# Lands of the Safia–Pongani Area, Territory of Papua and New Guinea

Comprising papers by B. P. Ruxton, H. A. Haantjens,
K. Paijmans, and J. C. Saunders

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Land Systems

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# PART I. INTRODUCTION AND REGIONAL DESCRIPTION* OF THE SAFIA–PONGANI AREA

By B. P. Ruxton†

## I. Introduction

The Safia–Pongani area covers 2700 sq miles in the Northern District of Papua and includes parts of the Tufi, Popondetta, and Kokoda subdistricts. It lies between the Buna–Kokoda (Haantjens *et al.* 1964*b*) and Wanigela–Cape Vogel (Haantjens *et al.* 1964*a*) areas previously surveyed by the Division of Land Research and Regional Survey in 1953 and 1954 respectively (Fig. 1). The boundaries are approximately longitudes 149°E. and 148°E. and latitudes 9°00′S. and 9°45′S.

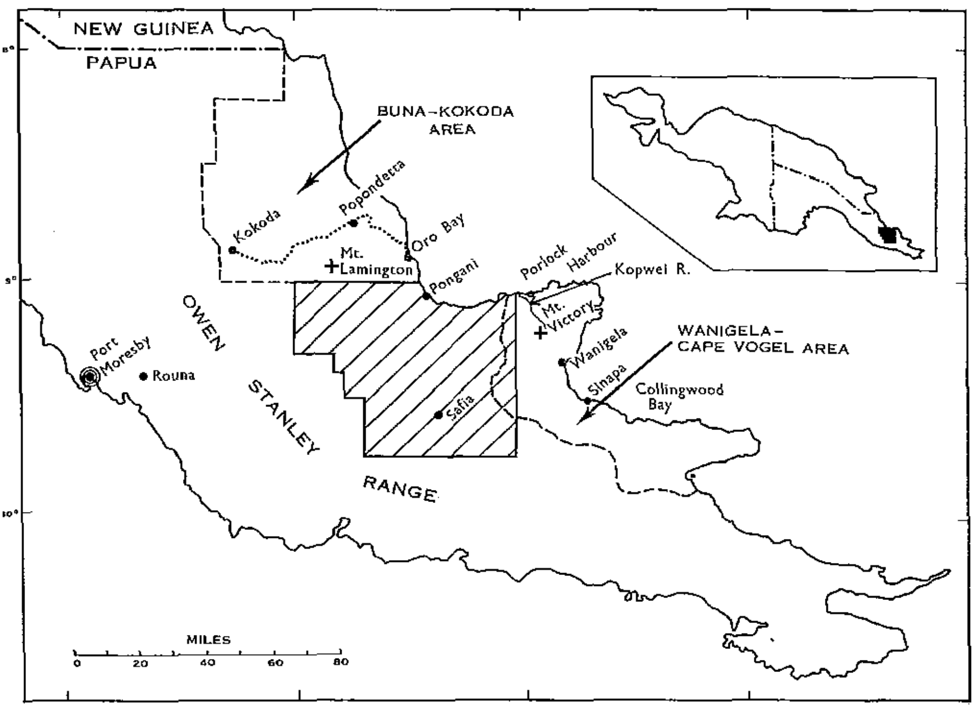


Fig. 1.—Location of the Safia–Pongani area.

Survey procedure was similar to that of previous surveys carried out by the Division in New Guinea. The survey team consisted of a geologist/geomorphologist, pedologist, and a plant ecologist, who, with the assistance of a transport officer,

* This Part has been compiled from data brought together by all four scientific members of the team. The Division's climatologist, E. A. Fitzpatrick, contributed to the section on climate and the team's technical assistant, P. A. Healy, to the section on population and communications.

† Division of Land Research, CSIRO, Canberra, A.C.T.

traversed the area mostly on foot (Fig. 2) and sampled nearly 500 sites altogether between July 3 and September 29, 1963. A work boat was used for a short period along the coast and a helicopter based at Safia was used for several days to visit otherwise inaccessible sites. During the period of the survey a forest botanist working separately sampled 82 forest plots throughout the area.

Complete aerial photograph cover was available at a scale of 1 : 50,000 at sea level, taken by Adastra Airways Pty. Ltd. in 1957, 1961, and 1962. The base map at a scale of 1 : 250,000 used in this report has been prepared by the Division of National

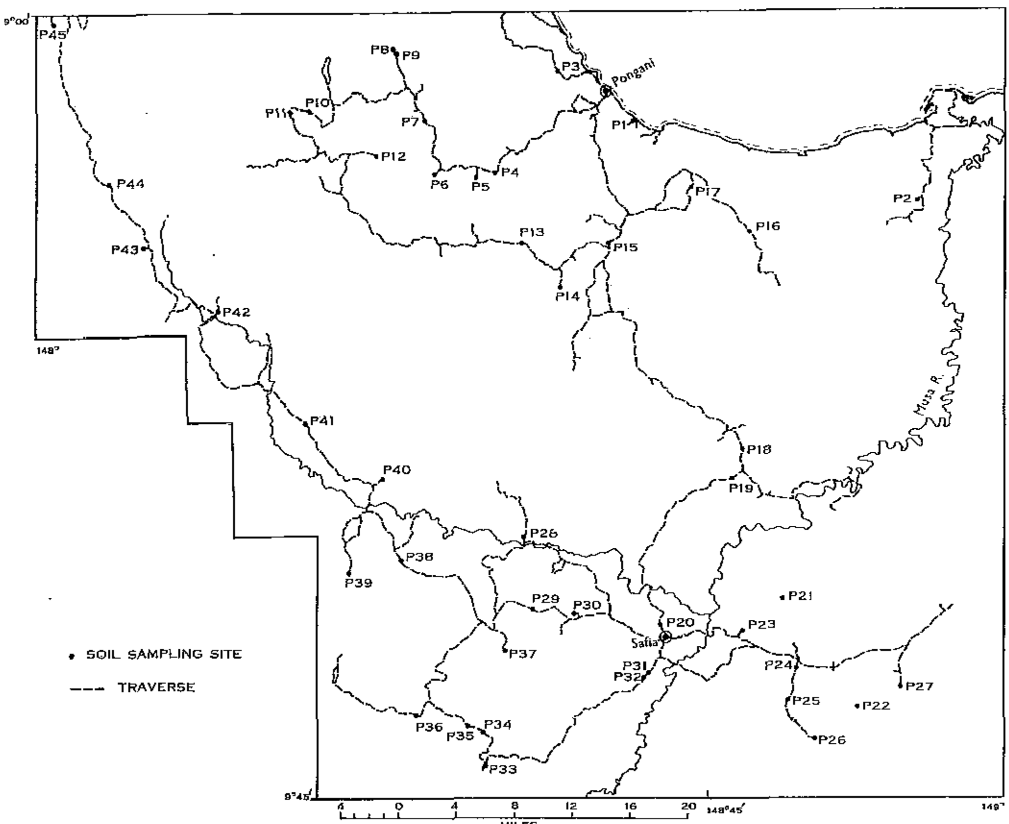

Fig. 2.—Traverses and soil sampling sites.

Mapping, Department of National Development, from the systematic air photograph coverage. Owing to very poor ground control the map is distorted and the 9° latitude northern boundary is represented by a curved line.

The first stage of the work consisted of aerial photograph interpretation carried out in Canberra in May and June 1963. This resulted in the establishment of 88 preliminary mapping units. The boundaries of these units were transferred onto air-photo mosaics for traverse planning in the field. During field work access to the preliminary mapping units was restricted to the proximity of native tracks and so the number of observations made in each varied considerably. The details of each site were recorded on a separate element card. On return to Canberra a further interpretation and remapping of the aerial photographs led to the definition of 44 land systems and one land system complex.

## II. Regional Description

Six physical regions are recognized (Fig. 3) and each one is described below in terms of its geology, geomorphology, soil, and vegetation. Reference is made to all the land systems within each region and this section should be read in conjunction with the land system map and the plates.

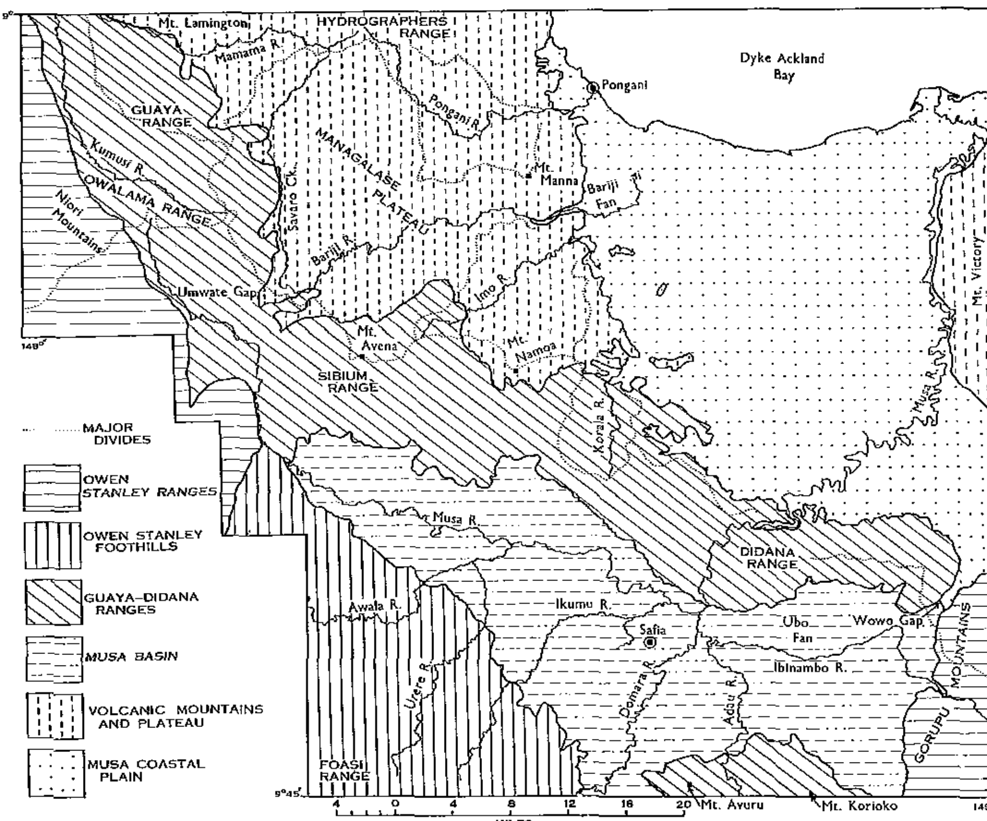


Fig. 3.—Physiographic regions and major divides.

### (a) *Musa Coastal Plain*

The Musa coastal plain extends 25 miles inland from Dyke Ackland Bay. It is made up of a central alluvial plain which is surrounded on three sides by freshwater swamps. A mangrove belt margins the coastline. Altitude ranges from sea level to 400 ft.

Recent silty alluvium, deltaic sand, and minor fan-glomerate and beach sand, mostly derived from the Musa River, make up the rapidly aggrading deposits of the Musa coastal plain.

A central stable alluvial plain (Momoiogo land system) has stratified silty soil commonly with thick dark topsoil, and tall alluvium forest (Plate 3, Figs. 1 and 2). Adjacent or nearby unstable, lower-lying, alluvial plains (Dove land system; Plate 2, Fig. 1) are mantled with open, irregular alluvium forest and have mostly gleyed, calcareous, stratified soils. They include the present meander tract of the Musa River with tall alluvium forest on the higher levee banks. The alluvial plains lead down to large freshwater swamps (Tortore land system; Plate 2, Fig. 2) with strongly gleyed, fine-textured soils and thin peat, and herbaceous vegetation or swamp woodland often dominated by sago or *Pandanus*. In the north the coast is fringed by a mangrove belt (Bendorodo land system; Plate 1, Fig. 2) with alkaline peat, mud, and sand. Present and prior beach ridges are scattered along the coast (Pawara land system; Plate 1, Fig. 1); the older ridges have gleyed sandy soils with dark topsoils and low to mid-height open forest; swamp woodland covers the intermediate sandy swales.

The plains are fringed by alluvial fans in the west and south. In the west these fans have clayey to gravelly dark brown alluvial soils derived from volcanic rock, and tall fan forest and grassland (Nembadi land system) and gleyed alluvial soils with irregular tall alluvium forest on the most poorly drained parts (Imo land system). The marginal fans in the south are similar but include inactive parts with gleyed texture-contrast soils with low fan forest (Korala land system).

### (*b*) *Musa Basin*

The Musa basin is an intramontane trough lying between the eastern end of the Guaya–Didana Range and the Owen Stanley foothills. A central, westerly-trending, linear strip of plains is surrounded by a series of fault benches in various stages of dissection. Altitude ranges from 360 ft to over 3000 ft.

The central east–west strip of recently aggraded fan-glomerate and alluvium is composed of flood-plain terraces (Gobera land system; Plate 8, Fig. 1) and coalescing alluvial fans with deep alluvial soils (Safia and Liamu land systems; Plate 4, Fig. 1; Plate 12, Fig. 1), stony and calcareous in the east (Ubo land system; Plate 4, Fig. 2) and commonly with thick dark topsoils. The vegetation is mainly tall grassland and tall mixed deciduous fan forest.

At the eastern and western ends of the Musa basin forested Pleistocene and Recent mudflow fans occur in various stages of dissection. Tilted older mudflow fans have strongly weathered dark brown to red clay soils and, at higher altitude, dominantly *Castanopsis* forest (Silimidi and Wowo land systems; Plate 6, Fig. 1). Less-weathered mudflow fans have shallow dark texture-contrast soils and mixed *Araucaria* and low hill forest (Darumu land system; Plate 5, Fig. 2). A recent mudflow tongue, with undifferentiated calcareous soils and mixed *Casuarina* fan forest, occurs on older weathered fan material with tall evergreen fan forest near the Ibinambo River (Ibinambo land system). At the western end of the Musa River the mudflow fans form a complex (Siviai land system), predominantly with deep, acid, weathered, brown clay soils and various types of forest.

Broadly folded Domara River beds of early Pleistocene age form a large part of the Musa basin. These conglomerate, greywacke siltstone, and calcareous mudstone beds have been intermittently uplifted and eroded, giving rise to a series of valley benches which are at present in various stages of dissection. Low hills with gentle and moderate slopes adjacent to the central linear aggrading strip have texture-contrast soils, commonly gleyed, covered with eucalypt savannah (Asaga land system; Plate 4, Fig. 2; Plate 5, Fig. 1). More-dissected higher valley benches form a series of hill ridges either with weakly acid, very shallow soils and eucalypt savannah (Arumbai land system; Plate 6, Fig. 2) or with strong earth flow and undifferentiated colluvial soils in deeply weathered areas with mixed deciduous hill forest (Avikaro land system; Plate 7, Fig. 1). A deeply incised hill block with spectacular cliffs and scree slopes occurs adjacent to the Adau River gorge (Adau land system; Plate 7, Fig. 2).

### (*c*) *Guaya–Didana Ranges*

The Guaya–Didana Ranges form a linear, arcuate group extending across the survey area from north-west to east and represent the eastern end of the Morobe arc. In the north-west, fault-block mountains and a high plateau rise to 5500 ft; in the centre the Sibium Range rises to 7164 ft at Mt. Avena; and in the east the Didana Range rises to just over 4000 ft.

The Morobe arc consists of a large linear batholith of basic–ultrabasic rock, probably of late Cretaceous or early Tertiary age, and at its eastern end it is intruded into Urere Metamorphic rocks which in places are still preserved as roof pendants within it.

The eastern and western parts of the Sibium–Didana Range are made up of forested mountain ridges with shallow, moderately weathered soils (Didana land system). Lower montane forest is developed above 3000–3500 ft. In the centre of this range the altitude decreases and fine-textured hill ridges with very shallow soils and small-crowned hill forest occur (Fiobobo land system; Plate 8, Fig. 1). Variably dissected fans in a series of upland basins in these hills (Boborobo land system) have partly strongly weathered red clay soils and partly undifferentiated alluvial soils with small-crowned hill forest and low fan forest.

A series of mountain blocks on ultrabasic rock on the south side of the Musa basin (Avuru land system; Plate 11, Fig. 1) is included in the Morobe arc. They have very shallow soils and a complex vegetation of eucalypt savannah, mixed deciduous hill forest, and mixed *Casuarina* hill forest. Avuru land system also includes a few small areas of hill ridges in the Owen Stanley foothills.

The north-western part of the Morobe arc is largely an ash-mantled landscape with lowland hill to lower montane forest. It includes mountain ridges with lower concave slopes (Guaya land system) and a hilly high plateau (Owalama land system).

Pleistocene and Recent mudflow and colluvial deposits fill the Kumusi and upper Musa fault troughs on the western margin of the Morobe arc. They are dissected into hill ridges that are heavily ash-mantled, with mainly secondary forest in the north (Kovio land system; Plate 8, Fig. 2) while in the south (Suwari land system) they have strongly weathered red clay soils with mid-slope and *Castanopsis* forest.

### (*d*) *Volcanic Mountains and Plateau*

The volcanic mountains and plateau form a complex group of landscapes in the north of the area ranging from sea level to over 6000 ft. They include a basalt shield volcano and an andesitic strato-volcano both deeply denuded, as well as recent constructional landscapes on basalt lava flows, scoria mounds, and cinder cones. Parts of the footslopes of the active volcano Mt. Lamington to the north and of the dormant volcano Mt. Victory to the east of the area surveyed have been included in this physical region.

Pleistocene and Recent volcanic activity, of basaltic, andesitic, dacitic, and rhyodacitic types, has built up the Hydrographers and Sesaro Ranges and the Managalase plateau. Large parts of these are now denudational landscapes with Recent airborne ash mantles derived mostly from Mt. Lamington volcano.

In the western part of the Managalase plateau accordant parallel low hill crests have a general slope of 1–2°. The less-dissected parts (Tahama land system; Plate 9, Fig. 1) have moderately weathered ash and colluvial soils and tall plateau forest and secondary vegetation. The more-dissected portions (Gorabuna land system) have less ash cover and mainly mid-slope forest. A late Pleistocene–Recent basalt field in the eastern Managalase plateau (Uoive land system; Plate 9, Fig. 2) has moderately to strongly weathered dark soils and tall partly secondary plateau forest. Fan slopes with basalt flows on the eastern margin of the field (Iwuji land system; Plate 10, Fig. 1) have moderately to little-weathered dark residual alluvial and ash soils and mid-height fan forest and eucalypt savannah. A line of dissected dacite cones (Manna land system; Plate 10, Fig. 1) cuts north across the basalt field and has very shallow soils with open mid-slope forest.

The Bariji River is deeply entrenched in the Managalase plateau and is margined partly by a gorge and partly by hill ridges sculptured from the plateau margins. These hill ridges and the gorge, with an upper basalt scarp, have very shallow soils and mostly small-crowned open hill forest (Bariji land system). Forested flood-plains and fan and lacustrine terraces with undifferentiated alluvial soils (Aiare land system) occur along the Bariji River and also in the Kumusi–Musa fault trough along the Guaya Range. South of the Bariji River dissected alluvial fans and boulder cones are partly ash-mantled and have mid-slope forest with dense to scattered *Araucaria* (Sibium land system).

The andesitic strato-volcano of the Hydrographers Range (Hydrographers land system; Plate 10, Fig. 2) is deeply dissected into mountain ridges with acid, shallow and deep red soils and lowland hill to lower montane forest. Some of the strongly weathered lower eastern slopes (planezes) retain the initial form of the volcano (Banderi land system; Plate 10, Fig. 2) and are covered mainly with mid-height grassland and open, partly secondary, mid-slope forest.

The Sesaro basalt shield volcano is also deeply denuded into mountain ridges (Sesaro land system) with stony, shallow, moderately weathered dark soils and mostly small-crowned hill forest.

### (*e*) *Owen Stanley Foothills*

The Owen Stanley foothills occupy the southern part of the area between the high ranges and consist of high hills with scattered mountain ranges of medium height (up to 5000 ft).

Tectonically these foothills make up the Amora block, which consists mostly of broadly folded and altered basalt conglomerate, and altered calcareous mudstone of Mesozoic age.

Mountain ridges of moderate height in the north (Amora land system; Plate 12, Fig. 1) and particularly in the south (Foasi land system) have broad crests with strongly weathered red soils and *Castanopsis* or lower montane forest. An upland basin between these mountains, composed of soft sedimentary rocks, is finely dissected into hill ridges with very shallow soils and mainly eucalypt savannah (Arumbai land system).

Adjacent to this basin and eastwards to the Musa basin mixed deciduous and secondary forest occurs on a series of hill ridges between 1000 and 3000 ft (Aimare land system; Plate 11, Fig. 2). These ridges are very deeply weathered and have undergone strong earthflow giving rise to very irregular slopes and undifferentiated colluvial soils with local, strongly weathered, red soils on old valley-side strips.

### (*f*) *Owen Stanley Ranges*

The Owen Stanley ranges are high rugged mountains at the south-eastern and western edges of the area, which rise to over 9000 ft.

These ranges are a part of the Owen Stanley metamorphic belt, which is made up of strongly folded Palaeozoic phyllite. The Niori Mountains (Misima land system), on the western edge of the area, consist of mountain ridges with straight slopes and undifferentiated colluvial soils. Forests range from lowland hill to lower montane. The Goropu Mountains (Suckling Complex land system), on the south-eastern edge of the survey area, differ in having numerous over-steepened slopes with large-scale slumping (Plate 12, Fig. 2). Montane forest and alpine grassland occur on the higher ridges and summits.

## III. Climate

Apart from five years' rainfall records at Safia Airstrip and two years' records at Sila Mission no climatic data are available for the Safia–Pongani area. The nearest rainfall-recording stations outside the area are Popondetta and Wanigela. The Safia records (Fig. 4) are similar to the longer-term records of Rouna (near Port Moresby), which occurs in a similar topographic position but at somewhat higher elevation on the other side of the Owen Stanley Range.

The low annual rainfall at Safia, as well as the apparently irregular rainfall distribution during the south-east season, are most probably due to the location of Safia near the centre of the low-lying Musa basin. Topography probably controls to a large extent the wide variations in rainfall throughout the area. It is therefore hazardous to extrapolate the climatic data too freely from Safia or Popondetta or

Wanigela. However, there appears to be a good correlation between vegetation, rainfall, and topography. Thus low rainfall at Safia coincides with the presence of extensive areas of grassland, eucalypt savannah, and mixed deciduous forest, as well as with many kinds of little-leached soils. A dry zone (Fig. 5) is therefore delimited in the Musa basin by generalizing from the detailed vegetation mapping and is in accord with topographic conditions. The mean annual rainfall in this dry zone probably ranges from 60 to 70 in. with Safia near the drier end of the range.

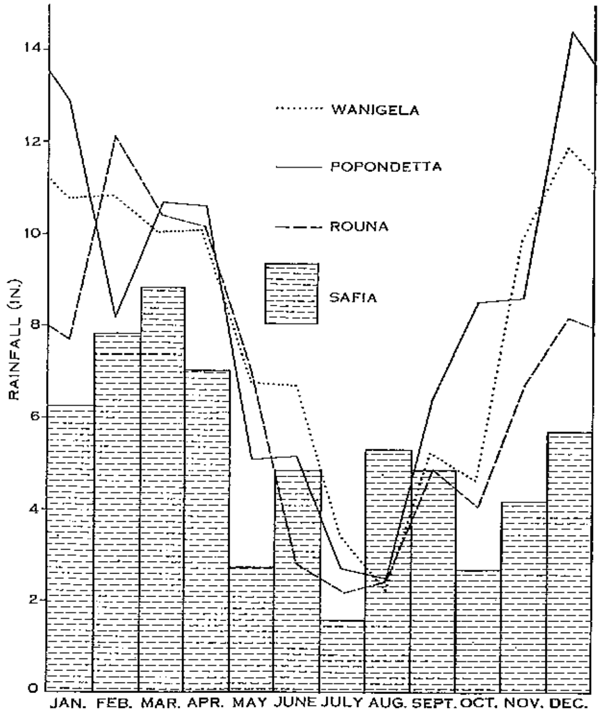


Fig. 4.—Mean monthly rainfall for Safia compared with three stations outside the survey area.

Wanigela—Mean from 7 yr of data; annual mean 92·9 in.
Popondetta—Mean from 5 yr of data; annual mean 96·2 in.
Rouna—Mean from 7 yr of data; annual mean 78·9 in.
Safia—Mean from 5 yr of data; annual mean 62·4 in.

The wet zone (Fig. 5) is delimited mainly on the occurrence of lower montane forest and *Castanopsis* forest which prevail at higher altitudes because of increased exposure, lower temperature, and higher cloud incidence. However, some lower-lying areas, with wet evergreen forests and strongly leached soils, were included in the wet zone. These include the north-west-trending Kumusi–upper Musa fault trough, which receives high rainfall in both the seasons, and Wowo Gap between the Didana Range and the Goropu Mountains. By comparison with similar areas elsewhere in New Guinea the rainfall in this zone is probably mostly between 100 and 150 in.

Mean cloud percentages of 80–90% in afternoons are likely in most of the lower montane zone. The mean annual temperature probably varies from 83°F at 2000 ft to 61°F at 7000 ft respectively, and there is little seasonal variation.

The remainder of the area is considered to have an intermediate rainfall between the wet and the dry zones. The data for Popondetta and Wanigela are probably representative for this intermediate zone in which the rainfall may vary from 70 to 100 in., locally even higher on exposed mountain slopes.

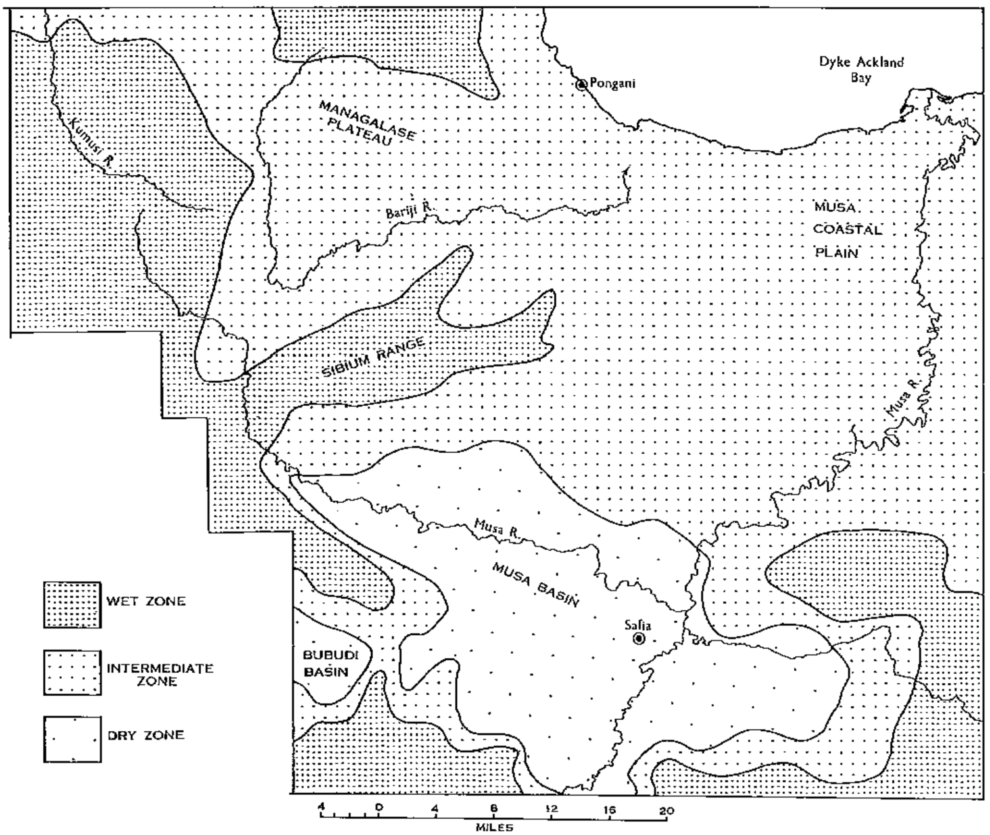


Fig. 5.—Climatic zones of Safia–Pongani area, based mainly on vegetation types.

The open low portions of the coastal plain, especially in the lee of the Hydrographers Range, probably form a drier part of the intermediate zone with high temperature. This is supported by the presence of more deciduous trees than are usually present in the evergreen forest. Eucalypt savannah is common on the lower eastern slopes of the Hydrographers Range and Managalase plateau and indicates a continuation of this drier part of the intermediate-rainfall zone. Diurnal build-up of cloud along the coast may result in higher rainfall in a narrow coastal strip, as in the Buna–Kokoda area (Slatyer 1964).

