu mouth. Steeped in water, the flour is extracted and cooked into a jelly-like gruel which forms a staple diet for much of the year for the flood-plain dwellers.

Fig. 1.—The Ramu River at Sotopu between the Sogeram and Guam Rivers. Tall palm aspect of alluvial flood-plain forest (Misinki land system).

Fig. 2.—Examining a young alluvial soil on a Ramu River scroll covered with tall *Saccharum robustum* of the herbaceous river-bank succession (Jibirogo land system).

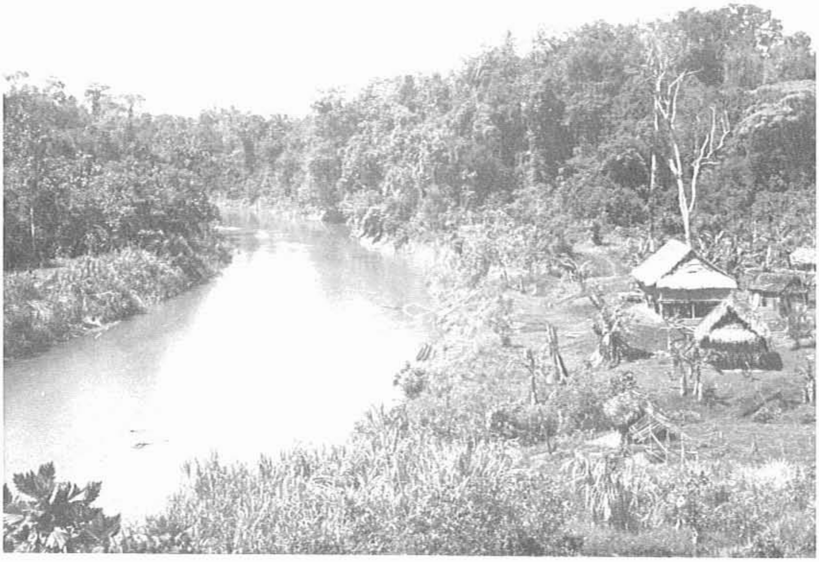


Fig. 1.—Mason village on the banks of the Keram River flowing through the flats of the lower Ramu valley. Here flood-plain forests reach close to the incised banks of the river except where narrow levees are cleared for village sites (Ramu land system).

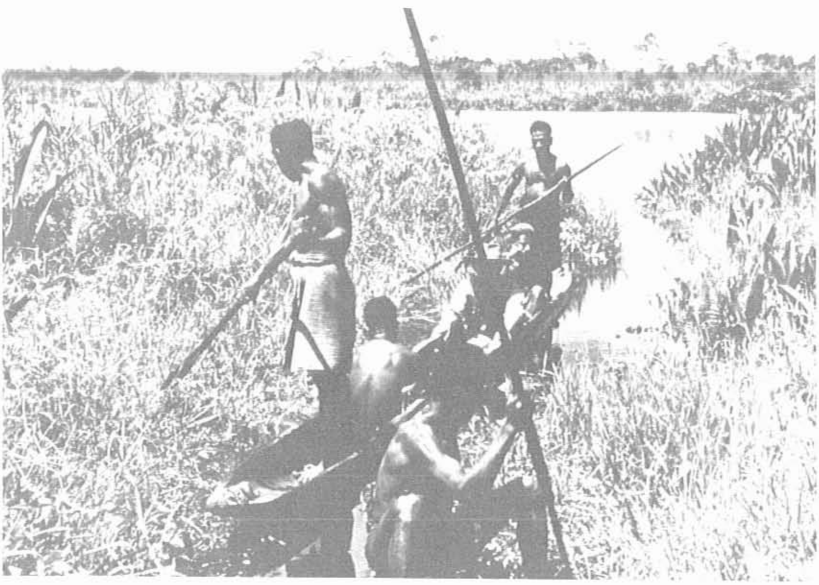


Fig. 2.—The herbaceous swamps and open lakes of Sanai land system. Transport is by canoe poled through miles of narrow waterways. The vegetation is of rice grasses, water ferns, sedges and fleshy lily-like *Hanguana*.

Fig. 1.—Recently established village of Misibero in the coastal foothills of the Adelbert Range. The site is on a flood-free terrace of Papul land system but forest felling for new gardens extends up the slopes into the lowland hill forest on Bagasin land system.

Fig. 2.—A poorly drained alluvial flat within the hilly Sirin land system. *Ophiuros–Imperata* grassland on the foreground slopes; slightly darker moist *Ischaemum* grassland in the centre. Remnant lowland hill forest.

Fig. 1.—A succession from alluvial flood-plain forest through herbaceous swamp to lake in a cut-off meander (Jibirogo land system).

Fig. 2.—Coastline from the hills above Bogia showing coconut groves and short *Themeda–Arundinella* grassland. Trees lining the watercourses are the introduced 'rain tree' (*Samanea saman*) which, together with local species, has an affinity to monsoon vegetation.

Fig. 1.—Uplifted coral limestone of Madang land system. This photograph, taken near Madang, shows three stages of uplift with undercut by wave action.

Fig. 2.—The north coast near Mirap. Note the driftline, sand binders and the strand woodland fronting the beach.