Slightly wetter and lower-temperature conditions are indicated for the Managalase plateau, as a result of its higher altitude (2000–3000 ft). Deciduous trees gradually die out westwards on this plateau. It is unlikely that the rainfall would be very much higher than on the coastal plain because the plateau is surrounded on three sides by high mountains.

The highest rainfall in the intermediate zone occurs probably on the lower parts of the mountain ranges. Of particular interest is the apparent rapid transition from the dry zone to the wet zone mainly on the south side of the Musa basin. Here, in places, mixed deciduous hill forest occurs adjacent to *Castanopsis* and lower montane forest, and there is probably a very rapid increase of rainfall with increasing altitude in this area.

## IV. Population and Communications

The indigenous population totals approximately 12,600, based on 1963 census figures, resulting in an average density of 4·7 per sq mile, which is well below the average for the whole of Papua and New Guinea. As shown on the population distribution map, by far the greatest density of population is in the western Managalase (4600), in the upper Kumusi valley (1300), and in the north-west coastal strip (1600). Scattered and sometimes very isolated villages occur in the remainder of the area, whilst large parts, notably most of the coastal plain, the eastern Musa basin, and the mountain ranges, are virtually unpopulated.

Present land use is almost confined to subsistence crops grown in shifting cultivation around the population centres. Taro is the main crop. Sweet potatoes are also grown, as well as plantains, particularly in the drier zone of the Musa basin, and yams, locally in the coastal plain. Subsidiary crops are sugar-cane, tobacco, maize, peanuts, papaw, and vegetables. Garden clearings are mostly made in secondary forest and regrowth, infrequently in virgin forest. All gardens are fenced as a protection against roaming wild and domestic pigs. Virtually no gardens were seen in eucalypt savannah and grassland, even in the Musa basin where these types of vegetation occur extensively. Shifting cultivation is practised on a great variety of land forms and soils. The impression was gained that the best gardens occur on well-drained alluvial plains and terraces, on ash soils in Tahama and Kovio land systems, and on steep, often stony, lower hill and mountain slopes.

Sago is important in the diet of coast and swamp dwellers, and serves as a stand-by in many other parts of the area. Potatoes are locally grown at higher altitude. Coconut palms are found in or near most village sites, particularly on alluvial soils and beach ridges. Many galip nut trees (*Terminalia kaernbachii*), apparently producing well, are a feature in Tahama land system.

Cash cropping is in its infancy. A beginning has been made with cocoa and lowland coffee in Tahama land system. Small older coffee plots exist in Kovio land system. Difficult communications are an obstacle to marketing in both cases.

No towns, vehicular roads, or natural harbours occur in this relatively isolated area. Except for an Anglican Mission and a government agricultural extension post at Sila there is no permanent European settlement. Indigenous villages are connected by good government tracks. Rope bridges span the larger rivers in the western part of the area. Grass air strips serve Sila, in the Managalase, and Safia, in the central Musa basin. Considerable stretches of the Musa, Foru, and Yupuri Rivers are navigable to motor launches but coastal bars make ingress either hazardous or possible only at high tide.

## V. Land Use Potential

Some 40% of the lands of the Safia–Pongani area, comprising 1060 sq miles, are well suited for agricultural purposes, and of this 530 sq miles have a high potential either for arable crops, for tree crops and grazing, or for grazing. Another 940 sq miles are not altogether useless or could possibly be reclaimed. The usable land falls mainly into three large areas, the coastal plain, the Managalase plateau, and the Musa basin. For forestry purposes also these are the areas of highest potential. Much of the remaining area is either too steep or is stocked with forests of low yield.

The coastal plain is the most accessible part of the area and a road along the coast from Oro Bay would be desirable prior to any large-scale development. An area of 220 sq miles of alluvial fans and plains in Nembadi and Momoiogo land systems has a high potential for arable crops, tree crops, and grazing. There are minor limitations owing to either poor drainage or stoniness. Access to Momoiogo land system could be readily established by a road from Nembadi and Imo land systems, via Karaisa. Expensive flood-control and drainage measures could increase or create possibilities for agricultural development in a large part of a further 265 sq miles of alluvial plain and swamp land in Imo, Dove, and Tortore land systems. The coastal plain carries much high-yielding tall alluvium forest in its flat centre part, with smaller areas of moderate- to low-yielding forest where drainage is impeded. Parts of the gently sloping fans on the southern and western margin carry forests of variable yield, the highest-yielding forest occurring in Nembadi land system.

On and adjacent to the Managalase plateau, some 230 sq miles of low hills and moderate to gently sloping land in Iwuji, Uoive, and Tahama land systems have a moderate to high potential for tree crops and grazing, but commonly only a low potential for arable crops. Whilst Iwuji land system is easily accessible from the east, 4 miles of very rugged ridge and ravine country separates the remainder of the usable land on the Managalase plateau from the coastal plain. Dense dissection will hinder large-scale development in Tahama land system because narrow strips of good land are separated by very steep slopes. Larger areas of reasonably level land occur in Iwuji and Uoive land systems but commonly have shallower soils.

At least 40% of this area carries forest with a high to moderately high stocking rate, whilst an area of high-yielding mixed *Araucaria* forest adjoins the Managalase plateau in the south (Sibium land system).

The Musa basin is an isolated area with relatively difficult access either by about 8 miles of very steep hilly country rising to 1400 ft across the Didana Range from the coastal plain or by traversing Wowo Gap (2250 ft) at the eastern end of the basin from the coast at Sinapa near Wanigela. Within the basin occur more than 300 sq miles of land with a high to moderate potential for agricultural development. Of these, about 80 sq miles in Safia, Liamu, and Ibinambo land systems are suitable for cultivation as well as for tree crops and grazing, although the irregular rainfall in the centre of the basin may introduce an element of risk for arable and tree crops. Deep and locally dense dissection and strongly weathered soils render 80 sq miles in Silimidi, Siviai, and Wowo land systems best suited for tree crops or grazing, whilst land use is best restricted to grazing because of soil deficiencies in most of 150 sq miles in Gobera, Ubo, Darumu, and Asaga land systems.

Much of the Musa basin has been cleared and apart from some forests on the south-western side, the highest forest potential occurs in the fan and hill forests at the eastern end of the basin near Wowo Gap. A possible road from Wowo Gap to the coast at Sinapa would link this area with the high-yielding forests of the coastal plain south of Sinapa in the Wanigela–Cape Vogel area.

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# PART II. LAND SYSTEMS OF THE SAFIA–PONGANI AREA

By H. A. Haantjens,* K. Paijmans,* and B. P. Ruxton*

## I. Introduction

The land system is a complex mapping unit designed for reconnaissance land resources surveys. It is composed of land units which are not individually mappable at the scale of working, but which are associated in such a way as to produce a characteristic recurring, catenary, or irregular pattern on aerial photographs (Haantjens 1965). The recognition and mapping of land systems is almost wholly based on air-photo interpretation guided by morphogenetic considerations (Mabbutt and Stewart 1963), whilst their description is based on the extrapolation of the limited data collected in the field.

Each land system is defined in terms of correlations between lithology, land forms, soils, and vegetation, which together produce characteristic land features in any given area. None of these factors has in principle an overriding influence on the definition of a land system, although mapping is generally based on differences in land forms or vegetation.

## II. Grouping of Land Systems

Since land systems are complex mapping units of rock, land form, soil, and vegetation, they can be grouped in many different ways depending on the particular objective of the grouping. The small-scale maps for geomorphology, soils, and regional potential for agriculture are examples of such specialized groupings, whilst in Part I the land systems are discussed as components of physiographic regions. In the reference to the land system map, a more general grouping has been used to draw attention to similarities in soils and vegetation as well as in land forms. The 11 groups of land systems have been arranged generally from depositional to constructional to erosional surfaces, from low to high relief, and from low to high altitude. The land systems in each group have been similarly arranged.

### (*a*) *Littoral Plains and Swamps*

Land systems in this group comprise young depositional surfaces of extremely low relief and occur mostly at or close to sea level (altitude up to 125 ft). They are further characterized by strong waterlogging as evidenced in the soils, water-tables, and vegetation. In other respects marked differences exist between the land systems in this group.

### (*b*) *Alluvial Plains and Terraces*

This group comprises unstable and stable flood-plain and terrace tracts, partly subject to regular flooding and characterized by undifferentiated alluvial soils and alluvium forest, locally replaced by tall grassland. Gradients and relief are very low,

* Division of Land Research, CSIRO, Canberra, A.C.T.

but altitude ranges from close to sea level to 1900 ft. With respect to land form, Imo land system comprises lowermost fan slopes rather than flood-plains. Slight soil development is common in the most stable land systems of this group.

### (c) *Alluvial Fans*

This group combines undissected to strongly dissected alluvial fans and fan complexes. Gradients and relief are greater than on the alluvial plains and flooding is virtually absent. There is a wide altitudinal range from close to sea level to 3000 ft. Characteristic soils range from slightly to strongly weathered and are commonly gravelly. The characteristic vegetation includes various kinds of fan forest and hill forest, which is replaced by grassland over large areas.

### (d) *Mudflow Fans*

Land systems in this group are on older, mostly Pleistocene, mudflow deposits that are generally deeply and strongly weathered and are found in varying stages of dissection. Suwari land system is only partly on mudflow deposits. Ranging in altitude from 750 to 4300 ft, these land systems, with the exception of Darumu, are characterized by weakly to strongly acid red and brown friable clay soils and are dominated by forest vegetation, mostly hill forest, but fan forest in Ibinambo land system.

### (e) *Volcanic Lands*

This group includes young constructional volcanic land forms on basalt between 250 and 4400 ft and partly covered with volcanic ash. There is a range of characteristically dark-coloured soils and ash soils. The vegetation pattern is complex owing to the impact of shifting cultivation and to variations in topography and rainfall.

### (f) *Low Hills and Undulating Surfaces*

The two component land systems have been grouped primarily on their similarities in land form, relief, and altitude, which does not exceed 1500 ft. They have marked differences in rock, soil, and vegetation, but soils tend to be rather shallow in both and well-developed forest does not occur in either.

### (g) *Hill Ridges with Hummocky Slopes*

Very strong earth flow on very deeply but immaturely weathered rock is typical in this group, which occurs between 850 and 3100 ft. Undifferentiated colluvial soils and moderately to little-weathered shallow soils are characteristic and support a vegetation of predominantly irregular mixed deciduous hill forest and regrowth.

### (h) *Hill Ridges with Shallow Soils*

This group includes land systems with a hilly to low mountainous relief (altitude up to 5500 ft) and predominantly steep to very steep straight slopes, with very shallow to shallow soils covered with low, usually open, hill forest and eucalypt savannah.

### (*i*) *Ash-covered Hill and Mountain Ridges*

The land systems in this group are all characterized by steep slopes but differ greatly in relief and altitude (350–5500 ft). They have all been mantled with recent andesitic volcanic ash from Mt. Lamington, which has partly been removed by erosion. They are characterized by various kinds of moderately weathered ash soils and largely covered with mid-slope to lower montane forest or regrowth.

### (*j*) *Mountain Ridges with Relic Weathering Profiles*

This group consists of land systems with steep slopes and mountainous relief (altitude up to 6300 ft), having very deep weathering with acid red clay soils on crests and moderately weathered to undifferentiated soils on the side slopes. They are covered with mid-slope to lower montane forest.

### (*k*) *Mountain Ridges with Immature Weathering*

This group comprises the steepest and highest mountain land systems in the area, with crestal altitudes between 4000 and 9000 ft. They have undifferentiated colluvial soils and moderately weathered shallow soils and are covered with mid-slope to montane forest.

## III. Assessment of Land Use Capability

In the land system descriptions the agricultural potential of each land unit has been assessed in terms of land classes defined in Appendix III. By relating these land classes to the proportion and distribution of the land units in each land system, a generalized statement can be made about the land use capability of each land system as a whole. To these assessments of land systems, as listed below in alphabetical order, have been added brief remarks on accessibility, natural forest resources, and possibilities for land reclamation. For a proper appreciation of the assessments it must be remembered that they have been made without any consideration of the size of the land systems. Thus, for the purposes of broad development planning, a highly rated but small land system could be of less importance than a large land system with lower land use capability.

*Adau Land System*.—This land system is unsuitable for any form of land use. Its scenic features would be of value in any development of a tourist industry in the area.

*Aiare Land System*.—Most of this land system is good land, suitable for arable and tree crops and grazing, commonly with minor to moderate limitations due to stoniness, erosion hazards, or poor drainage. Thus pasture appears to be the most suitable crop in parts of land units 1, 3, and 4. The scattered distribution of this land system is an obstacle to its development, particularly because it is mostly surrounded by rugged hilly country. Many areas have moderate- to high-yielding forest resources.

*Aimare Land System*.—Pockets of arable land with moderate erosion hazards in land units 1, 3, 4, and 5 (the last on apparently strongly leached soils) are so scattered and generally so small that they cannot form a basis for development. Land use should generally be restricted to grazing and tree crops under careful management, and to forestry, whilst considerable areas with very steep slopes (land units 2, 6, parts of 1 and 3) should be left under protection forest. Pastures or forestry are probably to be preferred above crops because of the relatively low rainfall, commonly rather shallow soils, the great irregularity of the terrain, and rather unstable slopes. The land system comprises many large and small stands of forest with a medium stocking rate, locally enriched by scattered *Araucaria*. Mixed *Araucaria* forest of high stocking rate occurs in land unit 3. Access will be a major problem in this area, not only because of its isolated position and rugged topography, but also because road construction may involve serious landslide hazards.

*Amora Land System*.—This land system is generally too rugged for development. Locally occurring areas with more gentle slopes (land unit 2) have soils that appear to be physically less suitable for tree crops than for grazing under careful management or for forestry. Small flattish crestal areas (land unit 3) are virtually inaccessible, whilst road construction would be a major general problem throughout the area. However, an access road to the northern slopes would pose no difficulties once the Musa basin has been opened up. There are extensive forest resources of moderate stocking rate, locally increased by *Araucaria* stands. Protection forest should be maintained over most of the land system, which forms an important part of the catchment area of the Musa River.

*Arumbai Land System*.—As a whole this land system comprises very poor land unsuitable for any agricultural development, except possibly extensive grazing under careful management on parts of land unit 1 and on land unit 2. Only the scattered pockets of land units 3, 4, and 6 are suitable for more intensive occupation, mostly for pastures. There are no timber stands of any significance and reafforestation would be difficult.

*Asaga Land System*.—Physically poor soils, in combination with rather low rainfall, appear to restrict land use capability to grazing, for which the topography is well suited except for the steepest slopes (land unit 4), which should preferably be kept in forest or reafforested. Careful management in grazing is required to improve pastures and prevent erosion, to which the soils appear to be very susceptible. Only limited drainage improvement appears feasible on low-lying flats (land unit 6). Access is poor at present, but would generally not present great problems once the Musa basin is opened up, except for the major project of a Musa River bridge to the northern part of the land system. There are no forest resources.

*Avikaro Land System*.—This land system has no arable land apart from small pockets with erosion hazards or physically poor soils (land units 1, 3). Because of highly irregular and mostly steep slopes, commonly rather shallow soils, and a rather low rainfall, the land use capability appears to be limited to grazing and forestry, with many very steep slopes (part of land units 1, 2) only marginally suitable for pasture development. Great care would be required to prevent erosion caused by overgrazing and there is a risk of damage by soil slumping and landslides. The irregular topography and commonly unstable slopes would tend to make internal access and road construction difficult. As large-scale erosion might lead to some disturbance in the potentially more productive lower parts of the Musa basin, land use is probably best restricted to forestry. Forest with moderate stocking rate covers about half the area and is locally enriched by scattered *Araucaria*.

*Avuru Land System*.—Although a large proportion of the land system (land units 2, 4, 5) would be suitable or marginal for grazing under careful management, the difficult access to these higher parts makes development most unattractive, the more so because the generally shallow soils do not appear to be suitable for tree crops. Lack of access will similarly prevent the exploitation of the low to moderate stocking rate forest occurring locally in land units 2 and 5, whilst reafforestation of the very steep lower slopes (land units 1, 3) may prove difficult. This land system offers virtually no prospects for development.

*Banderi Land System*.—Areas with deeper, strongly leached soils (land unit 2, small part of 1) are moderately suitable for tree crops, areas with shallow and locally stony soils (large part of land unit 1) for grazing. Soil fertility appears to be very low and land use potential may be further limited by rather low rainfall. Very steep dissection slopes (land unit 3) are best left under forest cover. There are only insignificant forest resources. The land system is accessible from the coast.

*Bariji Land System*.—This land is unsuitable for agriculture and forestry and should be left under protective forest. It forms a considerable barrier to access to the southern Managalase via the Bariji River valley.

*Bendorodo Land System*.—This land system is not only unsuitable for agricultural development in its present state, but because of the small tidal range and unfavourable soil conditions it is also very difficult and unattractive for land reclamation. It forms a considerable barrier to access inland from the coast. The mangrove forest would generally return low yields, the best potential occurring in narrow bands along tidal creeks and in the Musa River delta.

*Boborobo Land System*.—Approximately one-third of the area consists of arable land, mostly with minor to moderate limitations because of stoniness (land units 2, 3), erosion hazard (land unit 3), or minor flooding (land unit 2). About half of the area is too steep for cultivation (land unit 1) but appears suitable for grazing or tree crops, the latter being favoured in view of the deep, strongly leached soils. Dense dissection would make management rather difficult. A small proportion of the land has physically poor soils (land unit 4) and is suitable only for grazing, probably with problems involved in the establishment of improved pastures. Small swampy areas (land unit 5) have virtually no land use capability, although reclamation may not be too difficult. As most of these land types appear to occur in intricate patterns, the development of mixed farms may be the most appropriate form of land use. Present access is poor and any access roads would need to pass through stretches of steep mountains or hills that completely surround all occurrences of this land system, which is mainly forested with low-yielding forest types. Areas of moderate-yielding forest do occur.

*Darumu Land System*.—This land system is mostly suitable for grazing only, because of physically poor soils and erosion hazards. The land can be expected to respond well to careful pasture management, which should take into account the rather low rainfall. The steep dissection slopes (land unit 3) should be left under protection forest, and form an obstacle to access to the less steep land on top from the Ubo land system plains to the south. Forest resources include important stands of *Araucaria* of high stocking rate.

*Didana Land System.*—This land system must be considered unsuitable for agricultural development. The small crestal areas that could be used for tree crops (land unit 2) are inaccessible. Being an important part of the Musa River catchment area, the land system should be kept under protection forest. Forest is difficult of access and generally of low stocking rate, except for small stands of scattered *Araucaria.*

*Dove Land System.*—Land use potential is seriously restricted by poor drainage and flooding. As flood protection of the present Musa lobe is impracticable (it could be achieved only by complete diversion of the river through man-made channels to the swamps to the east and west), dry-season grazing appears to be the principal agricultural possibility on land units 2, 5, and parts of 1 and 3, with some potential for quick-growing arable crops and coconut palms on the drier levees of land unit 2. Away from the Musa River, flooding is a less serious but poor drainage a more important hazard on the back plains (land unit 1). This limits land use to dry-season grazing and rice-growing under natural or semi-controlled flooding. Drainage control appears to be possible only in large-scale projects but would greatly increase the productivity of this land. Throughout the land system the calcareous, alkaline nature of the soils may prevent the successful cultivation of some arable and many tree crops, but may favour certain leguminous crops and pastures. Forest resources are mainly of moderate to low yield (land unit 1), with some high-yielding forest in land unit 2.

*Fiobobo Land System.*—Most of this land system has virtually no land use capability and should be kept under protection forest, particularly because it constitutes an important part of the catchment area of the Musa River. Limited possibilities for grazing under careful management on physically rather poor soils exist in land units 2, 3, and 5, particularly where these form rather large complexes between the Nuaro basin and the Musa River. Access to this part of the land system would be easiest from the coastal plain to the north, because the bridging of the Musa River to the south would be a major project. Forest resources are extensive, but generally of very low quality.

*Foasi Land System.*—Broad crestal areas (land unit 2) and convex slopes (land unit 3) with deep but strongly leached soils could be used for tree crops suitable to the high elevation of this land, with similar possibilities on small foot-slope areas with little-leached soils (land unit 4). However, more than half of the land system is too rugged for any form of development and should be left under protection forest, making access to the more productive land units very difficult. Access problems are aggravated by the very isolated location of the land system. Areas suitable for land use carry forests of moderate stocking rate, locally increased by the presence of *Araucaria.*

*Gobera Land System.*—Because of flooding, poor drainage, or gravelly soils, this land system is generally suitable only for pastures, with limited possibilities for drainage improvement on the back plains (land unit 2). There are a few square miles of first-class land on the higher non-flooded parts of land unit 1, with a potential for arable and tree crops. There are no forest resources.

*Gorabuna Land System.*—The great preponderance of very steep slopes renders this land system virtually useless for permanent agricultural development. There may be limited possibilities for forestry, particularly after development in the western Managalase (Tahama land system) or on the south-western slopes of Mt. Lamington, which would make parts of this land system more accessible than at present. Forests of moderate to high stocking rate cover at least half of the land system.

*Guaya Land System.*—In spite of deep friable soils, land use potential is severely restricted by the steep slopes and dense dissection, which cause serious erosion hazards and strongly reduce accessibility. Small-scale development for tree crops may be possible in land units 2 and 5. These land units, carrying a forest of moderately high stocking rate, would also be the most suitable for forest exploitation. Generally speaking, the land system should be kept under protection forest, as it forms an important part of the catchment area of the Kumusi River.

*Hydrographers Land System.*—This rugged mountainous land has no land use capability, with the possible exception of some timber extraction from moderate- to high-yielding forests on the lower southern spurs (land units 5 and 6). It is best left under protection forest because it includes an important proportion of the headwaters of the Mamama and Pongani Rivers.

*Ibinambo Land System.*—In view of the scarcity of data, assessment must remain tentative. A large part of the land system appears to consist of good land, suitable for many forms of land use. The wet climate, deep, friable, but probably easily erodable soils, and the probable presence of many small dissection gullies would tend to favour its use for tree crops. The calcareous and probably very stony recent deposits (land units 2 and 3) are suitable only for grazing (probably mostly with little possibility of pasture improvement) or forestry. Virtually inaccessible at present, the land system could be simply linked to any future road system in the adjoining Ubo land system. It is completely forested with mainly high-yielding, tall, evergreen fan forest and mixed *Casuarina* fan forest.

*Imo Land System.*—This land is suitable for grazing (land unit 3 also for a limited range of crops) except during the wettest part of the year. Flood protection and drainage control appear to be difficult. It would, however, yield fertile land suitable for many types of agricultural production, except land unit 2, where very clayey soils could probably be used only for pasture, irrigated rice, and a limited range of arable crops. Forest resources of moderate to low yield are present, particularly in land unit 3.

*Iwuji Land System.*—Very limited data indicate that the land system consists largely of arable land with minor to moderate limitations due to erosion hazard and droughty soils. The locally shallow soils tend to be less favourable for tree crops, but grazing appears to be a very good alternative form of land use. Small very stony areas (land units 3 and 4) are best left unoccupied. The land system is readily accessible from the coast. Approximately half of it is covered with forest of moderate stocking rate.

*Korala Land System.*—Physically very poor (land unit 1) or very gravelly and stony soils (land unit 4) render the largest part of this land system suitable only for grazing, probably with problems involved in the establishment of improved pastures. Arable land with moderate limitations due to flood hazards that can probably be controlled by simple improvements of stream channels or due to stoniness occurs respectively in land units 3 and part of 2, the remainder of the latter being suitable only for pastures or tree crops. Forests with moderate to high stocking rate occur on about half of the land system.

*Kovio Land System.*—This land system is generally too steep or only marginally suitable for tree crops, with some good tree crop and local arable land on gentler slopes (land units 3 and 4). The strong transverse dissection renders access from the Kokoda–Popondetta road very difficult. There are limited forest resources of moderate to high stocking rate.

*Liamu Land System.*—This land system largely comprises very good land for a variety of uses, with locally only minor erosion hazards (land unit 4, part of 2). Small, very gravelly, active fans (land unit 3) would be best used for forestry purposes. The rather irregular rainfall would slightly favour pastures and tree crops above arable crops. Access is rather difficult as this land system occurs in an intramontane basin. There are mainly high-yielding forest resources throughout most of the area.

*Manna Land System.*—Generally unsuitable for any form of land use, this rugged land system forms a considerable barrier to access to the Managalase from the coast. Even the least steep slopes (land unit 3, part of 1) are only marginal for forestry, but if access is improved by the construction of a road from the coast to the Managalase, the proximity of the land system to the coast may make local forest exploitation profitable. Approximately 80% of the area is covered with forest of moderate to low stocking rate.

*Misima Land System.*—This land system is unsuitable for agriculture or forestry. As a most important catchment area for the Kumusi and Musa Rivers it should be maintained under protection forest.

*Momoiogo Land System.*—Most of this land system (land units 1, 2, 4) appears very suitable for arable cropping and pastures, although land drainage will commonly need to be somewhat improved by means of shallow trenches. The silty nature of the soils may lead to tillage problems unless the organic matter level in the topsoils is maintained or raised. The calcareous nature of many subsoils may pose problems in the cultivation of tree crops. Flood hazards may limit the safe use of land unit 3 to pastures, but generally they appear to be not serious and flood control can probably be easily effected by improving the drainage channels. The area near Embessa (land unit 6) is suitable only for grazing or certain tree crops (coconut palms), but forms a natural site for a settlement. The provision of good water during the dry season may present problems in this land system. The prior channels constitute a possible source of ground water and other sandy aquifers may be present. The ground water is probably very hard. There is a notable lack of road-surfacing materials. The land system carries a large area of forest of high stocking rate, both for commercial exploitation and for local requirements.

*Nembadi Land System*.—This land system is in the most accessible part of the area and comprises mostly good agricultural land for a variety of uses with locally minor limitations due to poor drainage or stoniness. However, most land in land units 3–5 is suitable only for grazing, due to poor drainage (which probably cannot be easily improved as it results from seepage), stoniness, and flooding or droughtiness. The small stands of forest are high-yielding and include areas of dense *Octomeles sumatrana*.

*Owalama Land System*.—Very steep slopes, isolated position, difficulty of access, and apparently very wet, cloudy climatic conditions combine to render this land system virtually unsuitable for development, with the possible exception of the exploitation of forest resources of moderate yield, predominantly in the south, where access could be gained once the Managalase area is opened up. Careful management is required to prevent erosion, for the land system contains important headwaters of the Kumusi, Mamama, Bariji, and Musa Rivers.

*Pawara Land System*.—Very sandy soils and poor drainage render this land system unsuitable for arable crops and most tree crops, with the notable exception of coconut palms in land units 1 and 4. The inland beach ridges (land units 1 and 3) appear to be suitable for grazing but the many swampy swales (land unit 2), which would be difficult to drain, make access difficult. There are no forest resources.

*Safia Land System*.—There is much very good arable land, but locally with minor to moderate limitations due to droughtiness (land units 1 and 2), poor drainage (land unit 3), or tillage problems on heavy clay soils (land units 1 and 5), whilst small gravelly or stony patches (land units 1 and 2) can be used only for grazing. The irregular and rather low rainfall tends to be a smaller limitation for pastures and tree crops than for arable crops. Access is rather difficult due to the location of this land in an intramontane basin. There are only very small areas of high-yielding forest.

*Sesaro Land System*.—This land system is unsuitable for development. Preservation of the present forest cover is necessary to maintain stability of the Imo River, whose catchment is virtually confined to this land system.

*Sibium Land System*.—Because of strong dissection the land system is on the whole best used for forestry. It is largely covered with high-yielding forests (commonly containing much *Araucaria*), and partly with moderate-yielding forest. The flatter areas of land unit 2 would also be suitable for agriculture, mainly tree crops and pastures. At present access to the land system is very poor but this could be improved once the southern Managalase was opened up.

*Silimidi Land System*.—Although a large part of the land system is suitable for cultivation, mostly with moderate erosion hazards, or for tree crops and pastures (land units 1 and 3), farming operations and access will be hindered by its steep dissection (land units 2 and 4). The deep, but probably nutrient-deficient and erosion-susceptible soils tend to favour tree crops even on the flatter areas. The considerable range of altitude, which appears to be associated with a rather wide range in rainfall, would require different crops in upper and lower parts of the land system. Of the large areas of forest the *Castanopsis* forest in the higher parts has a moderate stocking rate, the tall plateau forest and mixed deciduous forest a high and a moderate stocking rate respectively. Protection forest should be maintained on steep slopes.

*Siviai Land System.*—Approximately half of this land system (land units 1, part of 4 and 6) appears suitable for arable crops, with minor to moderate limitations due to erosion hazard and stoniness. As the soils are deep but strongly leached and the flatter areas are commonly interspersed with steep dissection slopes, tree crops are probably the most suitable form of land use and virtually the only one in land unit 3. The steepest slopes (land units 2 and 5) and valley tracts (land unit 7) have either no land use capability, or are suitable for forestry and marginal for tree crops. Dissection would hinder internal communications whilst the isolated position in the extreme west of the Musa basin will act as a deterrent to early development. There are limited forest resources of moderately high-yielding hill forest (land units 2 and 3) and some moderate-yielding fan forest (land unit 1).

*Suckling Complex Land System.*—This land system not only offers no possibilities for agricultural or silvicultural development, but the possibility of the occurrence of catastrophical landslides can be considered a potential danger for the low-lying lands of the eastern Musa basin. Its scenic features could make Mt. Suckling an asset in any development of a tourist industry.

*Suwari Land System.*—Although the ridge crests with deep but strongly leached soils (land unit 2) would be topographically suitable for tree crops and locally even for arable crops, and some of the steeper side slopes (land unit 1) can be considered marginal for tree crops, there appears to be little real potential for development along these lines, because of the generally rugged nature of this hill country. Forestry is probably the most appropriate form of permanent land use. The land system occurs in an isolated part of the area and access cannot be easily improved. It is mainly forested with moderately high-yielding foothill and mid-slope forest and smaller areas of low-yielding small-crowned hill forest, moderate-yielding *Castanopsis* hill forest, and high-yielding mixed *Araucaria* forest. Scattered *Araucaria* occurs in all forest types, increasing their yield.

*Tahama Land System.*—Although nearly one-third of the land system (land units 2, 4, and 5) consists of arable land with minor to moderate erosion hazards, and a further 5% of steeper land in land unit 2 is very suitable for tree crops, large-scale development will be handicapped by the dense dissection, which results in narrow strips of good land separated by very steep slopes (land units 1 and 3) that are best kept under forest cover. This situation tends to favour tree crops as the principal form of land use, for which the volcanic ash soils also appear to be very suitable. The parallel ridges make for good north–south communications, but present serious difficulties in east–west road construction, particularly in the northern and central parts. The present poor access to the area can be improved only by road construction through rugged terrain, involving long stretches between Mt. Lamington and Hydrographers Range for a road to Popondetta, a much shorter distance for a road to Pongani. Rather large areas of forest of high stocking rate occur in the north-west, pockets of forest of moderate stocking rate elsewhere.

*Tortore Land System.*—Apart from small sago resources and possibilities for rice-growing under conditions of natural or semi-controlled flooding in land units 3 and 4, this land is unsuitable for occupation. Because of its low topographic position land reclamation would be very difficult. In land unit 2 this would also involve blocking of the Musa River break-through and protection by levee banks against Musa flood water. Such reclamation would yield fertile land, but the predominantly very clayey nature of the soils would probably limit land use to grazing and a small variety of arable crops, such as rice and sugar-cane. This applies in particular to the permanent swamps (land unit 2), which are also the most difficult to drain. There is no forest except for some stands of sago in land unit 3.

*Ubo Land System.*—Although level, much of this land is too stony for cultivation or too poorly drained for arable and tree crops. The very calcareous, alkaline soils (combined in land unit 4 with rather poor drainage) are a further hazard for most tree crops throughout the land system and would probably limit the variety of arable crops that can be grown in land unit 4 and parts of 1 and 2. The rather low rainfall in the western and central parts may also constitute a hazard to tree crops. On the other hand, this land system, with the exception of land units 5 and 7, appears to be very suitable for pastures, although some drainage improvement would be necessary in areas with strong seepage (land unit 3). Irrigated rice would be a good alternative on poorly drained land units 3 and 4. Access is difficult at present but could be greatly improved by a road link with Collingwood Bay through the Wowo gap to the north-east. Approximately 50% of the land system is forested with mainly high-yielding forest with much *Casuarina* in land unit 5.

*Uoive Land System.*—Besides small areas of very good level land (land unit 6), there is much arable land with minor to moderate erosion hazards (land units 1, part of 3 and 4) that is also suitable for pastures and tree crops. Strongly acid soils may pose special fertility problems in parts of land unit 1, whilst compact or relatively shallow soils may locally prove a disadvantage for tree crops. The remainder of the land system is too steep for cultivation and partly suitable only for extensive grazing and forestry because of shallow stony soils (land units 2 and 9, locally 1), or also suited to tree crops (land units 3, 4, and 7). A practical problem in the utilization of much of the arable land lies in its scattered distribution and close association with steep slopes. A large proportion of the land system is therefore probably best used for tree crops and grazing. Access is difficult because a belt of very rugged hills (Manna land system) separates it from the coast. Forest of moderate to high stocking rate covers land units 2 and 7 and a considerable proportion of land unit 1.

*Wowo Land System.*—Although there are theoretical possibilities for cultivation on crests (land unit 2) and foot slopes (land unit 4), strong dissection, commonly steep slopes, deep but mostly strongly leached soils, and high rainfall tend to make tree crops the most suitable form of land use, whilst the steep lower slopes (land unit 3) should be left under forest cover. Internal access is very difficult, but much of the land system would be adjacent to any road from Collingwood Bay to the Musa basin. The whole land system is covered with forest of generally moderate, locally high stocking rate, particularly where *Araucaria* is present.

## IV. Correlation with Adjoining Areas

The location of the Safia–Pongani area between two other areas surveyed many years previously makes it necessary to consider in some detail the correlations between land systems in the three areas (Fig. 1).

In view of the progress made in survey techniques in the last decade, it seemed desirable to carry out land-system mapping in the Safia–Pongani area largely independently of what had been done in adjoining areas. However, in some instances there was every reason to continue land systems previously named in the Buna–Kokoda or Wanigela–Cape Vogel areas into the present survey area under the same names, even though they have been redescribed on the basis of the new information obtained. These land systems are:

| Buna–Kokoda Area | Wanigela–Cape Vogel Area |
|---|---|
| Hydrographers | Tortore |
| Misima | Dove |
| | Didana |

The planezes of the Hydrographers Range have been distinguished as a separate land system (Banderi) in the Safia–Pongani area, but were included with Hydrographers land system in the Buna–Kokoda area. Similarly, small parts of Uiaku land system of the Wanigela–Cape Vogel area, occurring at the foot of the Didana Range, have been mapped separately in the Safia–Pongani area as Korala land system.

In three cases the same land system has different names in adjoining areas. Small northern extensions of Guaya land system were mapped as Oivi land system in the Buna–Kokoda area. Oivi land system should be amended to restrict its occurrence to the Kokoda fault trough. The eastern part of Bendorodo land system has been wrongly mapped as Killerton land system in the Wanigela–Cape Vogel area. Killerton land system should be restricted to mangrove swamps east of the Kopwei River. The transition between Bendorodo land system in the Safia–Pongani area and Killerton land system in the Buna–Kokoda area is vague. The description of Bendorodo land system is based on the large mangrove swamps east of Songada, which differ from the small occurrences often associated with coral limestone in the Buna–Kokoda area.

The northern foot slopes of the Suckling Complex land system were included with Maneau land system in the Wani gela–Cape Vogel area.

Small southern extensions of the following Buna–Kokoda land systems have been mapped but have not been described in the Safia–Pongani area: Lamington, Hamamutu, Higatura, Awala, Amboga, and Warisota. In order to round off the map, a similar procedure was followed with one land system of the Wanigela–Cape Vogel area (Sesegara). For a description of these areas the reader is referred to the earlier reports (Haantjens *et al.* 1964*a*, 1964*b*).

Since the Safia–Pongani area essentially includes the whole of the lower Musa River, some overlap in mapping with the Wanigela–Cape Vogel area has been necessary in order to present a balanced map. The consequences of this for calculating areas of land systems occurring both in the Safia–Pongani and Cape Vogel areas have been stated in the descriptions of the land systems concerned.

In many cases land systems in the three adjoining survey areas possess similar affinities to those used in the grouping of the land systems in the Safia–Pongani area. All land systems with related counterparts in one or both of the other two areas, including the special cases discussed above, have been listed in Table 1, following the numerical order of the Safia–Pongani land systems.

TABLE 1

CORRELATION OF LAND SYSTEMS OF THE BUNA–KOKODA, SAFIA–PONGANI, AND WANIGELA–CAPE VOGEL AREAS

Land systems listed in each row have closely or broadly similar characteristics

| Buna–Kokoda Area | Safia–Pongani Area | Wanigela–Cape Vogel Area |
|---|---|---|
| Buna | Pawara | Buna |
| Killerton | Bendorodo | Killerton |
| Ambi | Tortore | Tortore |
| Deunia, Sageri | Imo, Dove, Gobera | Uiaku, Dove |
| Ilimo | Aiare, Liamu | |
| | Ubo | Uiaku |
| Ioma | Ibinambo, Siviai | Rakua |
| Komondo | Wowo | |
| *Mt. Green* | *Suwari* | *Budi* |
| Lamington | Uoive | Victory |
| | Asaga | Tokinawara |
| Hydrographers | Banderi | Bekalama |
| | Manna | Sesegara |
| | Adau | Tama |
| | Arumbai | Bewabewa |
| Hegahorte | Fiobobo | |
| Kokoda | Kovio | |
| Botue | Owalama, Guaya | |
| Hydrographers | Hydrographers | Trafalgar |
| | Didana | Didana |
| Misima | Misima, Suckling Complex | Maneau |
| Hamamutu, Higatura | | Kwin |
| Popondetta | | Wanigela |
| Amboga, Sananda | | Kopwei |
| Warisota | | Ismari |

## V. Explanatory Notes on Land System Descriptions

### (*a*) *Area, Altitude, and Relief*

Areas of land systems have been determined on a 2 miles to 1 inch map with a dot grid with 25 dots per sq in. The altitudinal range given refers to the lowest and highest levels of the land system in the area mapped, whereas the relief range refers to the minimum and maximum amplitude of relief within the land system when measured in areas not exceeding 1 sq mile.

### (*b*) *Block Diagrams and Plans*

The block diagrams and plans are composite diagrams made from a combination of typical forms or patterns in each land system, and the land units are not necessarily shown in their correct proportion. They are drawn to different scales and each block diagram has both the horizontal and vertical scale indicated on it. Where vertical sections are shown beneath the plans they have been modified from levelling survey data.

### (*c*) *Land Units*

The land unit description below the block diagram or plan gives a brief systematic correlation between land forms, soils, vegetation, and land classification.

The number of field observations mentioned in this section is only partly a measure of the reliability of the land system description. Obviously fewer observations are needed in a simple than in a complicated land system to give the same degree of reliability.

Areas of land units given are estimates only. The commonly uneven distribution and/or difficulty of recognition of individual land units on aerial photographs makes the application of simple statistical sampling methods to determine the areas almost impossible.

Soils are indicated only by their great group number and family name. Information about the soils listed can be easily obtained by referring to Part V (particularly Tables 4 and 5 and Figs. 10–14). The land class symbols are explained in Appendix III.

### (*d*) *Geomorphology*

Slope lengths are standardized as: short, $<500$ ft; medium, 500–1000 ft; long, 1000–2000 ft; and very long, $>2000$ ft. Slope declivities are standardized as: gentle, 2–6°; moderate, 6–15°; steep, 15–30°; very steep, 30–45°; precipitous, 45–70°; and cliffs, greater than 70°. Very gentle slopes, measured by levelling surveys, are given as gradients, otherwise they are expressed in degrees and minutes.

The degree of weathering is here termed skeletal, immature, or mature according to the dominance, abundance, or paucity, respectively, of rock fragments and unstable minerals in the weathered debris. The depth of weathering is termed shallow, deep, and very deep when it extends from 0 to 10, 10 to 50, and more than 50 ft, respectively. The base of the weathering profile is taken arbitrarily as the depth at which fresh bed-rock greatly predominates (i.e. is more than 80%).

### (*e*) *Soils*

Soil depth to the C or D horizon in residual soils has been indicated as follows: very shallow, $<12$ in.; shallow, 12–20 in.; rather shallow, 21–30 in.; moderately deep, 31–44 in.; deep, $>44$ in. This subdivision into five depth categories allows more detailed descriptions than the threefold subdivision in Part V.

Soil acidity descriptions are based on the following pH classes: strongly acid, 4–5; acid, 5–6; weakly acid, 6–6·5; neutral, 6·5–7·5; alkaline, 7·5–8·5; strongly alkaline, 8·5–9. Soils are described under these terms on the basis of their dominant pH. Some horizons may have slightly lower or higher pH.

The term gleyed is used to indicate the presence of mottles and/or grey colours that appear to be the result of temporary or permanent waterlogging.

The term thick dark topsoil refers to black, very dark brown, very dark grey, very dark grey-brown, and rarely to dark brown colours, normally in the top 10 in. or more, but 6 in. or more in alluvial soils and 4 in. or more in very shallow soils.

The term coarser-textured surface horizon applies to horizons at least 5 in. thick and at least one texture class coarser than the underlying horizon (clay over heavy clay, clay loam over clay, etc.). An abrupt texture change is *not* implied.

### (*f*) *Drainage Status*

The drainage status has been evaluated from slope, soil, vegetation, and climate characteristics, with emphasis on soil and vegetation properties in which drainage status is most directly expressed.

Excessively drained indicates a lack of soil moisture arising during rainless periods even of normal duration in relation to the local climatic conditions. Some deep sandy soils are probably excessively drained only in regard to shallow-rooting crops.

Well drained indicates the absence above 4 ft depth of any features pointing to waterlogging, coupled with a sustained supply of soil moisture during rainless periods of normal duration in relation to the local climatic conditions.

Imperfectly drained indicates either permanent slight waterlogging of the deeper subsoil due to seepage or slow permeability, or shallow waterlogging for short periods after heavy rains or floods. Dry-season water-tables are nearly always below 4 ft depth.

Poorly drained indicates either permanent waterlogging of the subsoil due to seepage or slow permeability, or waterlogging of most of the soil for relatively long periods due to seasonally high water-tables or frequent or prolonged flooding.

Very poorly drained indicates permanent waterlogging except in the topsoil. Water-tables between 2 and 4 ft depth are common and may rise to the surface during the wettest periods. In some cases very poor drainage is due to perched water-tables on slowly permeable substrata.

Swampy indicates permanent waterlogging of the whole soil, with water-tables at or close to the surface even during the dry season.

## VI. References


Haantjens, H. A. (1965).—Practical aspects of land system surveys in New Guinea. *J. trop. Geogr.* **21**, 12–20.

Haantjens, H. A., Fitzpatrick, E. A., Taylor, B. W., and Saunders, J. C. (1964*a*).—General report on lands of the Wanigela–Cape Vogel area, Territory of Papua and New Guinea. CSIRO Aust. Land Res. Ser. No. 12.

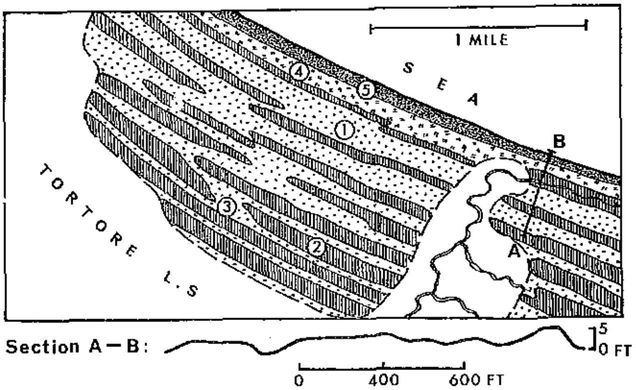
Haantjens, H. A., Paterson, S. J., Taylor, B. W., Slatyer, R. O., Stewart, G. A., and Green, P. (1964*b*).—General report on lands of the Buna–Kokoda area, Territory of Papua and New Guinea. CSIRO Aust. Land Res. Ser. No. 10.

Mabbutt, J. A., and Stewart, G. A. (1963).—The application of geomorphology in resources surveys in Australia. *Revue Géomorph. Dyn.* **14**, 97–109.

## (1) Pawara Land System (4 sq miles)

Low beach ridges and swales along the coast.

Altitude.—0–6 ft.




Land Units (8 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 1·5 | Wide beach ridges | 13, Kaevi | Mid-height to tall grassland and beach forest | II–IIId |
| 2 | 1 | Swales | 4, Abimboro | Sago and *Pandanus* swamp woodland; locally *Phragmites* | VIId |
| 3 | <1 | Narrow degraded beach ridges | 9, Feroroda | Beach forest | Vd |
| 4 | <1 | Present beach ridge | 5, Pawara | Mixed herbaceous vegetation; beach forest | $VIIs_1, s_2$ |
| 5 | <1 | Present beach | Dark beach sand | Bare ground | VIII |

Geology.—Recent littoral sand.

Geomorphology.—Littoral plains: a series of long parallel sand ridges 200–300 ft wide and up to 2–4 ft high near the coast (1), becoming narrower and lower inland (3), separated by swampy swales 50–200 ft wide that descend to 1 ft below mean sea level (2). At the coast the present beach is gently concave, up to 80 ft wide (5), and leads up to a beach ridge (4) 100–200 ft wide and 2–5 ft high. Very minor coral headlands occur near Pongani.

Soils.—Dark sandy soils occur throughout. Undifferentiated neutral sands with only minor development of a weakly acid dark topsoil are found on the frontal beach ridge (4); they merge into slightly more developed weakly acid and browner sands with a thick dark acid sandy loam to loamy sand topsoil on older ridges behind the coast (1), and into weakly acid to neutral gleyed sands with thick dark sandy clay loam topsoils on low degraded beach ridges (2). Weakly acid to neutral strongly gleyed sands with a thin peaty or clayey surface horizon occupy the swales (3).

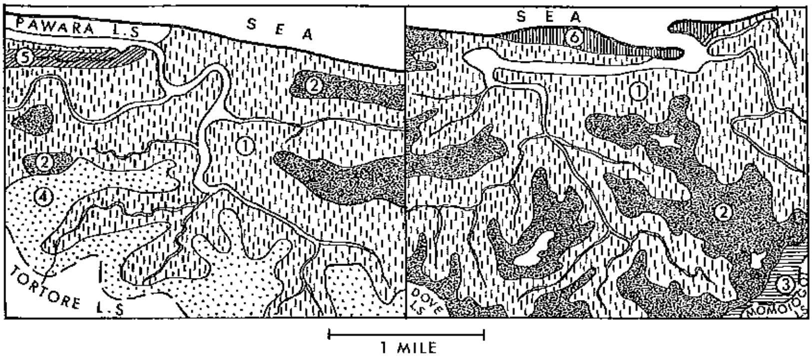
Drainage Status.—Mostly high, but apparently rather constant water-tables result in varying degrees of impeded drainage. Inland beach ridges (1,3) range from imperfectly to very poorly drained. Swales (2) very poorly drained to swampy. Water-table in frontal beach ridge (4) varies between 2 and 5 ft. Where the water-table is deep this land unit can be considered excessively drained.

Vegetation.—Mixed herbaceous vegetation of pioneering herbs, predominantly *Ipomoea pes-caprae* and *Canavalia maritima*, on the first beach ridge just above high-tide level, followed by beach forest with *Calophyllum inophyllum* (4). On wide beach ridges (1) largely secondary, low to mid-height, open forest with palm under-storey, commonly degraded to mid-height or tall grassland, merging into low very open forest on the slightly lower inland beach ridges (3). Swamp woodland with sago and *Pandanus*, locally pure *Phragmites*, in the swales (2) between the ridges.

## (2) Bendorodo Land System (55* sq miles)

Tidal mangrove swamps along the coast.

**Altitude.**—Intertidal zone.




Land Units (13 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 30–42 | Lower tidal flats | Mostly 2, Songada; also 1, Sebaga, and 4, Foru | Mangrove forest | VIII |
| 2 | 12–18 | Stable tidal flats | No data, probably 1, Sebaga | No data, probably mangrove scrub | VIII |
| 3 | 3–9 | Uppermost tidal flats | 2, Songada | Mangrove forest | VIII |
| 4 | 1–3 | Upper tidal flats | No data | Mangrove forest, fern scrub | VIII |
| 5 | 1–2 | Prior channels and swales | 2, Songada | Nypa palm | VIII |
| 6 | <1 | Present beaches, spits, and off-shore bars | Dark beach sand | Bare ground or *Casuarina equisetifolia* forest and mangrove scrub | VIII, $VIIs_1,s_2$ |

**Geology.**—Recent deltaic sand, alluvial silt, estuarine mud, and mangrove peat.

**Geomorphology.**—Littoral plains: intertidal swamps composed of mainly present and prior deltas of the Musa River and intervening strips of degraded beach ridges and depressions, with minor low beaches, spits, and off-shore bars. The tidal range is about 3 ft. Lower tidal flats (1) below mean sea level surround tidal creeks and recent deltas, and have abundant crab mounds up to 4 ft high in the sandier parts. These lead up to stable tidal flats (2) at about mean sea level, upper tidal flats (4) just above mean sea level, and the uppermost tidal flats (3), which are subject to freshwater flooding. Parts of the upper tidal zone consist of swales between degraded beach ridges and prior channels (5). Unit 6 is made up of present beaches, up to 50 ft wide, and ephemeral spits and off-shore bars rising to 2 ft above mean sea level.

**Soils.**—Very dark soft strongly gleyed alkaline muds, generally most sandy near coast (1) and most clayey inland (3), alternate with alkaline fibrous very dark brown mangrove peat. On the upper tidal flats (3, probably 4) the muds are somewhat firmer and have a weakly acid surface soil due to freshwater flooding. The peats range in depth from 2 ft to more than 5 ft, are underlain by sandy deltaic deposits, and appear to occur predominantly in areas unaffected by sedimentation (1, but mainly 2). Alkaline strongly gleyed very dark sands occur locally near the coast (1). The beaches (6) consist of well-sorted very dark sand.

**Drainage Status.**—Tidal water fluctuations are strongest in the lower tidal flats (1) and weakest in the uppermost tidal flats (2). Large parts of units 1, 2, and 5 do not normally fall dry and are covered by up to 3 ft of salt water or brackish water at high tide. Unit 3 has a permanently very shallow brackish water-table that rises above ground surface only during freshwater flooding.

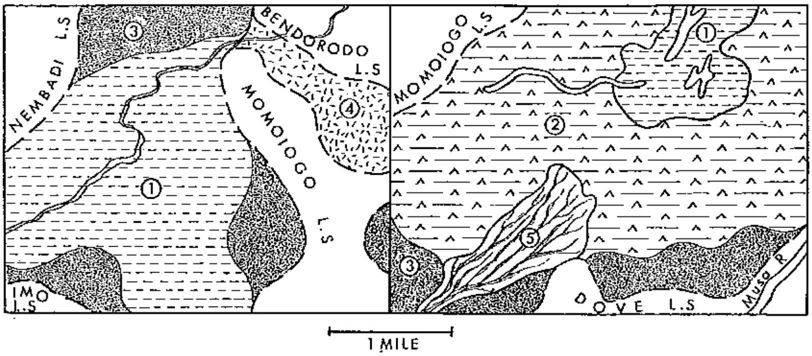
**Vegetation.**—Mangrove. Largely well-developed *Rhizophora–Bruguiera* to 80 ft high along tidal creeks (1), becoming scrub-like away from creeks (2). Typical of *Rhizophora*, mainly in unit 1, are rounded spots where all trees have died. In the Musa River delta (mainly 1) open upper storey of *Sonneratia* and/or mixed with freshwater species; away from creeks locally poor open *Avicennia* (4), much dying off, with undergrowth absent or dense ferns. *Nypa fruticans* lining creeks and in swales and depressions (5). On the seaward side pioneering *Casuarina* and *Avicennia* on sandy sites (6).

* An additional 5 sq miles in the Wanigela–Cape Vogel area also mapped and included in land unit areas.

## (3) Tortore Land System (140* sq miles)

Permanent and fluctuating freshwater swamps on coastal plain.

**Altitude.**—0–125 ft.




Land Units (13 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 65–70 | Permanent swamps | 2, Yupuru; minor 1, Karaisa | Mixed herbaceous vegetation, tall grass vegetation, sago and *Pandanus* swamp woodland | VIId,f |
| 2 | 45–50 | Permanent back swamp of Musa River | 3, Moiave | *Pandanus* swamp woodland | VIId,f,a |
| 3 | 22–26 | Seasonal back swamps | 3, Botame, Bariji; locally 9, Feroroda; probably 3, Moiave in eastern parts | Sago swamp woodland | VI–VIId,f |
| 4 | 10–12 | Fringing swamps adjacent to mangrove belt | 3, Moiave; 2, Yupuru with strongly alkaline subsoil | Mixed swamp woodland | VIId,a |
| 5 | 1–2 | Breakthrough splay of Musa River | No data | *Pandanus* swamp woodland | VIII |

**Geology.**—Recent alluvial silt and paludal clay overlying deltaic sand near coast.

**Geomorphology.**—Freshwater swamps: permanently and seasonally inundated land marginal to the littoral plains and the present and prior Musa meander tracts. Predominantly permanent swamps (1 and 2) and seasonal back swamps (3) sometimes with abrupt margins sloping at 1 in 200 for 600–800 ft. Fringing swamps (4) occur just above high-tide level adjacent to the mangrove belt and are occasionally flooded. Near Garagarata the breakthrough splay (5) of the Musa River has gradients of up to 1 in 80 and is covered by an anastomosing pattern of distributary channels.

**Soils.**—Strongly gleyed, but otherwise undifferentiated alluvial clay soils occur throughout, with variations due to differences in drainage and parent material. Weakly acid to neutral soft heavy clays, commonly submerged in several feet of water with masses of roots and organic residue, occur in permanent swamps (1) together with local shallow peat soils under *Phragmites* vegetation. More consolidated, slightly less gleyed soils, generally very clayey, are found in areas that are only seasonally inundated (3) or that have only recently become more swampy (2). The soils are calcareous and alkaline when derived from recent Musa deposits as in unit 2 and probably in parts of units 1 and 3. Even more alkaline soils, at least in the subsoil, occur in swamps fringing the mangrove belt (4), where brackish water-tables are common. These soils have sandy subsoils.

**Drainage Status.**—Generally swampy; parts of fluctuating swamps (3) are very poorly drained. Water-tables 2–4 ft above ground level characterize permanent swamps (1). The Musa River back swamp (2) and breakthrough splay (5) have water-tables from 0 to 18 in., indicating increased and more permanent swampiness of this land unit due to the influx of much Musa River water from the breakthrough at Garagarata. Very shallow but probably rather constant water-tables are found in the swamps fringing the mangrove belt (4). Lower but highly variable water-tables characterize the fluctuating swamps (3). During the wet season they probably rise to well above the land surface.

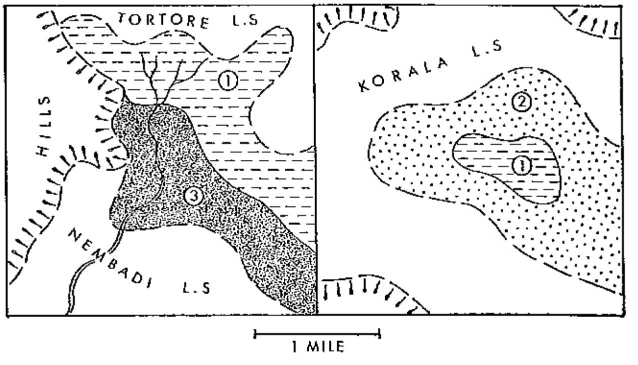
**Vegetation.**—The type of vegetation depends to a large extent on frequency and depth of inundation. Mainly low herbaceous vegetation covers the deepest parts of swamps (1) comprising floating mats of *Hanguana malayana* and *Leersia hexandra* in the west, and unidentified aquatic and herbaceous vegetation including ferns and very low stunted sago in the centre part of the eastern swamp (2). In more or less permanently swampy environment, bordering the deeper swamps, low open swamp woodland of stunted sago and *Pandanus* occurs (1,2); pure *Phragmites* covers extensive areas in the west (1). Swamp woodland with well-developed, more or less dense sago is found in seasonal back swamps (3). The swamps fringing the mangrove belt (4) have generally dense swamp woodland with scattered mangroves and locally dominating *Heritiera littoralis*. The breakthrough splay (5) is probably mainly *Pandanus* swamp woodland with a large number of dead trees. It is noteworthy that in the western marginal swamp the vegetation is mainly herbaceous, in the Musa River back swamp mainly woodland, open with predominantly *Pandanus*. Increased swampiness due to the recent breakthrough may account for the many scattered dead trees and young *Nauclea* trees mainly along the border.

* An additional 10 sq miles in the Wanigela–Cape Vogel area also mapped and included in land unit areas.

## (4) Imo Land System (10 sq miles)

Poorly drained alluvial fan-plains on western margin of coastal plain.

**Altitude.**—Just above sea level to 100 ft.




Land Units (7 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 4–6 | Seasonally flooded fan-plains | 3, Bariji | Irregular tall alluvium forest | VIId,f |
| 2 | 2–3 | Periodically flooded fan-plains | 3, Botame | | Vd,f |
| 3 | 1–2 | Occasionally flooded fan-plains | 6, Toma, Ovessa | | IVf, IVd,f |

**Geology.**—Recent alluvial silt overlying paludal clay near inland swamps.

**Geomorphology.**—Alluvial fans: lower fan segments on the western margin of the Musa coastal plain. These fan-plains range from higher occasionally flooded areas (3) at about 1 in 100, through periodically flooded areas (2) at about 1 in 300, to channelled seasonally flooded areas (1) at about 1 in 500.

**Soils.**—Undifferentiated weakly acid to neutral alluvial soils: strongly gleyed in lowest parts (1,2) with silty clay to clay texture and stratified subsoils (mostly sandy clay loam to silty clay, but ranging from sand to silty heavy clay) in unit 1, and very plastic heavy clay texture in unit 2; slightly to moderately gleyed silty clay loam to clay in higher parts (3). Buried topsoils occur ocally in units 1 and 3.

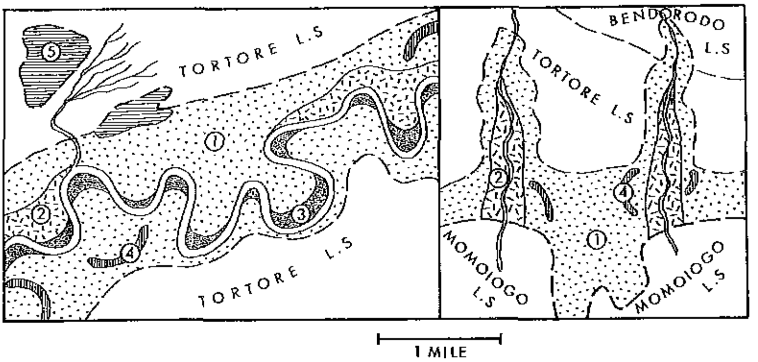
**Drainage Status.**—Units 1 and 2 are very poorly drained due to periodic inundation, and in unit 2 also to slow soil permeability, rather than to permanently high water-tables. Unit 3 poorly to imperfectly drained.

**Vegetation.**—Alluvium forest, with widely scattered high emergents and very irregular open canopy and lower storeys, covers all land units. Palms, climbers, and buttresses are common to abundant. Where drainage is poorest, *Pandanus* and sago are abundant and *Planchonia papuana*, *Bischofia javanica*, and *Terminalia canaliculata* are common (1). A somewhat denser type of forest with lower average crown size and tree girth, *Intsia bijuga*, *Anisoptera kostermansiana*, and *Terminalia* sp. common, and with deciduous trees, occurs in the basin south-west of Kakasa (2). Huge *Octomeles sumatrana* occurs throughout and seems to be densest on the best-drained land (3).

## (5) Dove Land System (80* sq miles)

Unstable, poorly drained alluvial plains with calcareous soils, on coastal plain.

**Altitude.**—Just above sea level to 210 ft.




Land Units (12 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 77–88 | Back-plain depressions | 3, Moiave, Musa; 6, Gobera | Irregular tall alluvium forest | VId,f,a |
| 2 | 16–22 | Levees | 6, Taruma | Tall alluvium forest | IVf,a, IVd,f,a |
| 3 | 4–8 | Scrolls | In north: 3, Musa; 6, Gobera. In south: no data | Tall grass vegetation, tall alluvium forest, secondary forest | VIf,a, VId,f,a |
| 4 | 1 | Oxbows | No data | Mixed herbaceous vegetation | VIII |
| 5 | 1 | Prior breakthrough splays | No data | Mainly tall grassland | ?Vd,a |

*Geology.—Recent alluvial silt and sand with local pebbles.*

**Geomorphology.**—Alluvial plains: poorly drained flood-plain of the Musa River. Levee banks (2) up to 2000 ft wide rise 12–24 ft above the present and prior Musa channels and merge into periodically flooded back-plain depressions (1) up to 4000 ft wide with gradients about 1 in 400. Along the inner bends of the Musa River, flood-plain scrolls (3) are developed up to 1000 ft wide and up to 6 ft above low-water level. Oxbows (4) up to 1 mile long and 300 ft wide are common. Near Garagarata two breakthrough splays (5) are up to 4000 ft long with gradients of up to 1 in 80.

**Soils.**—Undifferentiated alkaline calcareous stratified silty alluvial soils: moderately to strongly gleyed fine sandy loam to silty clay on back plains (1) together with less calcareous silty clay to silty heavy clay at greater distance from Musa River; moderately gleyed silty clay with sand to silty clay loam subsoil on down-stream scrolls (3) and probably also on prior breakthrough splays (5); locally slightly gleyed fine sandy loam to silty clay loam on levees (2) and probably also on up-stream scrolls (3), together with more sandy soils.

**Drainage Status.**—Generally poorly to very poorly drained (1, parts of 3 and probably 5), with swampy oxbows (4). Levees (2) and parts of scrolls (3) and probably also of breakthrough splays imperfectly to well drained.

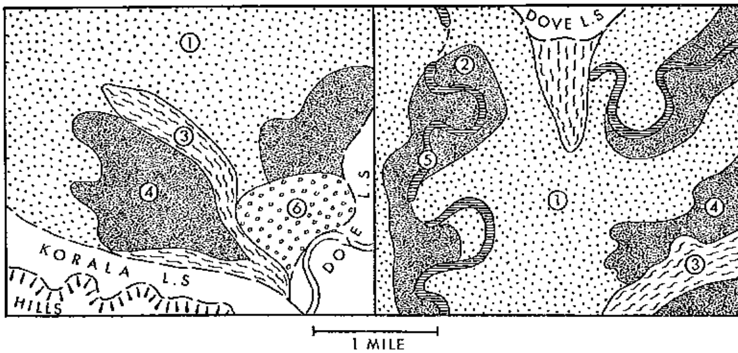
**Vegetation.**—Largely irregular tall alluvium forest with widely scattered tall trees and a very open canopy occurring in back-plain depressions (1). Sago and *Pandanus* very common, rattan abundant. *Planchonia* and *Bischofia* common; minor secondary forest. On levees (2) tall alluvium forest with less irregular canopy and scattered high emergents to 150 ft; *Pandanus*, rattan, climbers common; *Pometia*, *Terminalia*, and *Octomeles* common; secondary forest with *Canarium acutifolium*. Scrolls (3) show a succession from tall *Saccharum* at the river's edge leading to tall alluvium forest. Prior breakthrough splays (5) are mainly covered with grassland. Aquatic mixed herbaceous vegetation occurs in oxbows (4).

* An additional 30 sq miles in the Wanigela–Cape Vogel area also mapped and included in land unit areas.

## (6) MOMOIOGO LAND SYSTEM (175 SQ MILES)

Stable alluvial plains on coastal plain.

Altitude.—Just above sea level to 210 ft.




Land Units (19 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 90–110 | **Prior meander tracts** | 6, Ovessa dominant; 7, Safia subdominant; 7, Ubo minor | Tall alluvium forest | I, IId |
| 2 | 25–35 | **Terraced levees** | 7, Safia dominant; 7, Ubo minor | Tall grassland and secondary forest | I, IId |
| 3 | 18–28 | **Back plains** | 6, Ovessa | Irregular tall alluvium forest | IIIf |
| 4 | 17–25 | **Breakthrough splays** | 7, Safia dominant; 7, Ubo minor | Tall grassland, *Timonius–Commersonia* scrub and secondary forest | I, IId |
| 5 | 1–3 | **Prior channels** | 9, Obeia | *Pandanus* swamp woodland | VI–VIId,f |
| 6 | 1–2 | **High platform** | 7, Embessa | Mid-height grassland | $IIIs_2$, $VIs_2$ |

**Geology.**—Recent alluvial silt overlying deltaic sand near coast and paludal clay near swamps; some alluvial gravel near Embessa.

**Geomorphology.**—Alluvial plains: mostly stable parts of prior Musa flood-plains. Prior meander tracts (1) up to 10 miles long and 3 miles wide have longitudinal gradients of between 1 in 500 and 1 in 1000. Down their centres prior channels (5) about 200 ft wide with steep banks 6–10 ft high are margined by terraced levees (2) ranging from 10–20 ft above the channel and 100–500 ft in width. At Embessa a high platform (6) at 190–210 ft has a gradient of 1 in 400; this and a lower platform at 100 ft are margined by prior breakthrough splays (4) up to 1 in 80 and closely channelled. The less stable portions of the land system consist mainly of channelled back plains (3) subject to occasional flooding.

**Soils.**—Stratified, generally silty alluvial soils, weakly acid to neutral near the surface, alkaline and calcareous in subsoil or deeper subsoil. Textures are mainly silty clay loam to silty clay over loamy fine sand to silty heavy clay (1), silty clay loam over sand to clay (2), and silty clay loam to silty heavy clay (3 and 4). The soils of the levees (2) and the breakthrough splays (4) and commonly also those of the meander tracts (1) have rather thick dark topsoils and are locally calcareous above 2 or 3 ft depth. The soils of the back plains (3) and most of those of the meander tracts have poorly developed topsoils. Very gravelly or sandy soils with thick dark topsoil occupy the high platform (6). Strongly gleyed calcareous alkaline sands with thick dark clayey topsoils are found in the prior channels (5).

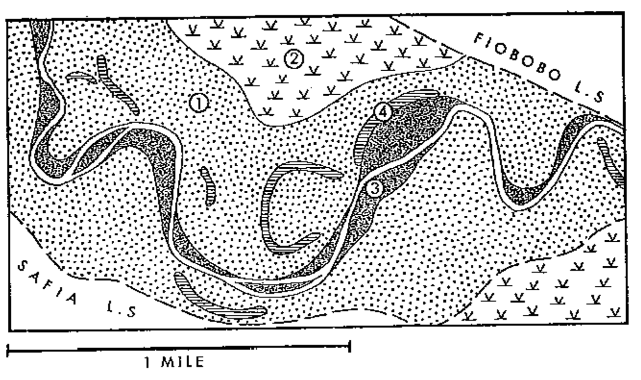
Drainage Status.—Land units 1–4 are well to imperfectly drained. The gravelly platform near Embessa (6) is excessively drained and the prior channels (5) are very poorly drained to swampy, with water-tables at 30 in. and above.

Vegetation.—Dominantly tall alluvium forest (1) with scattered high emergents up to 130–150 ft, occasionally 170 ft. The canopy, irregular, rather open to fairly dense, is at 115–130 ft. Lower storeys are irregular, generally rather dense. Palms, climbers, and buttresses are common. The imperfectly drained back plains (3) carry a poorer, slightly lower, and more irregular and open type of alluvium forest with abundant rattan and other palms. On the levee banks (2) and breakthrough splays (4) the original forest has mostly been replaced by tall grassland and secondary forest. Where burning of the grass has ceased, a rather dense scrub has developed which, given time and opportunity, may eventually revert to forest. Prior swampy Musa River channels (5) are covered with dense low small-crowned swamp woodland locally consisting of pure *Pandanus*. The high platform (6) supports mid-height grassland.

## (7) Gobera Land System (25 sq miles)

Alluvial terraces and flood-plains in the Musa basin.

**Altitude.**—360–500 ft near Gobera, 900–1050 ft near Namudi.




Land Units (8 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 16–19 | Alluvial terraces | 6, Ovessa; locally 7, Safia and Embessa | Mainly garden regrowth, secondary forest, and tall grassland; minor tall alluvium forest and eucalypt savannah | I, IVf, $VIs_2$ |
| 2 | 4–6 | Back plains | 3, Botame; locally 6, Gobera in east | Irregular tall alluvium forest, tall grassland, and secondary forest | $Vd,s_2$, VId,f |
| 3 | 1–3 | Flood-plain scrolls and channel bars | River wash | Bare ground, locally tall grass vegetation | VIII |
| 4 | <1 | Oxbows | No data | Tall grass vegetation and open water | VIII |

**Geology.**—Recent alluvial cobbles, gravel, and sand with local patches of silt and clay.

**Geomorphology.**—Alluvial terraces: of gentle gradient in the middle reaches of the Musa River. The terraces (1) are 16–25 ft above the present channel with gradients of 1 in 200 to 1 in 400, and they merge into back plains (2) up to 2000 ft wide. Both terraces and back plains are in part subject to flooding and numerous scour routes are present. Along the present channel scrolls and channel bars (3) up to 600 ft wide are common and prior channels are marked by oxbows (4) up to 1 mile long and 300 ft wide.

**Soils.**—Mainly neutral friable loamy alluvial soils with much gravel at varying depth and with thick dark topsoil on highest terraces (1). On poorly drained back plains (2) occur gleyed neutral to alkaline alluvial soils, mostly plastic heavy clay, but at eastern margin also calcareous silty clay loam, derived from Goropu Metamorphics. Loose sand and gravel are found on scrolls (3).

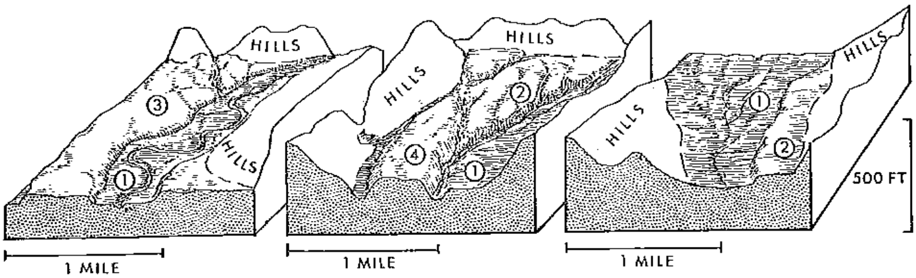
**Drainage Status.**—There is a marked contrast between the well to excessively drained terraces (1) and the poorly to very poorly drained back plains (2).

**Vegetation.**—Intricate pattern of garden regrowth, secondary forest, and tall grassland; minor remnant patches of fairly tall alluvium forest on well-drained flood-plain terraces (1) and of fairly tall irregular open alluvium forest with *Bischofia* and *Planchonia* common on poorly drained sites (2), both forest types with many deciduous trees. Where drainage is very poor, *Pandanus* swamp woodland with abundant rattan (2). In prior channels (4) tall *Saccharum* and open water. Minor eucalypt savannah with scattered groups of *Casuarina* north-east of Namudi in unit 1.

## (8) Aiare Land System (17 sq miles)

Terraces and flood-plains of upper Bariji, Musa, and Kumusi Rivers.

**Altitude.**—1000–1900 ft.




Near Bariji River — Near Kumusi River — Near Aiare

Land Units (14 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 10–11 | **Alluvial terraces and flood-plains** | 6, Ovessa; locally 6, Gorabunina | Tall evergreen fan forest; secondary forest; minor eucalypt savannah and mid-height grassland | I; II–IIIst; IVf; VIf,st |
| 2 | 2–5 | **High terraces** | 14, Aiare; 16, Kwena | Secondary forest; foothill forest | IIe |
| 3 | 2–3 | **Lacustrine terrace** | 6, Toma, Ovessa | Tall alluvium forest; minor secondary forest | IId, $IVs_3$ |
| 4 | <1 | **Channelled fan terraces** | 7, Safia; 6, Ovessa, Gorabunina; mostly stony | Regrowth and secondary forest | II–Vst |

**Geology.**—Recent coarse and fine fan-glomerate and alluvium. Near Toma fine lacustrine beds; in the Kumusi valley admixture of volcanic ash.

**Geomorphology.**—Alluvial terraces of steep gradient. Occasionally flooded low terraces and flood-plains (1) up to 30 ft above the stream channels contrast with stable high terraces (2) up to 100 ft above streams. Gradients range from 0° 30′ to 3°. In the Kumusi valley minor fan terraces (4) sloping 2–6° are channelled by numerous wash courses. Near Toma a lacustrine terrace (3) 50 ft above the Bariji River channel is up to 5000 ft wide and has a gradient of less than 1°.

**Soils.**—Predominantly undifferentiated weakly acid alluvial soils: stratified, friable, and loamy on low terraces (1), slightly to moderately gleyed very firm clay to heavy clay on lacustrine terrace (3), and stony on fan terraces (4). The friable soils consist locally mainly of volcanic ash (1,4) and the stony soils commonly have a thick dark topsoil (4). More-weathered soils occur on the high terraces (2): yellow-brown acid to weakly acid firm clay to heavy clay soils, and in Kumusi valley and Managalase area yellow-brown to dark brown very friable sandy clay loam ash soils with thick dark topsoils.

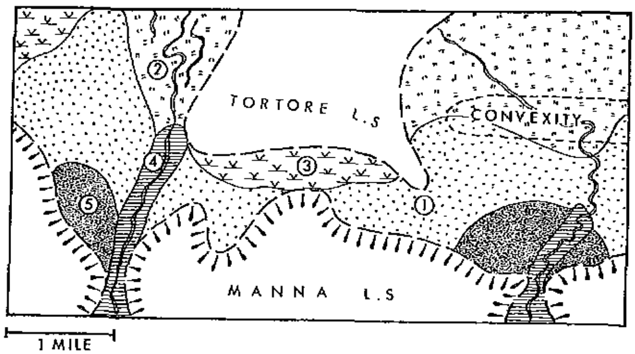
**Drainage Status.**—Well drained except for the lacustrine terrace (3), which is imperfectly to poorly drained because of slow soil permeability.

**Vegetation.**—Extensive secondary forest occurs in all land units. Mainly tall evergreen fan forest on gently sloping river terraces (1), rarely degrading into low open forest where frequently flooded, also minor eucalypt savannah and mid-height grassland; tall alluvium forest with deciduous trees on nearly level lacustrine terrace (3); mainly foothill forest on higher terraces with steeper gradient (2).

## (9) Nembadi Land System (45 sq miles)

Composite alluvial fans near Pongani derived from volcanic rocks.

Altitude.—Just above sea level to 160 ft.




Land Units (28 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 15–18 | Inactive fan slopes | 7, Kinjaki | Tall evergreen fan forest; mid-height to tall grassland | I, IId |
| 2 | 13–15 | Active fan slopes and convexity in composite fan | 6, Gombara | Garden regrowth, secondary forest, and tall grassland; tall evergreen fan forest | I, $IIs_2$ |
| 3 | 5–8 | Seepage areas | 9, Feroroda; locally 6, Toma | *Pandanus* swamp woodland; tall grassland; *Nauclea–Antidesma* savannah | IIId, Vd |
| 4 | 4–6 | Flood-plains and terraces | 7, Embessa; locally 6, Gombara; also river wash | Tall grassland; secondary forest; minor tall evergreen fan forest | VIst,f; $VIs_2$; IVf; also VIII |
| 5 | 3–4 | Upper platforms | 7, Embessa | Eucalypt savannah; tall grassland; secondary forest; minor tall evergreen fan forest | $IIIs_2$; $VIs_2$; $VIe,s_2$ |

Geology.—Recent fine fan-glomerate and alluvial sand with admixture of dacite ash.

Geomorphology.—Alluvial fans: of composite nature at several levels on the western margin of the Musa coastal plain. Upper platforms (5) up to 3000 ft long and sloping 1 in 200 occur at the effluence of the Bariji and Pongani Rivers from the mountains. They are about 140 ft above sea level and have abrupt convex margins at 3–4° leading down to concave fan slopes with gradients down to 1 in 500 of active (2) and inactive (1) type. On the Bariji River an upper fan is graded to 70 ft above sea level and passes by way of a wide convexity (2), 1 in 500 to 1 in 100 over 4000 ft, into a lower fan. Near the mountain front the lower inactive fan slopes have large seepage areas (3) with local micro-relief. Narrow flood-plains and terraces (4) margin the major rivers and continue along the narrow valleys into the hills.

Soils.—Predominantly friable dark brown weakly acid stratified alluvial soils: sandy clay to clay with thick dark topsoil on inactive fan slopes (1), sandy loam to clay loam with coarse sand to clay subsoil on lower inactive fan slopes (2). Similar soils, mostly with thick dark topsoil, are gleyed in seepage areas (3) and very stony or gravelly and rather sandy on flood-plains and terraces (4). The upper platforms (5) are characterized by very gravelly and loose sandy soils with thick dark topsoils.

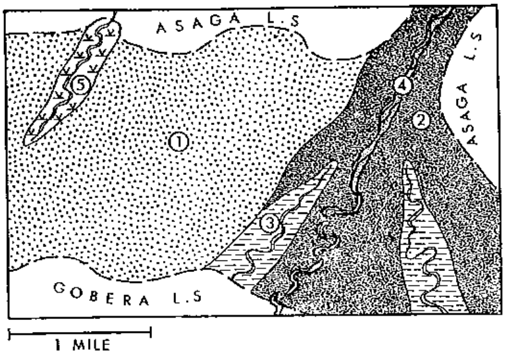
Drainage Status.—Mostly well drained (1,2,4), but poorly drained seepage areas (3) and excessively drained upper platforms (5) and locally terraces (4). Small parts of units 1 and 2 are imperfectly drained.

Vegetation.—Predominantly an intricate pattern of tall to mid-height grassland, tall evergreen fan forest with some deciduous trees, regrowth, and secondary forest (1,2,4,5). The most extensive fan forest areas are found on the lowest slopes (1,2) to the east and south-east, with *Octomeles sumatrana* and *Terminalia canaliculata* common where they grade into the coastal plain; *T. canaliculata* also common on imperfectly drained parts of inactive fan slopes (1) behind coastal beach ridges to the north. Tall eucalypt savannah mainly on the upper platform (5). In seepage areas (3) a varied vegetation consisting of *Pandanus* swamp woodland with abundant gingers or tall grassland merging into low *Antidesma* savannah with widely scattered *Nauclea* and *Eucalyptus* and locally *Phragmites*.

## (10) Safia Land System (40 sq miles)

Composite alluvial fans with grassland in Musa basin.

Altitude.—360–750 ft.




Land Units (20 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 24–26 | **Upper fans** | 7, Safia and minor Bibira, locally gravelly | Mainly tall, locally mid-height, rarely short grassland | I, II–III$s_2$; locally VI$s_2$; IId; II$s_3$ |
| 2 | 8–10 | **Active fans** | 6, Ovessa commonly gravelly | Tall mixed deciduous fan forest; secondary forest; minor irregular tall alluvium forest and tall grassland | I, II–III$s_2$; locally VI$s_2$, Vst |
| 3 | 3–5 | **Prior flood-plains** | 7, Safia; also 6, Ovessa | Tall grassland; locally tall grass vegetation | I, II–IIId |
| 4 | 1–2 | **Braided channels** | River wash | Bare ground; minor tall grass vegetation | VIII |
| 5 | 1 | **Inter-fan depressions** | 7, Foasi | Tall mixed deciduous fan forest | II$s_3$ |

**Geology.**—Recent coarse and fine fan-glomerate.

**Geomorphology.**—Alluvial fans: of composite nature at two levels in the Musa basin. Inactive upper fans (1) up to 2 miles long and sloping 1 in 25 to 1 in 200 have many linear furrows, gravelly rises, and occasional inter-fan depressions (5) up to 800 ft wide at 1 in 100 where minor streams occur. Present trunk streams are margined by active fans (2) up to 3 miles long at 1 in 50 to 1 in 300, with braided channels (4) up to 1000 ft wide and in their lower portions prior flood-plains (3) up to 2000 ft wide and at 1 in 200.

**Soils.**—Neutral friable stratified sandy clay loam to clay alluvial soils, commonly very gravelly on active fans (2), with thick dark topsoil and commonly gravel beds at shallow depth on upper fans (1), and non-gravelly, mostly clayey and with thick dark topsoil or buried topsoil on prior flood-plains (3). Heavy clay soils with thick dark topsoil occur locally on upper fans (1) away from large rivers, whilst predominantly heavy clay soils with very thick dark topsoil are the result of minor colluvial accumulation in small inter-fan depressions (5). Gravelly and sandy river wash in braided channels (4).

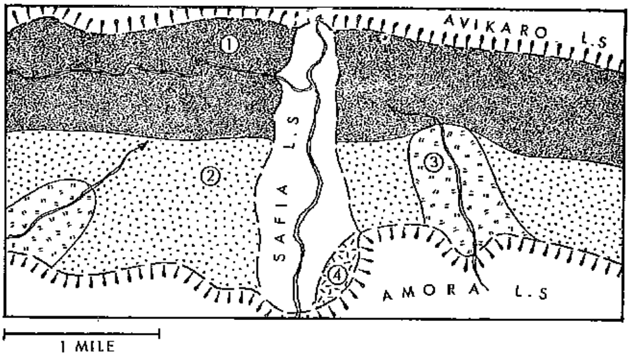
**Drainage Status.**—Generally well drained with small excessively drained gravelly patches in units 1 and 2. Prior flood-plains (3 are imperfectly drained.

**Vegetation.**—Largely tall to mid-height, rarely low, grassland with widely scattered low trees and shrubs of *Nauclea*, *Antidesma*, and *Ficus* (1–3). Patches of tall mixed deciduous fan forest, and irregular tall alluvium forest near rivers (2), often open and secondary. Grassland in prior flood-plain (3) irregular, with patches of bare ground or short grasses, locally *Phragmites* in prior channel depressions. Gravelly and sandy stream channels (4) bare or with patches of *Saccharum*.

## (11) Liamu Land System (25 sq miles)

Forested alluvial fans in Musa basin.

Altitude.—700–1150 ft.




Land Systems (12 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 12–15 | Lower fan slopes | 7, Safia, Kinjaki, and minor Bibira; rarely 6, Gombara | Tall mixed deciduous fan forest; secondary forest | I |
| 2 | 6–8 | Upper fan slopes | 6, Ovessa, locally gravelly | | I, IIe |
| 3 | 3–4 | Active fans | 6, Ovessa, Gombara, gravelly | | VI–VIIIs$_2$ |
| 4 | 1–2 | Dissected colluvial fans | 17, Arumbai | | II–IIIe |

Geology.—Recent coarse and fine fan-glomerate and colluvium.

Geomorphology.—Alluvial fans: piedmont alluvial fans in western Musa basin. Lower inactive fan slopes (1) are up to 1 mile long at 0°15′–1° with common active gully heads, and they lead up to upper inactive fan slopes (2) up to 2000 ft long and at 2–5°. In places adjacent to the mountain front, steep dissected colluvial fans (4) are up to 2000 ft long at 2–15°. Active fans (3) up to 1 mile long and sloping between 0°30′ and 2° margin streams.

Soils.—Weakly acid dark brown and brown alluvial soils: firm clay and locally heavy clay, mostly with thick dark topsoil and commonly with gravelly subsoil on lower fan slopes (1), friable clay with varying amounts of gravel on upper fan slopes (2), very gravelly on active fans (3). Very locally on remnants of older fans (4) occur neutral brown over yellow-red firm heavy clay soils with varying amounts of weathered gravel.

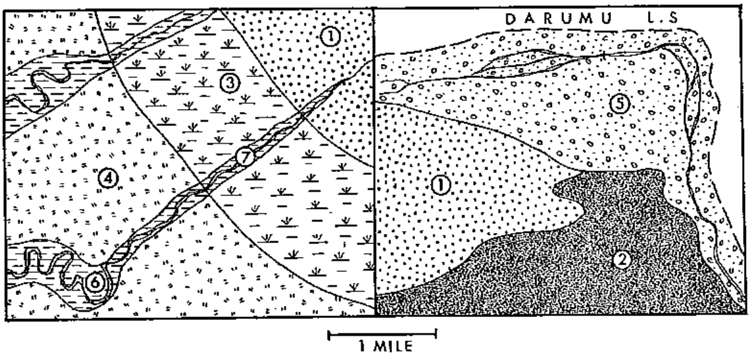
Drainage Status.—Well drained except the active fans which are excessively drained.

Vegetation.—Tall mixed deciduous fan forest in all land units; emergents to 150 ft, occasionally 165 ft. Many scattered patches of regrowth and secondary forest, more concentrated around Liamu in the north-west and Silimidi in the south-east, locally with abundant bamboo.

## (12) Ubo Land System (45 sq miles)

Relatively steep alluvial fans and plains in eastern Musa basin; calcareous soils.

**Altitude.**—370–3000 ft.




Land Units (17 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 13–16 | Upper fan slopes | 6, Taruma; 7, Ubo; commonly stony | Tall mixed deciduous fan forest, tall grassland | IVa, Vst,a |
| 2 | 7–9 | Undulating fan slopes | 6, Taruma, Ovessa; minor 7, Embessa, Safia; gravelly, stony | Tall evergreen fan forest with deciduous trees; mixed *Casuarina* fan forest | II; III; Vst |
| 3 | 7–9 | Lower fan slopes | 9, Obeia | Mainly tall grassland; irregular tall alluvium forest | Vd,a |
| 4 | 6–8 | Prior flood-plains | 7, Ubo; 9, Obeia | Tall grassland | IVd,a |
| 5 | 4–6 | Boulder fans | 6, Taruma gravelly stony | Mainly *Casuarina* fan forest; mixed *Casuarina* fan forest | VI–VIIst,a |
| 6 | 1 | Flood-plains | 2, Musa; locally 5, Ibau | Secondary forest; swamp woodland | Vd,a, VIf,st |
| 7 | <1 | Braided channels | River wash | *Casuarina* fan forest; tall grass vegetation | VIII |

**Geology.**—Recent coarse and fine fan-glomerate with calcareous cement in the lower parts.

**Geomorphology.**—Alluvial fans: of the Ibinambo River and Ibau Creek. Lower prior flood-plains (6) sloping at 1 in 100 to 1 in 300 merge into lower fan slopes (3) up to 2 miles long at 1° with strong seepage, and then upper fan slopes up to 4 miles long at 2–5° with scattered large boulders. Recent stream diversion has left numerous unused channels on an undulating fan surface (2) at 1–3° in the south. Near the mountain front boulder fans (5) at 1–5° margin the Ibinambo River. The streams on the lower fan slopes usually have braided channels (7).

**Soils.**—Alkaline calcareous fine sandy and silty stratified alluvial soils, commonly stony and generally with shallow gravel beds. Particularly stony and sandy on boulder fans (5) and locally on flood-plains (6). Strong gleying on lower fan slopes (caused by seepage (3), which locally gives rise to the formation of lime concretions) and on parts of the prior flood-plains (4) (which have non-gravelly soils) and flood-plains (6). Thick dark topsoils have developed on stable surfaces, particularly in units 3 and 4, commonly in unit 1 and locally in unit 2. On the slightly dissected deposits of unit 2 in the wetter south-eastern part of the land system free carbonate is commonly absent in the upper 3 ft of the soils.

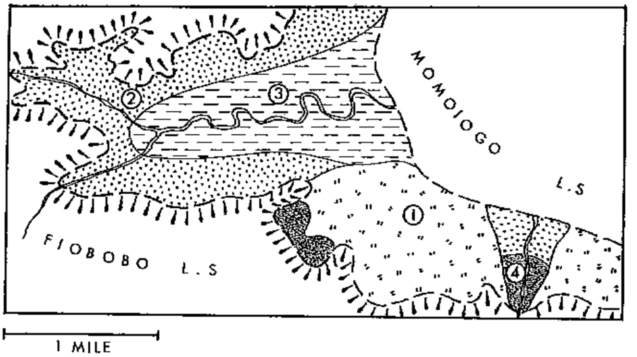
**Drainage Status.**—The greater part of the land system is well drained, but the prior flood-plains (4) and parts of the flood-plains (6) are imperfectly to poorly drained. Boulder fans (5) and parts of flood-plains tend to be excessively drained.

**Vegetation.**—Tall mixed deciduous fan forest predominant to the east and south (1,2), the proportion of deciduous trees decreasing to the east. Mainly tall grassland to the north and west (1,3,4) becoming patchy, with local dominance of *Phragmites*, on lower fan slopes (3) and prior flood-plains (4), and here also interspersed with remnant patches of tall mixed deciduous fan forest and open irregular often secondary alluvium forest near rivers; where drainage is poorest, *Pandanus* swamp woodland (3). On the upper boulder fans (5), *Casuarina* fan forest 65–130 ft high. On more stable fans, an open upper storey of *Casuarina* to 200 ft high over broad-leaf species (part 2, part 5). Garden regrowth and irregular very open swamp woodland with *Casuarina*, sago, and *Pandanus* on flood-plains (6). Narrow strips of *Casuarina* and *Saccharum* in gravelly stream beds (7).

## (13) Korala Land System (30 sq miles)

Fan complexes on southern margin of coastal plain; alluvial and texture-contrast soils.

Altitude.—30–400 ft.




Land Units (5 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 12–15 | Inactive fan slopes | 12, Nuaro; 10, Mamana; locally on rises 8, Domara | Low fan forest; locally eucalypt savannah and mid-height grassland | $VIs_2,s_3$; rises $VIe,s_2$ |
| 2 | 7–10 | Active fan slopes | 6, Ovessa generally gravelly | Mid-height fan forest; locally tall evergreen fan forest | IIIst, Vst |
| 3 | 4–7 | Flood-plains | 6, Ovessa | Tall evergreen fan forest | IIId,f |
| 4 | 1–2 | Upper fan slopes | Stony land; 6, Gombara gravelly | Low fan forest | VIst |

**Geology.**—Recent coarse and fine fan-glomerate and alluvial silt and clay.

**Geomorphology.**—Alluvial fans: piedmont alluvial fans fringing the southern margin of the coastal plain. Inactive fan slopes (1) with local microrelief and gravelly rises alternate with active fan slopes (2). Both are channelled and slope at 1–3°. Channelled flood-plains (3) margin the major streams, and adjacent to the hill front steeper partly reworked upper fan slopes (4) at 2–7° occur.

**Soils.**—All actively aggrading land units (2–4) have weakly acid to neutral undifferentiated alluvial soils: generally very gravelly brown friable sandy clay loam to clay on active fans (2), slightly gleyed firm clay, commonly with alkaline subsoil, on flood-plains (3), stony land and shallow dark brown rather sandy soil over cobbles on steeper slopes (4). The inactive fans (1) have moderately weathered soils characterized by very plastic heavy clay subsoils and coarser-textured surface layers. The subsoils are neutral to alkaline, locally with carbonate concretions, locally rest on gravel beds, and are gleyed except on gravelly rises. The surface layers consist of weakly acid firm sandy clay loam to clay (gravelly loam on rises) to a depth of 6–10 in. A thick dark topsoil is commonly present and may extend into the heavy clay subsoil.

**Drainage Status.**—Variable drainage status. Imperfectly drained flood-plains (3), well-drained active fans (2), excessively drained steeper slopes (4). Inactive fans (1) are poorly to very poorly drained, except for rises, but the soils of the whole of this land unit are subject to rapid drying out of the surface layers.

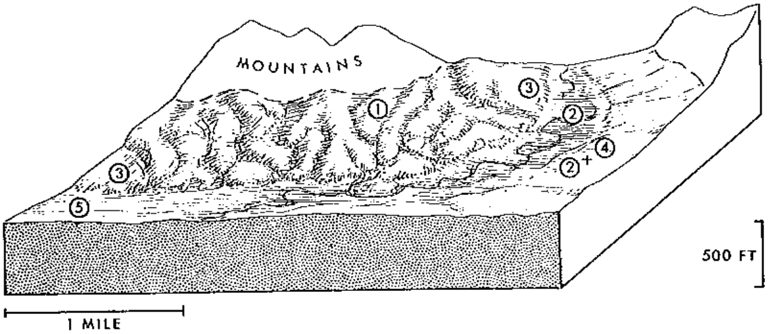
**Vegetation.**—Largely dense small-crowned thin-stemmed low fan forest with local patches of very small-crowned forest (1,4), south of Taruma with scattered emergent *Casuarina*, south of Ovessa low *Eucalyptus papuana–Melaleuca* savannah and mid-height grassland. Mid-height to tall fan forest on well-drained sites (2,3). The fan forest on the flood-plain around Korala (3) grades into tall alluvium forest.

## (14) Boborobo Land System (25 sq miles)

Upland basins in Sibium Range with variably weathered and dissected fans.

**Altitude.**—700–1450 ft.

**Relief.**—Variable, 20–150 ft.




Land Units (9 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 10–13 | Concavo-convex slopes, 0–30° | 18, Korua | Small-crowned hill forest; locally mid-height grassland | VIe |
| 2 | 4–6 | Fan slopes, 3–1° and flood-plains | 6, Gombara locally gravelly | Mid-height fan forest; minor secondary forest | I; II–IIIst; IIIf |
| 3 | 3–5 | Dissected fans, 5–1° | 13, Sesaro locally stony | Low fan forest; tall grassland | I; IIe; IIIst |
| 4 | 2–4 | Inactive fan slopes, 2–1° and mid-fan slopes, 8–5° | 12, Nuaro<br>17, Busi | Low fan forest | $VIs_2,s_3$<br>$IVs_3$ |
| 5 | 1–2 | Swamps | 1, Karaisa; 3, Botame | Swamp woodland | VIId |

**Geology.**—Pleistocene and Recent fan-glomerate with local thin volcanic ash. Paludal clay and peat in swamps, and minor alluvium.

**Geomorphology.**—Alluvial fans: variably dissected and occurring in five upland basins in the eastern Sibium Range. The older basin-fill deposits have deep mature weathering. Smooth concavo-convex low hills (1) merge into deeply channelled dissected fans (3) and undissected fan slopes (2,4) up to 4000 ft long. The inactive fan slopes have local microrelief. Local flood-plains (2) and swamps (5) are up to 2000 ft wide and margin the central streams.

**Soils.**—Deep yellow-red strongly acid friable heavy clay soils appear to be dominant on strongly weathered hilly dissected fan deposits (1), whilst locally gravelly or stony strong brown to dark yellow-brown acid clay to clay loam soils with thick dark topsoil are formed on younger less dissected fans (3). On the youngest undissected fan slopes and flood-plains (2) occur undifferentiated dark brown alluvial clay to clay loam soils, merging into strongly gleyed heavy clay alluvial soils, commonly covered with shallow weakly acid peat in central swamps (5). Gleyed alkaline very plastic heavy clay soils with a weakly acid firm clay surface layer 6–10 in. thick characterize inactive lower fan slopes in the Nuaro basin (4) and are associated with rare occurrences of yellow-red slightly gleyed weakly acid very plastic heavy clay soils on mid-fan slopes.

**Drainage Status.**—With the exception of small central swamps (5) with water-tables near the surface, and the inactive lower fan slopes (4), the land system is well drained. Unit 4 is imperfectly to poorly drained due to slow soil permeability, but the coarser-textured surface horizons are also subject to rapid drying.

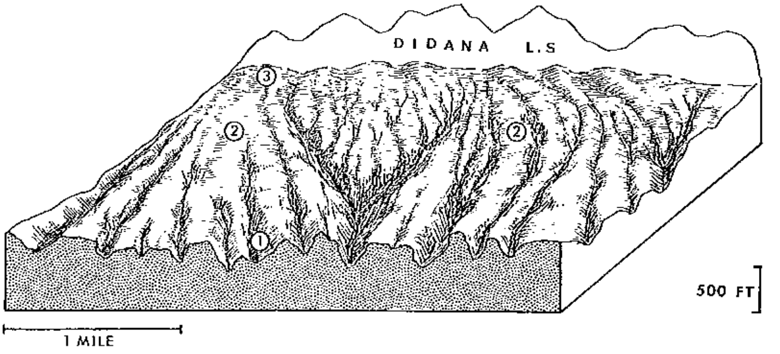
**Vegetation.**—On the low hills (1, part 3), mainly small-crowned hill forest; locally, near Orala and Sesaro, tall to mid-height grassland. Mid-height fan forest, partly secondary, in Boborobo and Sesaro basins on well-drained sites and around streams draining the basins (2). Low fan forest with a dense canopy formed by small-crowned thin-stemmed trees on lower and mid-fan slopes (4), locally with widely scattered *Casuarina* and to the south locally grading into *Pandanus* swamp woodland with dense sedge ground storey. In central swamps (5), swamp woodland with sago and *Pandanus*.

## (15) Sibium Land System (15 sq miles)

Steep deeply dissected alluvial fans and cones flanking northern Sibium Range.

Altitude.—1750–3000 ft.

Relief.—100–400 ft.




Land Units (1 Observation)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 9–10 | Straight slopes, 30–40° | No data. Probably stony land and unidentified acid brown clay soils | No data, mid-slope forest, mixed *Araucaria* hill forest | VIIe; VIIe,st; VIII |
| 2 | 3–5 | Concave slopes, 10–2° | Unidentified dark brown acid clay loam to clay soils. Locally stony land. Possibly also ash soils | Plateau forest; mid-slope forest; mixed *Araucaria* hill forest | II–IIIe; ?minor Vst; VIe,st |
| 3 | 1 | Alluvial cones, 17–10° | Stony land | Mid-slope forest; small-crowned hill forest | VIIe,st |

Geology.—Pleistocene and Recent coarse and fine fan-glomerate with local patches of volcanic ash.

Geomorphology.—Alluvial cones and fans: deeply dissected on the northern flanks of the Sibium Range. Short very steep straight slopes (1) make up the dissected parts, while very long narrow gentle (2) and moderate (3) concave slopes are parts of the original fan and cone surface.

Soils.—This land system has not been examined by the pedologist and limited data supplied by the geomorphologist during and after the survey do not allow definite classification of the soils. In unit 2 deep dark brown clay loam to clay soils appear to have developed in colluvial fan deposits. They have very dark weakly acid loamy surface soils resting on strongly acid clayey subsurface horizons merging into less clayey acid subsoils with marked influence of volcanic ash. The deeper subsoils are acid clays to heavy clays that can contain ultrabasic boulders. These soils appear to be related to 19, Samage family. Very bouldery upper slopes (3) have been classed as stony land. There is virtually no soil information on the steep slopes (1), which are probably partly very stony and partly covered by dark brown or yellow-brown acid clay loam soils. It is possible that the gentle crest slopes (2) are locally covered with moderately weathered volcanic ash soils, and some very stony black soils were observed on a lower slope in this land unit.

Drainage Status.—Generally well drained; steepest slopes in unit 1 probably excessively drained.

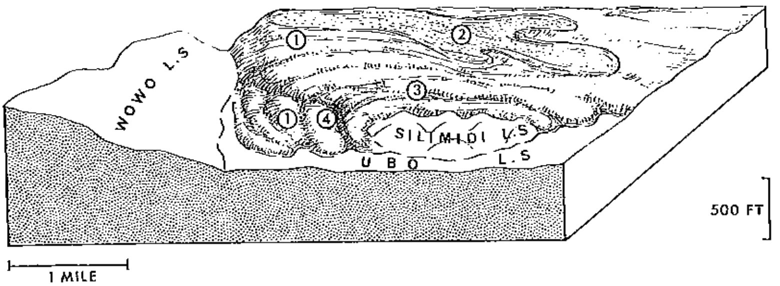
Vegetation.—The land system is almost completely forested, with plateau forest on gentle slopes (2) and mid-slope forest and small-crowned hill forest on steeper slopes (1,3). *Araucaria* occurs in all land units, scattered (3) or fairly dense (1, part 2), and with *Anisoptera* also common (2). Minor mid-height grassland and eucalypt savannah on lower slopes (1,2).

## (16) Ibinambo Land System (14 sq miles)

Undissected mudflow fan in eastern Musa basin, largely strongly weathered.

**Altitude.**—1900–3000 ft.

**Relief.**—Variable, 50–200 ft.




Land Units (3 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 10–11 | **Undulating surface, 1–5°** | 18, Wowo | Tall evergreen fan forest | I, IIe |
| 2 | 2–3 | **Mudflow tongue and flood-plain terrace** | No data. Probably 6, Taruma gravelly stony | Mixed *Casuarina* fan forest; minor *Casuarina* fan forest | VI–VIIst,a |
| 3 | 1 | **Wash courses, 0°30′–3°** | 6, Taruma gravelly stony | Tall evergreen fan forest | Vst,a |
| 4 | <1 | **Precipitous slopes, 50–70°** | Mainly stony land | No data, small-crowned hill forest | VIII |

**Geology.**—Late Pleistocene and Recent mudflow-fan deposits of unsorted Goropu Metamorphic rocks in a silty clay matrix. The Recent mudflow tongues are highly calcareous.

**Geomorphology.**—Mudflow fans: undissected, on northern margin very deep mass movement has caused a flow pattern of buckled ground and ravines. Very deep immature weathering. The gently undulating surface (1) of the fan is crossed by a recent mudflow tongue (2) and widely spaced wash courses (3) up to 1000 ft wide. Ravines up to 150 ft deep in the north have short precipitous slopes (4). A very small flood-plain terrace of Ibau Creek is also included in unit 2.

**Soils.**—Mostly deep friable clay soils: dark brown and neutral over dark red-brown and acid over strong brown and strongly acid (1). Stony calcareous undifferentiated colluvial soils, generally with much gravel at shallow depth, are found on wash courses (3) and presumably also cover the mudflow tongue and terrace (2).

**Drainage Status.**—Well drained.

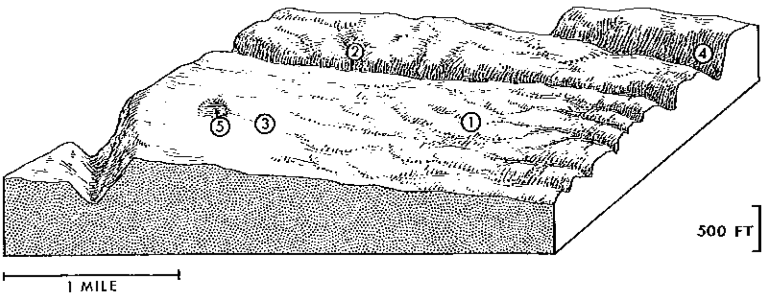
**Vegetation.**—Unbroken tall evergreen fan forest with emergents to 150 ft (1); Lauraceae common (high altitude); epiphytes, especially mossy, very common (high humidity). Tall mixed *Casuarina* fan forest on a mudflow tongue (2) within unit 1. To the south-west a narrow strip of *Casuarina* fan forest in Ibau Creek. Tall *Albizia* mainly along creeks. In wash courses (3) canopy more open, more climbers, little leaf litter. On occasional precipitous slopes (4) irregular small-crowned hill forest probably with *Casuarina papuana*.

## (17) Silimidi Land System (40 sq miles)

Deeply weathered corrugated mudflow fan in eastern Musa basin.

**Altitude.**—750–3500 ft.

**Relief.**—250–400 ft.




Land Units (4 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 28–32 | Undulating surface, 5–20° | 17, Silimidi | Mainly *Castanopsis* forest; mixed deciduous hill forest; mixed *Casuarina* hill forest; minor secondary forest and eucalypt savannah | IIIe, VIe |
| 2 | 4–6 | Irregular slopes, 30–50° | No data. Probably 17, Silimidi and stony land | No data | VIIe, VIII |
| 3 | 3–4 | Level surface, 0–3° | No data. Probably 17, Silimidi | No data, ?plateau forest | I |
| 4 | <1 | Precipitous slopes and cliffs, 50–90° | No data. Probably stony land and lithosols | No data | VIII |
| 5 | <1 | Flats in unit 3 | No data | No data, herbaceous vegetation | VIII |

**Geology.**—Pleistocene Silimidi beds, interbedded coarse fanglomerate and mudflows with at least two layers of ultrabasic breccia. Slight Recent tilting to WNW.

**Geomorphology.**—Mudflow fans: tilted and partly dissected, with very deep immature weathering and very deep secondary mass movement causing aligned corrugations. Predominantly corrugated undulating surface (1), mostly convex with short very steep irregular side slopes (2) and precipitous slopes and cliffs (4) up to 300 ft high adjacent to incised streams. An area less affected by mass movement forms a level surface (3) and has very small swampy flats (5) on it.

**Soils.**—Deep reddish over strong brown weakly acid to neutral friable clay to heavy clay soils with very poorly developed topsoils (1, probably 3). Similar soils may occur on the steep slopes of unit 2, probably shallower and more stony.

**Drainage Status.**—Well drained, except units 4 (excessively drained) and 5 (swampy).

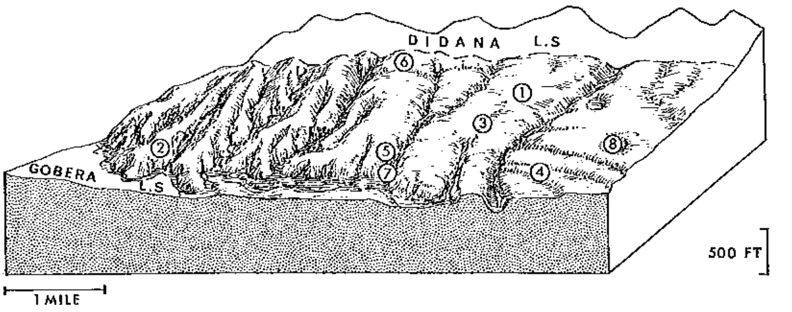
**Vegetation.**—Mainly *Castanopsis* forest in higher eastern part merging into mixed deciduous hill forest in the west, with common *Terminalia*, very common *Anisoptera*, and widely scattered *Araucaria*. Secondary vegetation ranging from grassland to young secondary forest, also some eucalypt savannah, near Silimidi, old secondary forest with patches of high emergent *Albizia falcata* further east. Probably tall plateau forest on the larger flattish areas of unit 3. Hill ridges of unit 1 in the north are commonly covered with mixed *Casuarina* hill forest; emergent *Casuarina papuana* over lower storeys of broad-leaf species. Poor irregular hill forest covers very steep slopes (2), grassland, scrub, and savannah probably precipitous slopes and cliffs (4). Very small flats (5) apparently have herbaceous vegetation.

## (18) Siviai Land System (25 sq miles)

Variably dissected strongly weathered mudflow fans in western Musa basin.

**Altitude.**—1050–2200 ft.

**Relief.**—Variable, up to 300 ft.




Land Units (6 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 9–10 | Fan slopes, 3°–0°30′ | 18, Siviai | Mid-height fan forest; some secondary forest | I, locally IIIst and Vst |
| 2 | 6–7 | Hill ridges, 30–40° | No data. Probably 14, Kambururu, and locally 18, Korua | No data, mid-slope forest and small-crowned hill forest | VIIe, VIII |
| 3 | 4–5 | Irregular slopes, 25–5° | 6, Minawake; 14, Aiare | Mid-slope forest; small-crowned hill forest; secondary forest | VIe |
| 4 | 2–3 | Land-slip strips | No data, probably same as unit 3 | Mixed *Casuarina* hill forest | ?IIIe, VIIe |
| 5 | 1 | Irregular lower slopes, 30–50° | Mainly stony land | No data, some small-crowned hill forest | VIII |
| 6 | 1 | Concave foot slopes, 7–4° | 14, Aiare | Small-crowned hill forest | IIe |
| 7 | 1 | Valley tracts | River wash | Eucalypt savannah | VIII |
| 8 | <1 | Depressions in unit 1 | 20, Imuru | Tall grassland | Vd |

**Geology.**—Late Pleistocene interbedded fan-glomerate and mudflows resting unconformably on both Domara River beds and Urere Metamorphic rocks.

**Geomorphology.**—Mudflow fans: variably dissected, ranging from hill ridges to unaffected level surfaces. Very deep immature weathering and very deep slumps in the south-east. Dominant undissected fan slopes (1) develop into hummocky gentle and moderate medium concave irregular slopes (3) and hill ridges (2) with medium, straight, very steep slopes on dissection. Through-going streams with narrow valley tracts (7) have very steep short irregular lower slopes (5) on their sides. In the south-east several land-slip strips (4) occur. Gentle concave foot slopes (6) margin the mountain front. Very small swampy depressions (8) occur on undissected fan surface.

**Soils.**—Strongly to moderately weathered acid soils: deep brown friable heavy clay with some concretions and thick less clayey dark brown to dark red-brown topsoil on undissected upper surfaces (1), very locally associated with strongly gleyed very plastic heavy clay soils with up to 20-in.-thick more friable clay surface horizon in swampy flats (8); mostly deep yellow-brown to yellow-red friable clay to clay loam, commonly with varying amounts of rather fresh gravel on colluvial slopes (3), concave foot slopes (5), and probably on hill slopes (2) and land-slip strips (4). The moderately weathered soils on slopes are associated in unit 3 and probably unit 4 with weakly acid more or less gravelly undifferentiated clayey colluvial soils, and in unit 2 probably with strongly acid red friable heavy clay soils on crests. Stony land on very steep dissection slopes (5).

**Drainage Status.**—Well drained except units 5 and 7 (excessively drained) and 8 (very poorly drained).

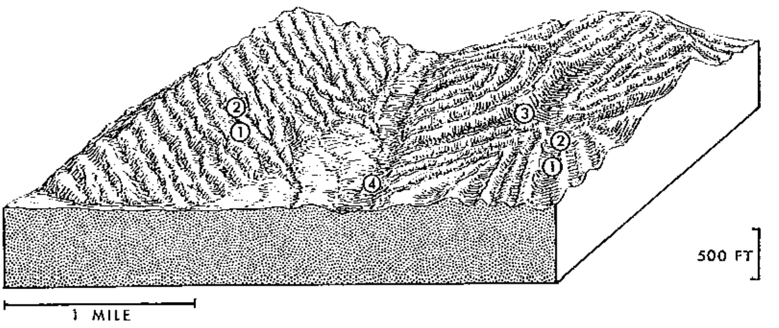
**Vegetation.**—Mainly mid-slope forest and small-crowned hill forest with scattered *Araucaria* (2,3); to the north-west, at the foot of the mountains, dominated by *Campnosperma* and *Livistona* palm (6). Mid-height fan forest, with *Anisoptera* very common, partly secondary, on a flattish area in the east (1). Extensive areas of secondary forest in the lower, southern part. Mixed *Casuarina* hill forest on crests of curved hill ridges in the south-east (4). Eucalypt savannah with scattered groups of *Casuarina* on terraces along major streams and in stream beds (7). Small-crowned hill forest, grassland, scrub, and savannah on very steep slopes adjacent to major streams (5). Tall grassland with widely scattered low trees in small poorly drained flats (8).

## (19) Wowo Land System (15 sq miles)

Parallel flat-topped hill ridges of deeply weathered mudflow fans on eastern margin of Musa basin.

**Altitude.**—1850–3500 ft.

**Relief.**—300–500 ft.




Land Units (3 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 6–7 | Upper convex slopes, 5–20° | 18, Moni; 17, Arumbai | Mid-slope forest, *Castanopsis* forest | VIe |
| 2 | 4–6 | Crestal strips | 18, Wowo | *Castanopsis* forest | IIIe |
| 3 | 1 | Lower straight slopes, 30–50° | No data. Probably 14, Kambururu | No data, probably mid-slope forest | VIIe, VIII |
| 4 | <1 | Concave foot slopes, 3–30° | 14, Aiare | Mid-slope forest | IIe, IId |

**Geology.**—Pleistocene Silimidi beds; interbedded coarse fanglomerate and mudflows, about 100 ft thick, resting unconformably on Goropu Metamorphic rocks. Strong Recent tilting.

**Geomorphology.**—Mudflow fans: strongly tilted and deeply dissected. Deep immature weathering. Parallel ridges with narrow straight crestal strips (2), moderate upper short convex slopes (1), and short very steep lower straight slopes (3) occasionally leading down to gentle and moderate short concave foot slopes (4).

**Soils.**—Deep strongly to moderately weathered strongly to weakly acid friable soils: strong brown rather heavy clay with yellow-brown less clayey surface horizon on convex upper slopes (1); thick dark brown clay with strong brown deeper subsoil on crestal strips (2); probably brown silty clay with varying amounts of gravel on very steep slopes (3); brown clay, slightly mottled in subsoil, on foot slopes (4).

**Drainage Status.**—Well drained except for imperfectly drained parts of foot slopes (4).

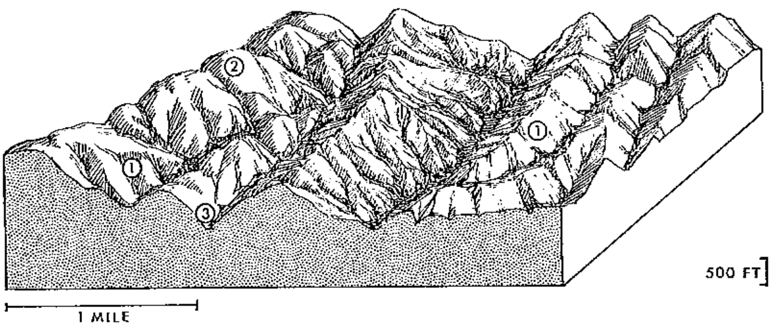
**Vegetation.**—Predominantly *Castanopsis* forest on the numerous long spur crests and ridges (2, part 1). Mid-slope forest (1,3,4) with scattered *Araucaria* on steep slopes (3), becoming larger-crowned and similar to plateau forest on gentle concave foot slopes (4).

## (20) Suwari Land System (45 sq miles)

Deeply weathered hill ridges on various rock types in the west.

**Altitude.**—West 1750–4300 ft; east 1000–1500 ft.

**Relief.**—West 300–1000 ft; east 200–400 ft.




Land Units (12 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 27–31 | Straight slopes, 30–45° | 14, Kambururu; locally 18, Aimare | Mid-slope forest; small-crowned hill forest; *Castanopsis* forest; mixed *Araucaria* hill forest; minor foothill forest | VIIe, VIII |
| 2 | 9–11 | Ridge and summit crests, 0–25° | 18, Moni, Aimare; locally 16, Sibium | Mainly *Castanopsis* forest; mid-slope forest | IIIe, VIe |
| 3 | 4–7 | Precipitous slopes and cliffs | No data. Probably mainly stony land | No data | VIII |

**Geology.**—?Cretaceous Urere Metamorphic rocks, conglomerate, and shale; ?late Cretaceous ?early Tertiary basic–ultrabasic plutonic rocks; both overlain by thick ?Pleistocene mudflows and colluvium. Pyroxene–basalt lava flow near Aiare. Patchy cover of andesitic ash in the west.

**Geomorphology.**—Hill ridges: with relict weathering profiles. Predominantly medium to very steep straight slopes (1) meeting in ridge and summit crests (2) up to 1000 ft wide. Precipitous slopes and cliffs (3) up to 300 ft high margin incised streams.

**Soils.**—Deep acid to strongly acid yellow-brown to yellow-red friable clay loam soils with much weathered gravel in subsoil occur on very steep slopes (1) and merge on crests (2) into deep strongly acid yellow-red to red, and moderately deep acid strong brown firm to friable heavy clay soils with brown less clayey surface horizon. The moderately deep heavy clay soils occur locally also on steep slopes (1), whilst moderately deep to deep acid yellow-brown friable clayey ash soils with thin dark topsoils locally overlie the weathering profile on crests (2).

**Drainage Status.**—Well drained.

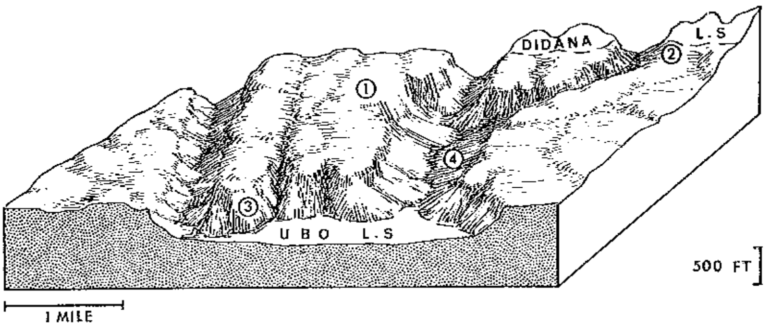
**Vegetation.**—Mainly mid-slope forest; *Castanopsis* forest on the numerous crests of unit 2. Small-crowned hill forest and mixed *Araucaria* hill forest on straight slopes (1), also at higher levels irregular type of *Castanopsis* forest, minor foothill forest on lower slopes. Irregular open canopy forest on precipitous slopes (3). Secondary forest around Aiare in the south.

## (21) Darumu Land System (18 sq miles)

Hillocky mudflow fans in eastern Musa basin with shallow texture-contrast soils.

Altitude.—1300–2200 ft.

Relief.—100 ft on plateau; 500 ft where dissected.




Land Units (2 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 6–8 | Hummocky slopes, 5–20° | 8, Berudi, locally stony | Mixed *Araucaria* hill forest; minor eucalypt savannah and very small-crowned hill forest | VIe,$s_2$,$s_3$, VIe,$s_2$ |
| 2 | 5–7 | Concave foot slopes, 10–2° | No data. Probably rather similar to unit 1 | No data, small-crowned hill forest and mixed deciduous hill forest | ?VIe,$s_2$ |
| 3 | 3–5 | Straight slopes, 30–40° | No data. Probably stony land and lithosols | No data, some small-crowned hill forest | VIII |
| 4 | 1 | Lower concave slopes, 25–5° | No data. Probably 6, Minawake | No data, mixed deciduous hill forest | ?VIe |

**Geology.**—Pleistocene Silimidi beds, interbedded coarse fanglomerate and mudflows with at least two layers of ultrabasic breccia.

**Geomorphology.**—Mudflow fans: with abundant small hillocks dissected by through-going streams. Shallow skeletal and immature weathering. Dominant gentle and moderate undulating hummocky slopes (1) merging into very long gentle concave foot slopes (2) adjacent to the mountain front. Through-going streams have medium very steep straight side slopes (3) with occasionally irregular gentle to moderate medium concave slopes (4), probably due to slumping.

**Soils.**—Very limited data indicate a predominance of shallow and locally stony neutral very plastic heavy clay soils with weakly acid thick dark coarser-textured topsoil and strongly weathered C horizon (1,?2). Lower concave slopes (4) probably have undifferentiated colluvial clayey and gravelly soils; steep slopes (3) probably have very shallow soils and stony land.

**Drainage Status.**—Mostly excessively drained, probably with temporary waterlogging after heavy rain in unit 1. Lower slopes (4) probably well drained.

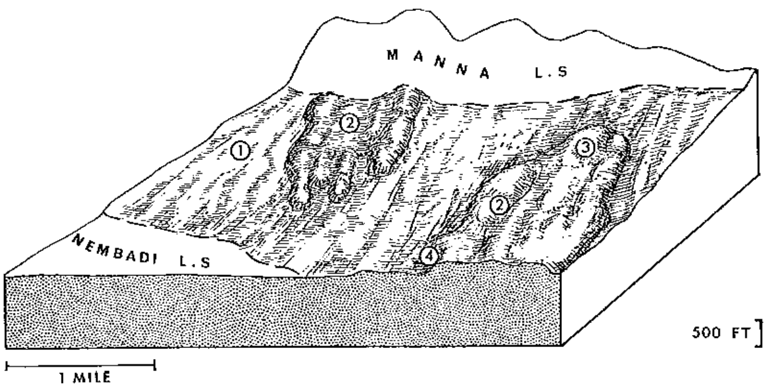
**Vegetation.**—On the plateau surfaces (1) mixed *Araucaria* hill forest with scattered *Casuarina* along the edges, interspersed with extremely small-crowned low hill forest mainly on the hummocks (forest regeneration from grassland?), minor eucalypt savannah with scattered *Casuarina* trees. Small-crowned hill forest, short grassland, scrub, and savannah on very steep slopes adjacent to incised streams (3). On the gentle hill slopes north of the plateau surfaces (2) small-crowned hill forest and mixed deciduous hill forest, which also occurs on lower foot slopes (4).

## (22) Iwuji Land System (17 sq miles)

Broad lava fans on eastern margin of Managalase area.

**Altitude.**—100–2000 ft.

**Relief.**—25–250 ft.




Land Units (8 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 8–9 | **Concave slopes, 10°–0°30′** | 16, Gewoia; probably 7, Kinjaki and Embessa | Mid-height fan forest and eucalypt savannah; minor mid-height grassland and tall evergreen fan forest | II–IIIe; locally $?IIIs_2$ |
| 2 | 6–8 | **Gently undulating surfaces, 0°30′–6°** | 8, Bua | | $IIe,s_2$ |
| 3 | <1 | **Scoria cones, side slopes 25–30°, and tumuli** | 7, Avikaro | | $VI–VIIs_3$ |
| 4 | <1 | **Irregular slopes, 30–35°** | Mainly stony land | No data, low fan forest | $VIIe,s_3$ |

**Geology.**—Late Pleistocene and Recent andesitic basalt lava flows with a thin veneer of fan-glomerate and rhyodacite ash.

**Geomorphology.**—Volcanic land forms: broad lava fans forming the eastern margin of the Mt. Manna volcanic field. Dominantly very long gentle concave slopes (1) with abundant gently undulating surfaces (2) on the most recent lava flows, which are margined by short very steep bouldery irregular slopes (4). Elliptical tumuli (3) up to 300 ft long and 6 ft high and scoria cones (3) up to 150 ft high occur on the most recent flows.

**Soils.**—The land system is characterized by weakly acid dark brown soils with thick dark topsoils. They comprise moderately deep to rather shallow firm clay soils on basalt with friable sandy oam to sandy clay loam surface layers approximately 1 ft thick (2), probably medium-textured and gravelly alluvial soils on fan-glomerate and locally friable sandy clay soils on ash deposits in unit 1, and very shallow medium-textured soils on tumuli and scoria cones (3) merging into stony land on short steep side slopes (4).

**Drainage Status.**—Mostly well drained with a tendency to excessive drainage in parts of unit 2 with rather shallow soils. Units 3 and 4 excessively drained.

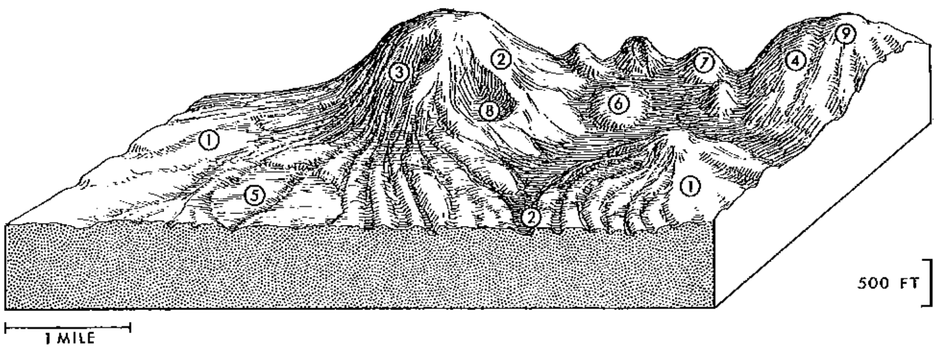
**Vegetation.**—Mid-height fan forest and tall *Eucalyptus tereticornis* savannah on the long gentle slopes of units 1–3; the forest occurs mainly in the higher western part, the savannah on the lower south-eastern and eastern slopes. In the north occasionally mid-height grassland or, on the lowest slopes, irregular tall evergreen fan forest (1).

## (23) Uoive Land System (115 sq miles)

Basalt plateaux in central Managalase area.

**Altitude.**—
250–4400 ft.

**Relief.**—
Very variable, up to 1000 ft.




Land Units (27 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 67–80 | Gentle undulating slopes, 0–10° | 14, Afore; 18, Togofu; 19, Samage; 16, Gewoia; locally 15, Ondoro and stony land | Regrowth and secondary forest, tall plateau forest | II–IIIe; locally VIst |
| 2 | 15–20 | Irregular slopes, 25–35° | 13, Geriwu; stony land | Mid-slope forest | VIIe,$s_2$ |
| 3 | 7–8 | Lava cones, 20–5° | 8, Bua; 16, Kwena | Largely regrowth; tall grassland | IIIe, VIe |
| 4 | 6–7 | Frilled flow-domes, 30–5° | 8, Bua | Largely regrowth and secondary forest | VI–VIIe; locally IIIe |
| 5 | 2–3 | Flats, 0–2° | 16, Uoive; 7, Kinjaki | Regrowth; tall grassland | I |
| 6 | 2 | Blocky cascades, 0–10° | Lava rubble land | Small-crowned hill forest | VIII |
| 7 | 2 | Cinder cones, 30° side slopes | 14, Afore | Mid-slope forest; mid-height grassland; foothill forest | VIIe |
| 8 | 2 | Explosion craters, 50–90° side slopes | No data. Open water and probably alluvial soils | No data, probably plateau forest, swamp woodland, open water | ? |
| 9 | 1–2 | Scoria mounds, convex, 2–30° | 13, Geriwu; stony land | Small-crowned hill forest; minor eucalypt savannah | VI–VIIe,$s_2$ |

**Geology.**—Late Pleistocene and Recent andesitic basalt lava flows, lava cones, cinder cones, scoria mounds, and blocky cascades. Minor explosion craters and a thin veneer of dacite ash.

**Geomorphology.**—Volcanic land forms: mostly a plateau between 2000 and 3000 ft composed principally of lava flows. Shallow skeletal weathering. Predominantly gentle undulating slopes (1) on flat-lying lava flows with short irregular steep slopes (2) on the flow margins and along dissecting ravines. Partly dissected lava cones (3) up to 600 ft occur mainly in the north-west. Frilled flow-domes (4) with bulging ridges have convex outlines and rise up to 800 ft above the general level near Bua. A large scoria mound (9) is situated at the eastern end of a line of perfectly preserved cinder cones (7) up to 600 ft high near Uoive. On the margins of the plateau some lava flows have formed blocky cascades (6). Scattered explosion craters (8) up to 1000 ft wide and 600 ft deep occur, and some are filled in as alluvial flats (5).

**Soils.**—A great variety of residual dark-coloured basalt soils and volcanic ash soils occurs on the lava flow surfaces (1) because of differences in age between lava flows and varying degrees of admixture with ash. Stony land is found near Ondoro and Dareki together with moderately deep to deep sandy loam to sandy clay ash soils. Moderately deep weakly acid dark brown firm clay soils occur on young gently undulating basalt flows and also on cinder cones (7), whilst deep acid dark brown very firm to very plastic sandy heavy clay soils with thick weakly acid coarser-textured surface horizons were commonly observed on rounded crests and steeper slopes of older flows in the west and south, where they are associated with deep dark brown sandy clay ash soils with thick dark topsoils on flatter areas and in depressions. The most-developed basalt soils, strongly acid moderately deep dark red-brown heavy clay soils, occur on surfaces of more dissected flows in the south-east. Finally, moderately deep weakly acid dark brown clay soils with thick dark coarser-textured topsoil occur on a large dissected lava cone (3) and on a frilled lava dome (4) in the centre of the land system. In contrast to the lava-flow surfaces, the very steep marginal and dissection slopes (2) as well as local scoria mounds (9) have poorly developed shallow acid dark soils or stony land. Small lava cones in the west (3) are thickly ash-mantled weakly acid yellow-brown very friable sandy clay loam soils with thick dark topsoil. Similar but more sandy soils occur together with alluvial soils with thick dark topsoil on small alluvial flats (5).

**Drainage Status.**—Well drained, except units 2, 4, and 9, which are excessively drained, and unit 7, which is partly poorly drained to swampy.

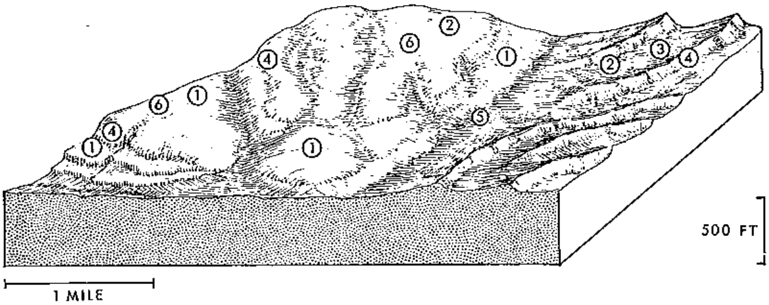
**Vegetation.**—Largely regrowth and secondary forest (1,3–5), locally with bamboo common, around the population centres Dareki, Kawowoki, Miniore; in the west near Afore fairly large areas of tall grassland. Where undisturbed the vegetation is tall plateau forest occurring as remnants in populated areas and on a few isolated smaller and one large lava flow in the south. Steep side slopes carry mid-slope forest (2). Probably *Castanopsis* forest and minor lower montane forest on highest ridges in the south. Low thin-stemmed nearly pure *Rhus taitensis* on bouldery land (6). Small-crowned hill forest and minor very open *Eucalyptus tereticornis* savannah on the shallow soils of unit 9. Rather irregular type of mid-slope forest and minor foothill forest and mid-height grassland in unit 7. Varied conditions in explosion craters (8): tall forest, swamp woodland, and open water without vegetation.

## (24) Asaga Land System (60 sq miles)

Valley benches, low cuestas, and valley-side strips with eucalypt savannah in Musa basin.

**Altitude.**—550–1200 ft, increasing westwards.

**Relief.**—25–200 ft.




Land Units (28 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 15–21 | Gentle concave lower slopes, 3°–0°30′ | 11, Dowai, Urere | Largely *Eucalyptus alba* savannah; minor mixed deciduous hill forest | VI$s_2$,$s_3$,e |
| 2 | 12–18 | Undulating slopes, 0–5° | 11, Dowai, Urere; locally 7, Moikodi, and 8, Domara; rarely 17, Jare | Eucalypt savannah | VI$s_2$,$s_3$,e; locally III$s_3$,e, Vst |
| 3 | 9–15 | Moderate concave slopes, 20–3° | 8, Domara; 11, Fiobobo; 7, Ariari; locally 17, Jare, Arumbai | As unit 1 | VIe,$s_3$ |
| 4 | 4–8 | Straight slopes, 20–30° | 14, Ibidura; 7, Asaga | | VIIe,$s_2$ |
| 5 | 3–5 | Wash courses and flats, 1°–0°15′ | 8, Domara; 7, Moikodi; locally 10, Mamana | As unit 1; locally *Nauclea–Antidesma* savannah | IV$s_2$,$s_3$; locally IV$s_3$ |
| 6 | 2–3 | Flats | 10, Awala | Mid-height grassland and *Nauclea–Antidesma* savannah | VId,$s_3$ |

**Geology.**—Plio-Pleistocene Domara River beds, greywacke siltstone, mudstone, and conglomerate; gently dipping and broadly folded. Local fan-glomerate and alluvium.

**Geomorphology.**—Low hills and undulating surfaces: valley-side strips, valley benches, and low cuestas in the Musa basin. Generally shallow skeletal weathering with local shallow mature weathering on some crests. Dominant very long gentle concave lower slopes (1) of valley-side strips lead down to widely spaced wash courses and flats (5) up to 2000 ft wide with local microrelief. The valley benches have gentle undulating crestal slopes (2) and are margined by short steep straight slopes (4). Low cuestas have similar scarp slopes (4) with long moderate concave dip slopes (3). Small flats (6) with converging drainage and local microrelief are associated with units 1–3.

**Soils.**—Predominantly weakly acid variably gleyed very plastic heavy clay soils with neutral to alkaline C horizon and with 5–9-in.-thick friable generally much coarser-textured surface horizon: weakly to moderately gleyed and mainly rather shallow on very long concave and undulating slopes (1,2); shallow and commonly gravelly or stony, but with thick dark topsoil on parts of dip slopes (3) and isolated small crestal areas of unit 2; similar but deeper and partly moderately gleyed on wash courses (5); strongly gleyed neutral but with weakly acid thick dark topsoil on drainage-collecting flats (6). Uniformly textured shallow to moderately deep weakly acid to neutral brown plastic heavy clay soils with thick dark topsoil occur locally on lower flats (5) and very locally on crests (2). Small more-weathered crestal areas in units 2 and 3 have shallow to moderately deep weakly acid to neutral yellow-red clay to heavy clay soils, commonly gravelly and in few cases with coarser-textured surface horizon. Steep slopes in units 3 and 4 are characterized by shallow to very shallow weakly acid moderately to very gravelly clay soils, mostly with thick dark topsoil.

**Drainage Status.**—Mostly excessively drained with temporary waterlogging after heavy rain, with parts of unit 5 predominantly poorly drained and poorly to very poorly drained small flats (6). Steeper slopes and crests (4, part 3, small parts of 2) excessively drained.

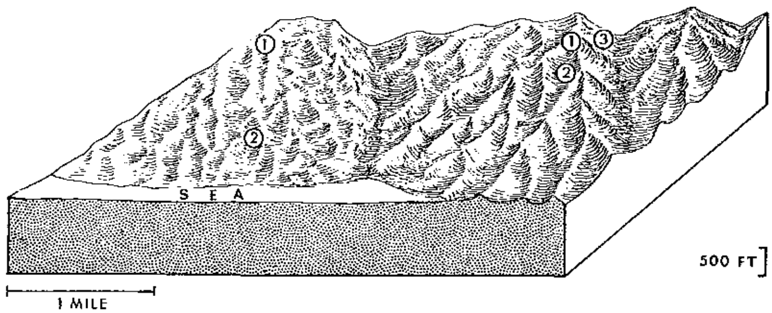
**Vegetation.**—Predominantly eucalypt savannah, mainly of rather low, often crooked *Eucalyptus alba*. Irregular mainly narrow patches of rather poor mixed deciduous hill forest, mainly in valleys and gullies. *Nauclea–Antidesma* savannah locally on sites with impeded drainage within the eucalypt savannah (5). Patchy tussocky mid-height grassland with few or rather many low *Nauclea* and *Antidesma* trees in poorly drained flats (6).

## (25) Banderi Land System (10 sq miles)

Strongly weathered planezes of Hydrographers Range.

**Altitude.**—0–1500 ft.

**Relief.**—300–800 ft.




Land Units (5 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 3–4 | Ridge crests, 0–20° | 18, Aimare; 14, Kambururu; locally 13, Geriwu, and 18, ?Korua | Mid-height grassland; minor eucalypt savannah and small-crowned hill forest | VIe,$s_2$; locally IIIe |
| 2 | 3–4 | Concave slopes, 20–10° | 18, Boro | Foothill forest; mid-slope forest; secondary forest | VIe |
| 3 | 1–3 | Straight slopes, 30–45° | 14, Kambururu; probably 13, Geriwu | Secondary forest; mid-slope forest | VIIe,$s_3$, VIII |

**Geology.**—Pleistocene andesitic ash and agglomerate with minor lava flows.

**Geomorphology.**—Low hills and undulating surfaces: radial hill ridges of partially dissected planezes with relict weathering profiles on the ridge crests. Predominant convex ridge crests (1) up to 600 ft wide with medium concave side slopes (2) and medium very steep straight lower slopes (3) in the more dissected portions.

**Soils.**—Strongly acid to acid, moderately to strongly weathered friable clay soils: shallow to rather shallow yellow-brown, commonly mottled and commonly with coarser-textured surface horizon on lower ridge crests (1), with locally deeper red heavy clay in the higher part of this unit; moderately deep brown to strong brown on upper side slopes (2); rather shallow yellow-brown silty clay on very steep slopes (3). Very shallow stony acid soils with thick dark topsoil occur locally on lower ridge crests (1) and are probably common on very steep slopes (3).

**Drainage Status.**—Ridge crests and very steep slopes (1,3) mostly excessively drained, partly well drained. Upper slopes (2) well drained.

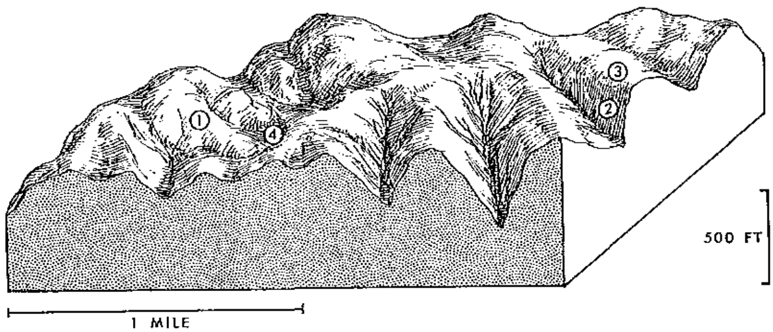
**Vegetation.**—Irregular fish-bone pattern of mid-height grassland on ridge crests and spurs (1) and irregular open commonly secondary mid-slope forest on side slopes (2,3). Foothill forest on lower slopes of unit 2. Minor narrow strips of eucalypt savannah on crests (1).

## (26) Avikaro Land System (95 sq miles)

Low hill ridges with strong earth flow in Musa basin, mainly on argillaceous rocks.

**Altitude.**—850–1950 ft.

**Relief.**—150–600 ft.




Land Units (14 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 47–57 | Very irregular slopes, 35–5° | 6, Minawake; 7, Ariari; locally 7, Bibira, Foasi | Mixed deciduous hill forest; secondary forest; minor eucalypt savannah | IIIe; VIe; VI–VIIe,$s_2$ |
| 2 | 26–30 | Straight slopes, 25–35° | 7, Moikodi; 8, Berudi | Mixed deciduous hill forest; secondary forest | VIe, VIIe |
| 3 | 9–19 | Upper slopes, 10–15° | 7, Asaga, Ariari; 6, Sisiworo; locally 11, Urere | | VIe,$s_3$; locally IVe,$s_2$,$s_3$ |
| 4 | 1 | Depressions in unit 1 | 3, Botame | Locally *Pandanus* swamp woodland | VId,$s_3$ |

**Geology.**—Plio–Pleistocene Domara River beds, mainly mudstone, greywacke-siltstone, and minor conglomerate. Gently dipping and broadly folded.

**Geomorphology.**—Low hill ridges: with very irregular hummocky slopes and very small depressions and lakes. Deep to very deep immature weathering with very strong deep earth flow. Dominant hummocky, medium to long, very irregular slopes (1) with common gullies and small depressions (4), interspersed with short very steep straight slopes (2) leading up to short moderate straight upper slopes (3).

**Soils.**—Complex soil pattern with weakly acid to neutral generally shallow clay soils with thick dark topsoils slightly dominant. These include very shallow clay to heavy clay on soft weathered C horizon or gravel beds (1,3); locally deeper heavy clay with very thick (up to 34 in.) dark topsoil on gentle slopes in unit 1; shallow very firm heavy clay which may be gravelly or have a coarser-textured surface horizon (2). Weakly acid undifferentiated clayey colluvial soils, commonly with gravel, are dominant on irregular slopes (1) and similar but very shallow soils are common on moderate upper slopes (3), where shallow gleyed very plastic heavy clay soils with coarser-textured surface horizon also occur locally. Depressions (4), where not forming lakes, have strongly gleyed weakly acid very plastic heavy clay alluvial soils.

**Drainage Status.**—Variably well and excessively drained, with very small very poorly drained to swampy depressions.

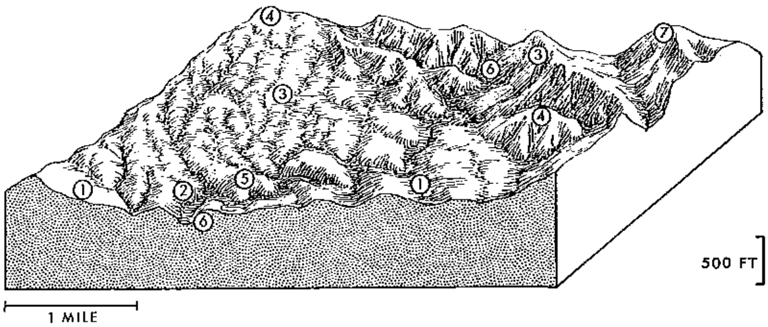
**Vegetation.**—Predominantly mixed deciduous hill forest (1–3), open and irregular with many larger trees bent downslope on the unstable slopes of unit 1. Bamboo often common, and locally abundant in secondary forest. Extensive areas of secondary forest. Minor eucalypt savannah mainly on crests and upper slopes in unit 1.

## (27) Aimare Land System (80 sq miles)

High hills with strong earth flow on hornfelsed basalt and conglomerate in Owen Stanley foothills.

Altitude.—1000–3100 ft.

Relief.—400–1000 ft.




Land Units (28 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 30–40 | Very irregular slopes, 35–5° | 6, Minawake | Mixed deciduous hill forest | IIIe, VI–VIIe |
| 2 | 20–30 | Straight slopes, 30–45° | 6, Minawake; 14, Didana; 7, Ariari; 6, Sisiworo | Mixed deciduous hill forest; eucalypt savannah; regrowth and secondary forest | VIIe,$s_2$, VIII |
| 3 | 6–10 | Corrugated surface, 10–30° | No data. Probably 6, Minawake; 7, Moikodi; 14, Emo | Mainly mixed *Araucaria* hill forest | IIIe, VI–VIIe |
| 4 | 6–10 | Ridge and summit crests, 0–15° | 7, Moikodi; 14, Emo | Mixed deciduous hill forest; secondary forest; locally *Castanopsis* forest | IIIe, VIe |
| 5 | 2–3 | Accordant spur crests, 0–10° | 17, Mioki, Arumbai; 18, Moni, Aimare | As unit 2; locally *Castanopsis* forest | IIIe, VIe |
| 6 | 1–2 | Irregular slopes, 40–60° | No data. Probably stony land | No data | VIII |
| 7 | 1–2 | Same as unit 4 on Domara River beds | 8, Berudi; 11, Dowai, Urere | Eucalypt savannah; secondary forest | VIe,$s_2$,$s_3$ |

**Geology.**—?Cretaceous metamorphic rocks, hornfelsed basalt with local calcareous pelite and limestone. Broadly folded, locally sheared and contorted; local patches of Plio–Pleistocene Domara River beds.

**Geomorphology.**—High hill ridges: with very irregular hummocky slopes and very small depressions and lakes due to very strong deep earth and debris flow. Deep to very deep immature weathering with relict weathering profiles on dissected valley-side strips between 2000 and 2400 ft. Dominant hummocky, medium to long, unstable slopes (1) with common gullies interspersed with medium very steep straight slopes (2) leading up to stable rounded ridge and summit crests (4 and 7) up to 600 ft wide. Near Ariari a valley-side strip has undergone wholesale mass movement resulting in a corrugated surface (3), while adjacent to the Urere River accordant spur crests (5) have relict weathering profiles. Medium precipitous irregular slopes (6) margin incised streams.

**Soils.**—Predominantly weakly acid to neutral generally gravelly moderately deep undifferentiated colluvial soils (1,2, probably 3) and very shallow to shallow soils with or without thick dark topsoils on soft weathered rock (2). Deep weakly acid to neutral brown to yellow-brown clay soils, with or without thick dark topsoil, occur on more stable convex crestal slopes (4, probably 3), whilst similar slopes on greywacke–siltstone (7) have rather shallow weakly acid to neutral very plastic heavy clay soils with coarser-textured surface horizons, medium to thick dark topsoils, and locally gleyed subsoils. The strongly weathered broad accordant spurs (5) have rather shallow to deep dark red-brown to red, weakly to strongly acid, friable to firm heavy clay soils, mostly with less clayey surface horizon.

**Drainage Status.**—The greater part of the land system is well drained, but the steep straight slopes of units 2 and 6 are generally excessively drained. Impeded drainage occurs locally in the slowly permeable soils of unit 7. Periods of soil-moisture deficiency can be expected throughout most of the land system, which is largely situated in the Musa valley low-rainfall belt.

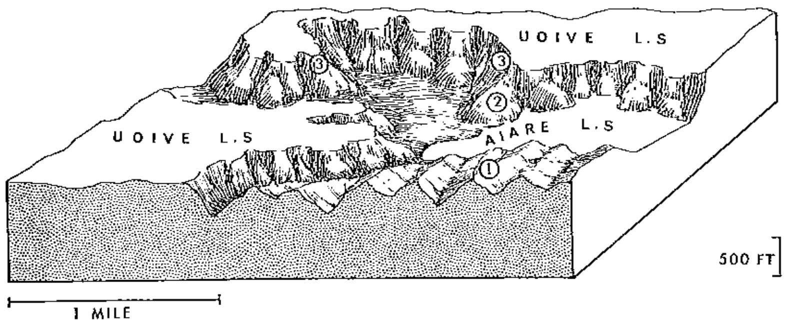
**Vegetation.**—Mixed deciduous hill forest covers most of the area and occurs on all land units. The forest tends to be more open and irregular on unstable slopes (1,2). At higher levels of units 4 and 5 it merges into *Castanopsis* forest. Climbing and scrambling bamboo is a normal feature and locally very common. As in evergreen hill forest, *Pometia* is very common on lower slopes. Widely scattered *Casuarina* and *Araucaria* occur throughout; in an area east of Ariari (3) *Araucaria* grows fairly dense, towering above otherwise low small-crowned forest. Around the population centres large areas of secondary forest are found; here also eucalypt savannah is common, especially near Imuruwake and along the Urere River.

## (28) Bariji Land System (25 sq miles)

Scarps and hill ridges adjacent to Bariji River gorge.

**Altitude.**—1000–1800 ft.

**Relief.**—250–600 ft.




Land Units (4 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 12–15 | **Straight slopes, 30–40°, and minor narrow crests** | 6, Sisiworo, Kosiwara; 8, Berudi; locally 18, ?Korua on narrow crests | Small-crowned hill forest; mid-slope forest; minor secondary forest and tall evergreen fan forest | VIIe,s₂, VIII |
| 2 | 7–10 | **Upper slopes, 40–60°** | Stony land; locally 14, Afore | Small-crowned hill forest; mid-slope forest | VIII |
| 3 | 1–3 | **Cliffs, 60–90°** | Stony land and rock outcrop | Small-crowned hill forest | |

**Geology.**—Pliocene Mamama beds, flat-lying lacustrine mudstone, ash, and greywacke; overlain by andesitic ash and agglomerate, and capped by Pleistocene and Recent basalt lava flows. In the south, late Pleistocene fan-glomerate overlies the Mamama beds.

**Geomorphology.**—Hill ridges: of equilibrium type with shallow skeletal weathering. Predominant medium very steep straight slopes (1) either meeting in narrow sharp ridge crests (1) or leading up to medium straight precipitous upper slopes (2) and cliffs (3) up to 250 ft high.

**Soils.**—Very shallow undifferentiated dark brown acid to weakly acid loam to clay loam soils (1) and stony land (2,3). Locally rather shallow more weathered dark brown neutral soils; firm sandy clay to sandy clay loam (2) and very firm heavy clay with dark more friable clay topsoil approximately 10 in. thick (1). What appear to be truncated acid yellow-red clay soils occur locally in the south on narrow crests on fan deposits.

**Drainage Status.**—Excessively drained.

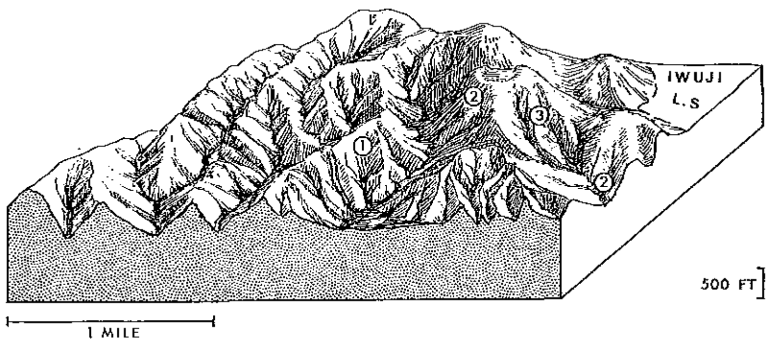
**Vegetation.**—Low and open hill forest, with bamboo often common, occurs in all land units, becoming very low and very open on precipitous slopes (3). To the east some deciduous trees come in. Some regrowth and secondary forest south of Toma and north of Biriri. Minor tall evergreen fan forest on gentle foot slopes of unit 1 near Bariji River.

## (29) Manna Land System (25 sq miles)

Hill ridges and dissected rhyodacite cones in eastern Managalase area.

**Altitude.**—200–3700 ft.

**Relief.**—500–1000 ft.




Land Units (4 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 16–19 | Straight slopes, very short to short, 30–40° | 6, Minawake; 13, Geriwu | Mid-slope forest; small-crowned hill forest; mid-height grassland; eucalypt savannah; minor secondary forest | VIIe,$s_2$, VIII |
| 2 | 2–5 | Precipitous slopes, very short, 40–70° | 7, Avikaro | Eucalypt savannah | VIII |
| 3 | 3–4 | Constructional slopes, of dacite cones, 30–35° | 6, Sisiworo | Mid-slope forest; minor lower montane forest | VIIe,$s_2$ |

**Geology.**—?Cretaceous Urere Metamorphic rocks, hornfelsed basalt, overlain by Pliocene Mamama beds of lacustrine sediments and agglomerate; with late Pleistocene and Recent rhyodacite cones in eastern part of land system.

**Geomorphology.**—Hill ridges: mostly of equilibrium type with shallow skeletal and immature weathering. Predominantly short to medium very steep straight slopes (1) meeting in sharp ridge crests. In the east rhyodacite cones have medium very steep straight slopes (3). Short precipitous slopes (2) margin incised streams.

**Soils.**—Very shallow acid to weakly acid loam to clay soils, having thick dark topsoil in units 1 and 2. Rather shallow undifferentiated dark brown colluvial soils occur also in unit 1.

**Drainage Status.**—Generally excessively drained.

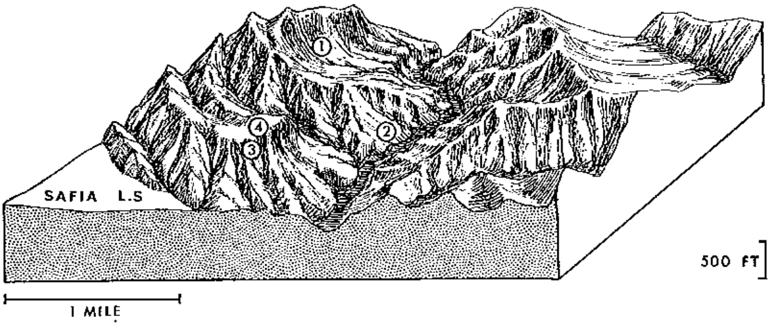
**Vegetation.**—Largely mid-slope forest, mainly in central highest part (3), with minor lower montane forest on narrow highest crests. Small-crowned hill forest especially in the south, with low eucalypt savannah on crests and very steep slopes (2, part 1); locally mid-height grassland; secondary forest around Ondoro in the north-west.

## (30) Adau Land System (10 sq miles)

Precipitous hill ridges and cliffs south-east of Safia.

**Altitude.**—600–2000 ft.

**Relief.**—1200 ft.




Land Units (0 Observation)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 4–6 | Straight slopes, 40–60° | No data. Probably rock outcrop and lithosols | No data | VIII |
| 2 | 1–3 | Concave slopes, short, 30–10° | No data. Probably stony land | No data, some mixed deciduous hill forest | ?VIIe,$s_2$ |
| 3 | 1–2 | Cliffs, up to 1000 ft high, 60–90° | Rock outcrop | Bare ground | VIII |
| 4 | 1 | Crestal flats, up to 600 ft wide, 2–10° | No data. Probably 8, Domara, stony | As unit 2 | ?VIIe,$s_2$ |

**Geology.**—Plio-Pleistocene Domara River beds, conglomerate, greywacke, and shale. Recently upfaulted.

**Geomorphology.**—Hill ridges: with precipitous slopes and prominent rock cliffs. A fine to ultra-fine pattern of dissection and shallow skeletal weathering. Dominant short precipitous straight slopes (1) meet in very sharp ridge crests. Cliffs (3) up to 1000 ft high surround isolated crestal flats (4) up to 600 ft wide and lead down to medium scree-mantled concave slopes (2).

**Soils.**—No data are available, but the land surface is likely to consist mainly of rock outcrop, stony land, and undifferentiated very shallow soils, with probably shallow neutral heavy clay soils with thick dark coarser-textured and stony topsoil on crestal flats (4).

**Drainage Status.**—Excessively drained.

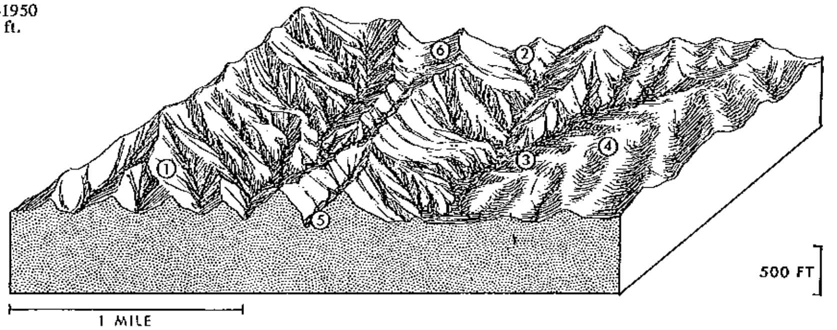
**Vegetation.**—Mainly low open forest, savannah, scrub, and short grassland (1), and bare ground (3). Irregular mixed deciduous hill forest on less steep slopes (2,4).

## (31) Arumbai Land System (120 sq miles)

Finely dissected hill ridges in Musa and Bubudi basins with intricate pattern of eucalypt savannah and mixed deciduous hill forest.

**Altitude.**—Musa basin, 650–1950 ft; Bubudi basin, 1900–3350 ft.

**Relief.**—250–1000 ft.




Land Units (20 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 85–95 | Straight slopes, 30–45° | 7, Asaga, Avikaro; 6, Sisiworo, Kosiwara, and locally Minawake | Largely eucalypt savannah; mixed deciduous hill forest | VIIe,$s_2$, VIII |
| 2 | 10–15 | Upper slopes and dip slopes, 10–25° | 7, Moikodi; 8, Berudi; 11, Fiobobo | Eucalypt savannah; garden regrowth | VIe,$s_2$ |
| 3 | 7–11 | Lower concave slopes, 10–3° | 14, Ibidura; 11, Fiobobo, Dowai; 17, Arumbai | Eucalypt savannah; mixed deciduous hill forest | IIIe,$s_3$ |
| 4 | 5–10 | Ridge crests, 1–5° | 17, Jare, Arumbai; 18, Korua; very locally 20, Imuru | Eucalypt savannah | IIIe |
| 5 | 1–3 | Precipitous slopes and cliffs, 50–90° | No data. Probably lithosols and rock outcrop | No data, eucalypt savannah | VIII |
| 6 | <1 | Benches and perched shallow valleys, 15–1° | 10, Awala | Eucalypt savannah | VIe,$s_3$ |

**Geology.**—Plio-Pleistocene Domara River beds, mainly greywacke–siltstone, conglomerate, and mudstone, broadly folded.

**Geomorphology.**—Hill ridges: of equilibrium type with a very fine dendritic drainage pattern. Generally shallow skeletal weathering with local shallow mature weathering on crestal areas. Predominantly short to long very steep straight slopes (1) meeting in sharp ridge crests. Remnants of former erosion surfaces occasionally form convex ridge crests (4) up to 400 ft wide. Structural control is often evident and dip slopes of hogbacks form medium to long moderate to steep upper slopes (2). In the less-incised portions short gentle concave lower slopes (3) occur with occasional deep gullies. Precipitous slopes and cliffs (5) up to 250 ft high margin incised streams. In the Bubudi basin there are very minor slope benches and perched shallow valleys (6) with short moderate to gentle concave slopes.

**Soils.**—Predominantly very shallow weakly acid clay to heavy clay soils, with or without thick dark topsoil (1,5, locally 2), mostly overlying hard weathered rock or gravelly sediments, locally on soft weathered rock. Undifferentiated gravelly colluvial soils occur locally on lower slopes in unit 1. More weathered weakly acid very firm to very plastic heavy clay soils have developed on most gentler slopes. These include shallow brown soils with thick dark topsoil and commonly a coarser-textured surface horizon (2); moderately deep to shallow brown soils with coarser-textured surface horizon (2,3); similar but gleyed soils (3); olive soils with alkaline C horizon (3) and less plastic reddish soils with coarser-textured surface horizon (3,4). Moderately deep to deep uniformly textured weakly to strongly acid reddish soils were found on some crests (4), very locally together with truncated strongly mottled acid heavy clay soils. Moderately deep strongly gleyed neutral very plastic heavy clay soils with 8–13-in.-thick dark weakly acid friable clay to clay loam topsoil occupy the small rather flat areas of unit 6.

**Drainage Status.**—Generally excessively drained. Crests (4) well to excessively drained, gentle lower slopes (3) well to imperfectly drained, small flat areas of unit 6 poorly drained.

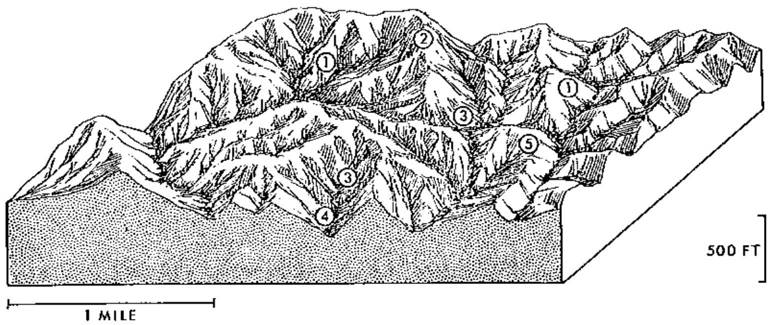
**Vegetation.**—The vegetation forms an intricate pattern of eucalypt savannah on crests and upper slopes and mixed deciduous hill forest on mid and lower slopes. *Anisoptera* is common throughout the forest; *Pometia* is common on lower slopes. Bamboo is usually present, locally common and commonly abundant in garden regrowth. On the steepest slopes (5, parts of 1) the forest tends to be irregular, open, and low, whilst in the eucalypt savannah the eucalypts are low and thin, the ground cover of grasses open. On poorly drained flatter areas (6) the eucalypts are widely scattered and sedges are very common in the grass cover.

## (32) Fiobobo Land System (200 sq miles)

Hill ridges on basic–ultrabasic rocks in Sibium and Didana Ranges.

**Altitude.**—225–2500 ft.

**Relief.**—400–1000 ft.




Land Units (11 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 160–170 | **Straight slopes, 30–45°** | 14, Didana; also 7, Avikaro; 6, Sisiworo | Small-crowned and very small-crowned hill forest; minor short grassland and scrub | VIIe,$s_2$, VIII |
| 2 | 12–20 | **Ridge crests, 0–20°** | 11, Fiobobo; 8, Berudi | As unit 1; minor secondary forest | IVe,$s_2$,$s_3$, VIe,$s_3$ |
| 3 | 8–16 | **Concave foot slopes, 20–10°** | 14, Didana stony; stony land | Mixed deciduous hill forest | VIe,st |
| 4 | 2–6 | **Precipitous slopes and cliffs, 50–90°** | No data. Probably rock outcrop and lithosols | No data | VIII |
| 5 | 2–4 | **Broad crests, 0–20°** | 17, Jare | Mid-slope forest | IIIe, VIe |

**Geology.**—?Cretaceous Urere Metamorphic rocks, mostly hornfelsed basalt, and ?late Cretaceous or ?early Tertiary basic–ultrabasic plutonic rocks.

**Geomorphology.**—Hill ridges: of equilibrium type with relict weathering profiles on subaccordant crests between 1250 and 1400 ft near the Musa gorge; otherwise shallow skeletal and immature weathering. Predominant medium and long very steep straight slopes (1) meet in convex ridge crests (2) up to 100 ft wide and locally up to 600 ft wide (5) near the Musa gorge. Precipitous slopes and cliffs (4) up to 200 ft high occur adjacent to incised streams, whereas in the less-incised portions of the land system short moderate concave foot slopes (3) are common and are often boulder-mantled.

**Soils.**—Predominantly very shallow neutral to weakly acid soils: dark red-brown to brown gravelly clay (1) and stony clay to heavy clay (3), and undifferentiated clay soils (1). Deeper but still rather shallow weakly acid to neutral very firm to very plastic heavy clay soils with friable to firm clay surface horizon, 6–12 in. thick, and commonly thick dark topsoil occur on many ridge crests (2) and have a thick mottled clayey C horizon. A few broad crests (6) are characterized by deep yellow-red to red weakly acid firm heavy clay soils.

**Drainage Status.**—Mostly excessively drained with generally well-drained foot slopes (3,4) and broad crests (6). Many crests (2) are imperfectly drained but also subject to rapid drying of the surface soil.

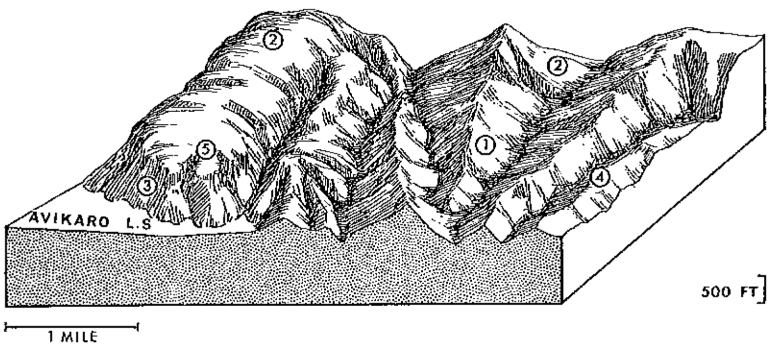
**Vegetation.**—Largely low small-crowned to very small-crowned thin-stemmed hill forest (1,2,4), very open on steepest slopes (4), locally scattered *Araucaria* and/or *Casuarina*, bamboo common. Poor and irregular mixed deciduous hill forest, with *Pometia* and *Anisoptera* common, on lower slopes bordering Musa valley (3), and here locally also small, occasionally large, areas of short grassland and scrub on steep slopes (1). Mid-slope forest to the north and north-east and locally elsewhere on deeper soils (5), *Anisoptera* common throughout.

## (33) Avuru Land System (60 sq miles)

Block mountains and hill ridges on ultrabasic rock in the south.

**Altitude.**—800–5500 ft.

**Relief.**—Very variable, 400–3000 ft.




Land Units (15 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 25–35 | Straight slopes, 30–40° | 7, Avikaro; locally 14, Didana | Short to mid-height grassland; eucalypt savannah | VIIe,$s_2$, VIII |
| 2 | 25–30 | Upper ridge crests, 10–30°, and irregular slopes, 10–30° | 7, Avikaro; 8, Berudi; 14, Didana; 17, Mioki; probably 18, Boro, at highest altitudes | Mixed *Casuarina* hill forest; mid-slope forest; lower montane forest; eucalypt savannah | VI–VIIe, VI–VIIe,$s_2$ |
| 3 | 1–2 | Fault scarps, 45–60° | No data. Probably rock outcrop and lithosols | No data, eucalypt savannah, scrub, and short grassland | VIII |
| 4 | 1 | Lower ridge crests, 3–25° | 18, Aimare | Eucalypt savannah | IIIe |
| 5 | <1 | Concave slopes, 5–20° | 6, Minawake; 7, Safia, Foasi; commonly gravelly or stony | Mid-slope forest; mixed deciduous hill forest; minor secondary forest and eucalypt savannah | IIIe; VIe; Vst |

**Geology.**—?Late Cretaceous or ?early Tertiary ultrabasic plutonic rocks. Pleistocene and Recent strong marginal up-faulting.

**Geomorphology.**—Block mountains and hill ridges: the former little dissected with shallow immature weathering, the latter with shallow skeletal weathering. At high levels, particularly in the block mountains, ridge crests (2) up to 2000 ft wide are surrounded by medium moderate irregular slopes (2) that lead down to long straight precipitous fault scarps (3). The hill ridges at lower levels have predominantly long very steep straight slopes (1) meeting in ridge crests (4) up to 600 ft wide. In the less-incised parts short concave foot slopes (5) occur.

**Soils.**—Predominantly very shallow weakly acid to neutral generally gravelly clay soils; mainly with thick dark topsoil overlying hard weathered rock (1,2), but commonly more weathered dark red-brown soils with poor topsoils (locally in 1, common in 2) or brown soils with coarser-textured surface horizon and thick dark topsoil (2). Such very shallow soils merge into shallow to moderately deep weakly acid to neutral dark red-brown to dark brown friable clay soils on short upper slopes in unit 2 and into moderately deep acid yellow-brown to strong brown firm rather heavy clay soils with less clayey surface horizon on crests (4). Rather similar but more acid soils occur probably at greater altitude in unit 2. On the other extreme there is probably hardly any soil on precipitous fault scarps (3). Various kinds of weakly acid to neutral colluvial soils, ranging in texture from gravelly clay loam to heavy clay and mostly having a thick dark topsoil, are found on local concave slopes (5).

**Drainage Status.**—Predominantly excessively drained with some well-drained crestal areas in units 2 and 4 and well to imperfectly drained colluvial slopes (5).

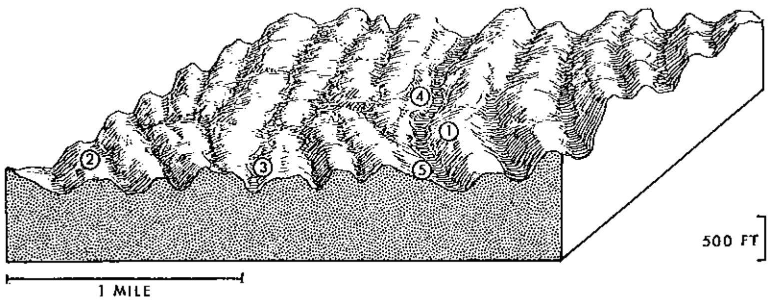
**Vegetation.**—Mainly short grassland, eucalypt savannah with widely scattered low eucalypts, and scrub (1,3,4). Mixed *Casuarina* hill forest fringing eucalypt savannah (2) and in a large complex in the south-east and here extending into the lower montane zone (2). Remnants of mid-slope forest with scattered *Araucaria* and *Casuarina* on more favourable sites (2,5). Minor mixed deciduous hill forest and secondary forest.

## (34) Tahama Land System (100 sq miles)

Ash-covered low hill ridges of western Managalase area.

**Altitude.**—1700–3200 ft.

**Relief.**—100–400 ft.




Land Units (18 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 35–50 | Upper straight slopes, 30–50° | 14, Kiara; 15, Ondoro | Regrowth and secondary forest; plateau forest; minor *Castanopsis* and mid-slope forest | VIIe, VIII |
| 2 | 25–40 | Ridge crests, 0–20° | 16, Gewoia, Kwena | Regrowth and secondary forest; plateau forest, tall grassland; minor *Castanopsis* forest | II–IIIe, VIe |
| 3 | 13–28 | Lower straight slopes, 30–50° | 14, Kambururu; locally 17, Jare | Secondary forest; foothill forest | VIIe, VIII |
| 4 | 2–5 | Concave slopes, 7–1° | 16, Kwena | Plateau forest; secondary forest; foothill forest | IIe |
| 5 | 1 | River terraces | 16, Kwena; probably 6, Gorabunina | Mainly secondary forest | I; IIst; IVf |

**Geology.**—Thick Pleistocene andesitic ash and agglomerate overlain by andesitic lahars. Late Pleistocene and Recent andesitic ash thickens north-west and averages 50 ft on ridge crests.

**Geomorphology.**—Hill ridges: of equilibrium type with accordant crests and relict weathering profiles. Parallel ridge crests (2) up to 600 ft wide lead down to upper (1) and lower (3) short very steep straight slopes. Adjacent to the larger streams medium lower concave slopes (4) and alluvial terraces (5) occur, 10–25 ft above the streams and up to 300 ft wide.

**Soils.**—Volcanic ash soils with thick dark topsoils on gentle to moderate slopes: dark brown weakly acid firm to friable sandy clay with sandy clay loam surface horizon on ridge crests (2), yellow-brown and dark brown very friable sandy clay loam on concave slopes (4), higher terraces (5), and locally on ridge crests (2). Alluvial ash soils occur on narrow flood-plain terraces (5). Straight slopes below crests (1) have deep acid yellow-brown loamy colluvial soils with much ash admixture and locally sandy ash soils with thin dark topsoils. Lower straight slopes (3) have acid to very acid yellow-brown to yellow-red silty clay to clay loam soils with very locally yellow-red to red weakly acid firm heavy clay soils.

**Drainage Status.**—Well drained.

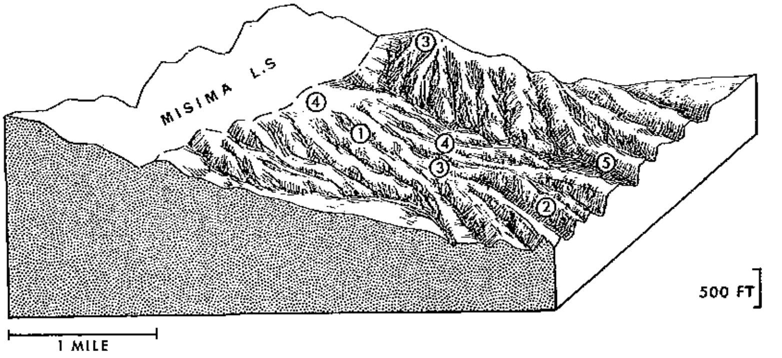
**Vegetation.**—Predominantly secondary forest and garden regrowth with many small scattered areas of tall grassland. To the north-west fairly large areas of plateau forest and, on the ridges at higher altitude, *Castanopsis* forest; locally mid-slope forest (1) and foothill forest on lower slopes (3).

## (35) Kovio Land System (19 sq miles)

Ash-covered high hill ridges in upper Kumusi River valley.

**Altitude.**—1500–3500 ft.

**Relief.**—750–1500 ft.




Land Units (14 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 6–8 | Upper straight slopes, 35–45° | 15, Sibium; 16, Uoive, Kwena; 14, Kiara | Mid-slope forest; regrowth and secondary forest | VIIe, VIII |
| 2 | 6–8 | Irregular lower slopes, 25–40° | 14, Aiare, Kiara | Mainly secondary forest; mid-slope and foothill forest | VIIe, VIII |
| 3 | 3–5 | Broad ridge crests, 0–20° | 16, Uoive, Owalama; very locally 18, Korua | Mainly secondary forest; *Castanopsis* forest; mid-slope forest | IIIe, VIe |
| 4 | 1–2 | Concave slopes, 15–2° | 6, Minawake; 14, Kiara; locally stony | Secondary forest | II–IIIe, Vst |
| 5 | <1 | Precipitous slopes and cliffs, 50–90° | ?6, Minawake, and stony land | No data | VIII |

**Geology.**—Late Pleistocene and Recent thick gravelly colluvium mantled in most parts by andesitic ash layers.

**Geomorphology.**—Hill ridges: of equilibrium type with deep immature weathering. Dissected former valley benches adjacent to the Owen Stanley fault. Predominantly short very steep straight slopes (1) and long irregular steep slopes (2) lead up to broad ridge crests (3) up to 1000 ft wide. Gentle to moderate long concave slopes (4) occur at the fault scarp and at the head of the lower benches. Precipitous slopes and cliffs (5) up to 200 ft high margin incised streams.

**Soils.**—Acid to weakly acid friable yellow-brown volcanic ash soils occur on ridge crests (3) and steep upper slopes (1). They have sandy loam, sandy clay loam, and sandy clay textures, and generally thick dark topsoils. They are deepest on crests and generally merge between 2½ and 6 ft into weathering profiles on steep slopes. On such slopes (1) the ash soils commonly have only thin dark topsoils and are associated with deep acid yellow-brown colluvial soils with much ash admixture. On lower slopes (2) these colluvial ash soils are in turn associated with acid strong brown to yellow-brown clay soils with gravelly layers. Strongly acid yellow-red firm heavy clay soils of the weathering profile are very locally exposed near crests (3). Acid undifferentiated or ash-mixed colluvial soils generally with moderately thick dark topsoil occur on gentle concave slopes (4). The steepest slopes (5) have stony land and probably undifferentiated gravelly colluvial soils.

**Drainage Status.**—Well drained, except for small parts of unit 4 along the Owen Stanley fault where strong seepage causes poor drainage.

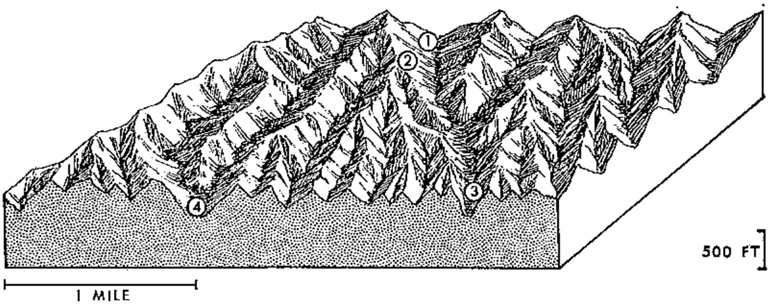
**Vegetation.**—Predominantly secondary forest and regrowth. Otherwise mid-slope forest at higher levels with *Castanopsis* common (1); foothill forest in valleys (2). *Castanopsis* forest (3) on upper slopes and crests. Irregular open forest where the hills slope very steeply down to streams (5).

## (36) Gorabuna Land System (30 sq miles)

Accordant hill ridges with ash-covered crests in the north.

**Altitude.**—1600–3200 ft.

**Relief.**—300–800 ft.




Land Units (7 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 25–26 | Straight slopes, 30–45° | 14, Kambururu, Kiara | Mid-slope forest; foothill forest; secondary forest | VIIe, VIII |
| 2 | 3–4 | Ridge crests, 0–30° | 16, Kwena | | IIIe, VIe |
| 3 | <1 | Precipitous slopes, 50–70° | No data. Probably mainly stony land | No data | VIII |
| 4 | <1 | Flood-plain terraces | 7, Embessa; 3, Bariji | Regrowth; sago swamp woodland; tall grassland | VIf,st, Vd,f |

**Geology.**—Pliocene Mamama beds of flat-lying conglomerate and mudstone. Pleistocene andesitic ash and agglomerate overlain by thick mudflow deposits. Remnants of late Pleistocene and Recent andesitic ash layers.

**Geomorphology.**—Hill ridges: of equilibrium type with relict weathering profiles on the parallel accordant crests. Predominantly short very steep straight slopes (1) lead up to ridge crests (2) occasionally up to 400 ft wide. Precipitous slopes and cliffs (3) up to 250 ft high margin incised streams, and rare flood-plain terraces (4) up to 600 ft wide margin some non-incised streams.

**Soils.**—Strongly acid to acid, yellow-brown to strong brown friable clay loam soils, commonly with much volcanic ash admixture (1). Deep dark brown weakly acid very friable sandy clay loam ash soils with thick dark topsoils on crests and uppermost slopes (2). Variable dark brown alluvial soils on flood-plain terraces (4) including stony coarse-textured soils with thick dark topsoil, and medium-textured soils with gleyed subsoil.

**Drainage Status.**—Well drained, except for small poorly drained parts of unit 4.

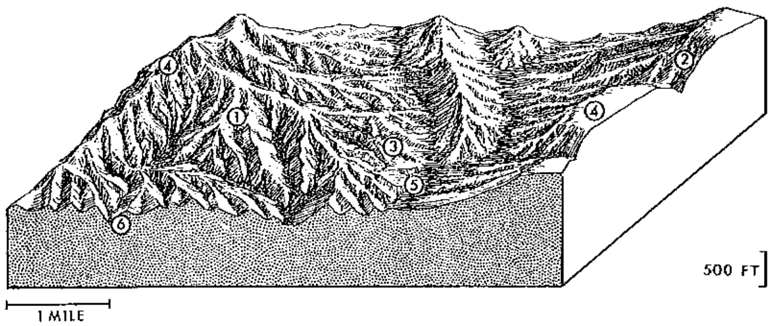
**Vegetation.**—Largely mid-slope forest with *Lithocarpus* common, also foothill forest (1,2). Large areas of secondary forest in the east and west. Regrowth, sago swamp woodland, and tall grassland on flood-plain terraces (4). Probably poor open forest on precipitous slopes (3).

## (37) OWALAMA LAND SYSTEM (90 SQ MILES)

Hilly ash-mantled high plateau of Owalama Range.

**Altitude.**—2000–5000 ft.

**Relief.**—Very variable, 30–1000 ft.




Land Units (8 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 36–45 | **Straight slopes, 30–40°** | 16, Uoive, Kwena; locally 18, Boro, and probably 14, Kiara | Mid-slope forest; lower montane forest | VIIe, VIII |
| 2 | 18–22 | **Irregular slopes, 30–45°** | As in unit 1, probably more 18, Boro | Mid-slope forest; small-crowned hill forest; minor lower montane forest | VIII |
| 3 | 13–18 | **Ash ridges, 55°, and minor valley flats, 10–1°** | 16, Owalama; no data for valley flats | As unit 2; no data for valley flats | |
| 4 | 12–15 | **Ridge and summit crests, 0–20°** | 16, Kwena; locally 14, Kiara | *Castanopsis* forest; lower montane forest | IIIe |

**Geology.**—?Late Cretaceous or ?early Tertiary basic–ultrabasic plutonic rock with late Pleistocene and Recent andesitic ash up to 120 ft in the north, thinning to 8 ft in the south. Recent up-faulting to form high plateau.

**Geomorphology.**—Hill ridges: of equilibrium type with a very fine dendritic drainage pattern. Deep mature weathering on the rocks below the Recent ash cover. Dominantly medium very steep straight slopes (1) and long very steep irregular slopes (2) meet in ridge and summit crests (4) that locally are up to 1000 ft wide. In flatter areas a maze of ash ridges (3) with short precipitous slopes are separated by valley flats up to 200 ft wide.

**Soils.**—Predominantly deep friable acid ash soils with thick dark topsoil: sandy loam (1,2), sandy clay loam (1,2,4), and sandy clay (3). Colluvial soils with much ash admixture were observed in unit 4, but probably occur also in units 1 and 2. Deep acid to strongly acid stony brown friable clay to heavy clay soils formed on basic–ultrabasic rock occur locally on steep slopes (1,2) in the south where the ash cover is thinnest.

**Drainage Status.**—Well drained, except for small poorly drained to swampy valley flats (part of 3).

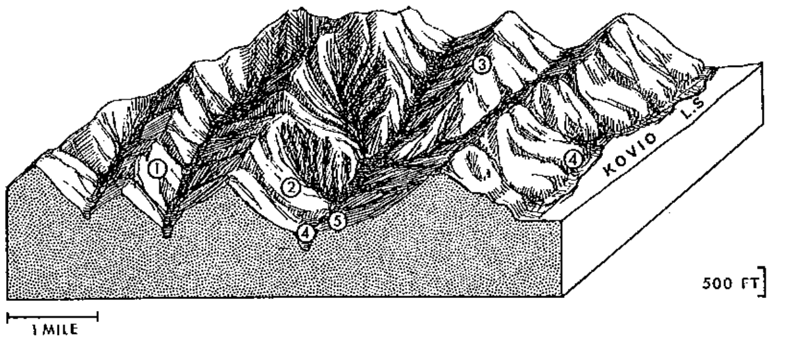
**Vegetation.**—Densely covered with forest, largely *Castanopsis* and lower montane forest (1,4), also rather irregular mid-slope forest (1,2,3) with *Canarium* sp. and *Castanopsis* common. To the south poor small-crowned hill forest with scattered *Araucaria* (2). Small-crowned forest in small possibly swampy valley flats (part of 3) in the central part of the land system.

## (38) Guaya Land System (85 sq miles)

Ash-covered mountain ridges of Guaya Range with dissected concave lower slopes.

**Altitude.**—900–5500 ft.

**Relief.**—800–2000 ft.




Land Units (10 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 45–50 | Straight slopes, 30–45° | 16, Kwena, Uoive; locally 18, Boro | *Castanopsis* forest; lower montane and stunted lower montane forest; secondary forest | VIIe, VIII |
| 2 | 25–30 | Concave lower slopes, 15–20° | 14, Kiara; 16, Owalama | Mainly foothill forest; mid-slope forest | VI, VIIe |
| 3 | 3–6 | Ridge crests, 0–30° | 16, Kwena; very locally 17, Silimidi | Lower montane forest; *Castanopsis* forest; mid-slope forest | IIIe, VIe |
| 4 | 2–4 | Precipitous slopes, 45–60° | 15, Ondoro; probably 14, Kiara; locally 18, Boro | *Castanopsis* forest | VIII |
| 5 | 1–2 | Alluvial terraces | 6, Gorabunina | Foothill forest | IIIe |

**Geology.**—?Late Cretaceous or ?early Tertiary basic–ultrabasic plutonic rocks and thick late Pleistocene and Recent andesite ash layers generally thinning southwards. Recent up-faulting to form block mountains.

**Geomorphology.**—Mountain ridges: with subaccordant crests in the south and prominent lower concave slopes in the north. Incised streams adjacent to marginal fault scarps have dissected most of the concave slopes into a maze of low ridges. Deep mature weathering of the rocks beneath the Recent ash. Dominant medium very steep straight slopes (1) meeting in narrow locally very sharp ridge crests (3) up to 200 ft wide. In the north gentle to moderate very long concave lower slopes (2) are frequently dissected in low ridges with steep side slopes, and occasional alluvial terraces (5) occur up to 40 ft above the streams and up to 200 ft wide. Precipitous slopes (4) up to 200 ft high margin incised streams.

**Soils.**—Mostly deep acid to weakly acid moderately weathered yellow-brown ash soils: sandy clay loam and sandy loam with thick dark topsoil on crests and upper slopes (1,3), sandy clay with thick dark topsoil, and colluvial soils with much ash admixture on lower slopes (2). The latter occur also on precipitous lower slopes (4) together with less colluvial sandy clay loam ash soils with thin dark topsoils. The ash soils generally overlie weathering profiles, which appear locally at the surface, giving rise to strongly weathered very clayey but friable soils. The only profile of this kind observed (in unit 3) is a weakly acid strong brown soil, but similar and more acid soils are likely to occur locally, also in units 1 and 4.

**Drainage Status.**—Well drained.

**Vegetation.**—Owing to the high altitude the main vegetation types are *Castanopsis* forest and lower montane forest (3, part 1). On very steep slopes the forest is open and irregular (1,4). *Casuarina*, widely scattered or forming a very open upper storey, occurs in unit 4. Mainly foothill forest is found in units 2 and 5. Old secondary forest with much *Albizia* is mainly concentrated along larger rivers, especially between Emo and Sirorata and between Gorabuna and Sirorata, often on very steep slopes. Widely scattered high emergent palms to 120 ft occur on the western edge of the land system.

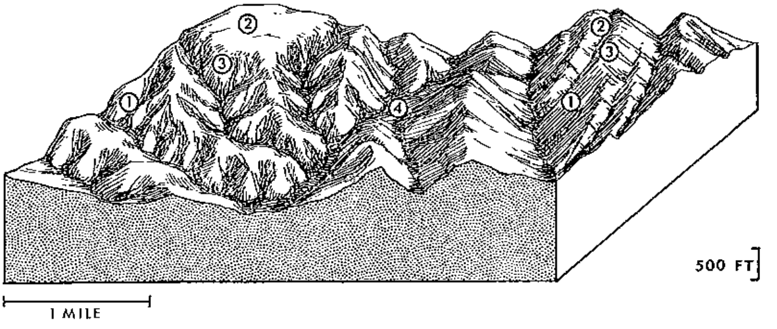
**Inclusion.**—Very steep low hills of strongly weathered basalt near Sirorata, with shallow weak red strongly acid soils (18, Sirorata) and yellow-brown ash soils (16, Kwena) on crests. *Castanopsis* and mid-slope forest.

## (39) Foasi Land System (70 sq miles)

Mountain ridges in the south with prominent deeply weathered broad crests.

**Altitude.**—3000–5500 ft.

**Relief.**—1000–2000 ft.




Land Units (8 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 39–45 | Straight slopes, 35–45° | 14, Kambururu; probably also 6, Minawake, on lower slopes | Lower montane forest | VIII |
| 2 | 14–18 | Ridge and summit crests, 1–15° | 18, Korua | Lower montane forest; *Castanopsis* forest | II–IIIe |
| 3 | 7–10 | Upper convex slopes, 10–40° | 18, Korua; 17, Jare | *Castanopsis* forest; minor regrowth and secondary forest | VI–VIIe |
| 4 | 2–4 | Concave foot slopes, 20–10° | 6, Minawake | Foothill forest; mid-slope forest | IIIe, VIe |

**Geology.**—?Cretaceous Urere Metamorphic rocks, hornfelsed basalt, calcareous pelite, and some limestone. Broadly folded and locally intensely sheared.

**Geomorphology.**—Mountain ridges: mostly of equilibrium type, compartmented by rectangular drainage trending north-east and north-west. Shallow and deep immature weathering with relict weathering profiles on broad crests. Predominantly long very steep straight slopes (1) occasionally with short moderate concave foot slopes (4). Moderate to very steep medium upper convex slopes (3) with knife-edge ridges due to small-scale slumping lead up to broad ridge and summit crests (2) up to 1000 ft wide.

**Soils.**—Moderately weathered deep strongly acid red-brown to strong brown very friable silty clay to sandy clay loam soils on very steep slopes (1) merge into strongly weathered deep yellow-red to red strongly acid (acid to weakly acid in unit 3) firm to friable heavy clay soils on broad crests (2) and upper slopes (3). Weakly acid undifferentiated clayey colluvial soils with gravelly layers occur on local concave foot slopes (4), and probably on lower portions of long straight slopes (1).

**Drainage Status.**—Well drained.

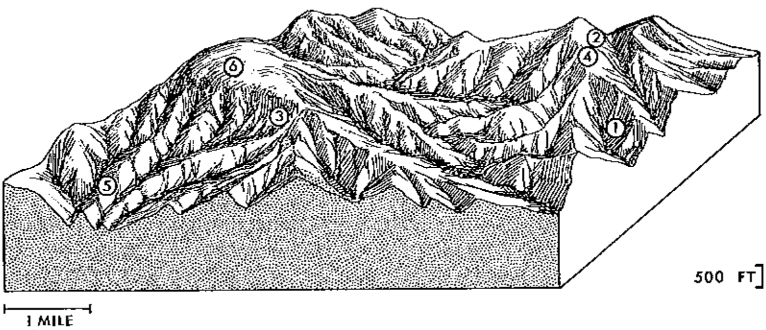
**Vegetation.**—Largely lower montane forest (1,2) and *Castanopsis* forest, *Castanopsis* abundant particularly on crests (2). On lower slopes (4) mid-slope forest with *Lithocarpus* and *Castanopsis*, locally *Dillenia*, common. Foothill forest at foot of slopes (4). Widely scattered *Araucaria* common, sometimes fairly dense on the slump slopes of unit 3. Minor regrowth and secondary forest.

## (40) Hydrographers Land System (55 sq miles)

Mountain ridges of dissected andesitic strato-volcano (Hydrographers Range).

**Altitude.**—250–6280 ft.

**Relief.**—1000–2500 ft.




Land Units (5 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 32–40 | Straight slopes, 30–50° | 13, Geriwu and stony land | Mid-slope forest | VIII |
| 2 | 7–13 | Upper straight slopes, 25–35° | 14, Kambururu | Lower montane forest; *Castanopsis* forest | VIIe, VIII |
| 3 | 2–4 | Precipitous slopes and cliffs, 50–90° | Rock outcrop and stony land | No data, some bare ground and grassland | VIII |
| 4 | 2–4 | Upper spur crests, 2–25° | 15, Siurani; 18, ?Korua | Stunted lower montane forest | IIIe, VIe |
| 5 | 2–4 | Lower spur crests, 2–25° | 18, Togofu | Mid-slope forest; secondary forest | |
| 6 | 1–2 | Undulating slopes, 5–20° | No data. Probably 16, Kwena; 18, Korua | No data, probably plateau forest | VIe |

**Geology.**—Pleistocene andesitic ash and agglomerate with thick late Pleistocene and Recent andesitic ash layers in the west.

**Geomorphology.**—Mountain ridges: of equilibrium type of deeply dissected strato-volcano in the early residual stage. Shallow immature weathering except on major spurs and some upper slopes with relict weathering profiles. Predominantly medium very steep straight slopes (1) meeting in spur crests up to 100 ft wide (4) at higher altitudes and 300 ft wide (5) lower down. Intervening short steep upper straight slopes (2) are developed on relict weathering profiles. Precipitous slopes and cliffs (3) up to 300 ft high, sometimes resembling pali, are common along the sides of some headwater valleys. A broad col with gentle to moderate undulating slopes (6) is an ash-covered lava flow.

**Soils.**—Limited data indicate a sequence of strongly weathered acid to strongly acid friable heavy clay soils on crests (moderately deep and dark red-brown in unit 5, probably deep and red in unit 4); moderately weathered deep acid to strongly acid strong brown to yellow-red very friable silty clay to silty clay loam soils on very steep upper slopes (2); little-weathered shallow acid dark brown gravelly clay loam to sandy loam soils with thick dark topsoil, and stony land on very steep lower slopes (1). On ash-covered crests (4, probably 6) a deep dark brown sandy clay ash soil with thin dark topsoil, sandy clay loam surface horizons, and probably a podzolic organic B horizon at 15–18 in. was observed at 5000 ft, whilst normal yellow-brown sandy clay loam ash soils with thick dark topsoil may also occur.

**Drainage Status.**—Well drained (1,2,4,5,6) to excessively drained (1,3).

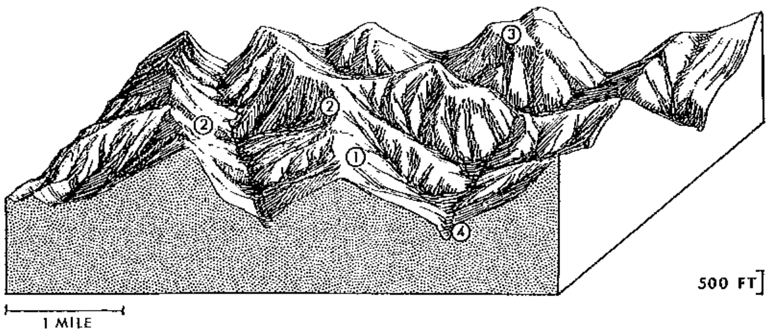
**Vegetation.**—Mainly mid-slope forest becoming irregular to the north-east (old secondary) and poor to the south-east (1), and via *Castanopsis* forest merging into lower montane forest at higher altitude (2), stunted lower montane forest on highest crests (4). Very open forest on steepest slopes with patches of bare ground and grassland (3). Very rarely tall plateau forest on gentle slopes (6).

## (41) Amora Land System (95 sq miles)

Mountain ridges in Owen Stanley foothills with hummocky concave slopes and common deep earth flow.

**Altitude.**—1100–5500 ft.

**Relief.**—1500–2500 ft.




Land Units (5 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 55–65 | Straight slopes, 25–50° | 6, Minawake | Mid-slope forest; lower montane forest; mixed *Araucaria* hill forest; secondary forest; minor mixed deciduous hill forest and eucalypt savannah | VIIe, VIII |
| 2 | 14–24 | Concave slopes, 20–5° | 11, Fiobobo | Mid-slope forest; secondary forest; minor mixed *Araucaria* hill forest | VIe,$s_3$ |
| 3 | 6–11 | Ridge and summit crests, 0–20° | 18, Boro, ?Korua | Lower montane forest; *Castanopsis* forest | IIIe, VIe |
| 4 | 5–9 | Precipitous slopes and cliffs, 50–90° | Stony land and rock outcrop | No data | VIII |

**Geology.**—?Cretaceous Urere Metamorphic rocks, hornfelsed basalt, and conglomerate; broadly folded, locally intensely sheared.

**Geomorphology.**—Mountain ridges: of equilibrium type with mostly shallow and deep immature weathering and relict weathering profiles on some crests. Common deep earth flow and occasional slumping. Predominantly long very steep straight slopes (1) meet in broad ridge and summit crests (3) up to 1000 ft wide. Common gentle to moderate hummocky concave slopes (2) are associated with earth flows and slumps, and precipitous slopes and cliffs (4) up to 300 ft high occur as scarps and are also adjacent to incised streams.

**Soils.**—Rather shallow weakly acid undifferentiated colluvial clay soils with varying amounts of gravel (highest in subsoil) on very steep slopes (1) contrast with moderately deep to deep weakly acid very plastic heavy clay soils with approximately 15–20-in.-thick firm clay surface horizons on gentler slopes (2). These latter soils locally merge into underlying weathering profiles. Deep acid to very acid brown friable clay soils and probably also red heavy clay soils are characteristic for upper broad ridge crests (3).

**Drainage Status.**—Mostly well drained, locally imperfectly drained in unit 2, excessively drained in unit 4.

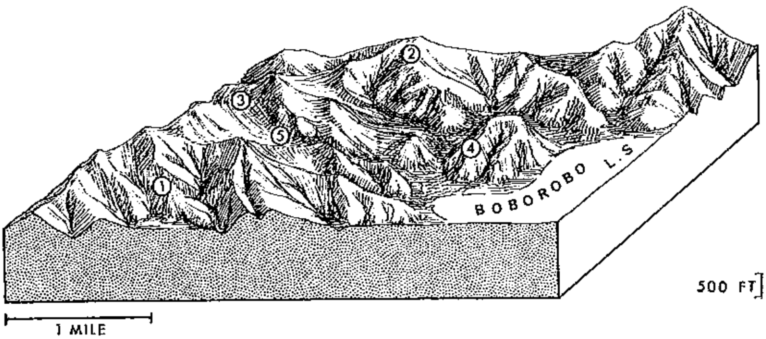
**Vegetation.**—Densely forested with lower montane and *Castanopsis* forest (1,3) and a rather irregular type of mid-slope forest that becomes very open and irregular on precipitous slopes (4). Scattered to fairly dense *Araucaria* in the north-west in otherwise poor forest on unstable slopes (1,2). Secondary forest particularly near Namudi and Liamu. Minor mixed deciduous hill forest with patches of eucalypt savannah (1) in the south-east.

## (42) Sesaro Land System (70 sq miles)

Mountain ridges of dissected basalt shield volcano in centre of area.

**Altitude.**—50–4400 ft.

**Relief.**—1000–3000 ft.




Land Units (7 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 55–57 | **Straight slopes, 30–45°** | 14, Afore; very locally 18, Togofu; stony | Mid-slope forest; small-crowned hill forest; locally lower montane forest; minor eucalypt savannah and mid-height grassland | VIIe,$s_3$, VIII |
| 2 | 7–10 | **Ridge crests, 2–30°** | 7, Avikaro; locally 18, Aimare; commonly stony | Small-crowned hill forest | VIe, VIIe,$s_2$ |
| 3 | 2–3 | **Irregular slopes, 45–60°** | Stony land | | VIII |
| 4 | <1 | **Volcanic necks, 25–35°** | 14, Afore; locally rock outcrop and stony land | Mid-slope forest; mid-height grassland | VIIe,$s_2$, VIII |
| 5 | <1 | **Concave foot slopes, 25–5°** | No data. Probably stony land | Foothill forest | VIe,st |

**Geology.**—Pliocene Sesaro volcanic rocks, mostly andesitic basalt agglomerate with some lava flows and minor intrusives. Often moderately dipping between 20° and 45°.

**Geomorphology.**—Mountain ridges: of equilibrium form forming a concentric belt around the Sesaro upland basin. Two centrally placed volcanic necks are included. Mainly shallow immature weathering. Predominantly medium very steep straight slopes (1), often bouldery, meeting in narrow ridge crests (2) up to 150 ft wide that frequently bear large monoliths. Locally short precipitous irregular slopes (3) correspond with hard rock bands, and below them occur moderate to gentle short boulder-mantled concave foot slopes (5). The volcanic necks (4) up to 1000 ft high have mostly steep and very steep slopes with minor rock cliffs and scree slopes.

**Soils.**—Shallow stony acid to weakly acid dark brown clay loam to silty clay soils (1,4) with thick dark topsoil on crests (2). Rather shallow to moderately deep acid to strongly acid dark red-brown, and stony brown firm heavy clay soils with less clayey surface horizon occur locally on crests (2), very locally on steep slopes (1). Stony land on steepest slopes (3,4) and probably on concave foot slopes (5).

**Drainage Status.**—Excessively drained, well drained in highest parts.

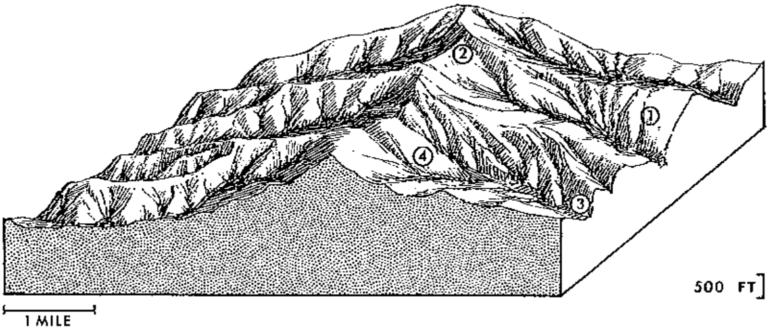
**Vegetation.**—Largely mid-slope forest (1), to the north and north-east small-crowned hill forest (2,3, part 1), with some deciduous trees and *Anisoptera* very common, to the north interspersed with eucalypt savannah and mid-height grassland (1). Lower montane forest at higher altitudes in unit 1. Foothill forest on foot slopes (5).

## (43) Didana Land System (140* sq miles)

Mountain ridges on basic–ultrabasic rocks in Sibium and Didana Ranges.

**Altitude.**—250–7150 ft.

**Relief.**—1000–3000 ft.




Land Units (7 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 120–140 | Straight slopes, 30–45° | 14, Didana, Emo; commonly stony | Lower montane and stunted lower montane forest; small-crowned hill forest; mid-slope forest | VIIe,$s_2$, VIII |
| 2 | 16–25 | Ridge crests, 2–30° | 18, Boro, Moni; 16, Kwena; 15, Sibium; 14, Kiara | *Castanopsis* forest; lower montane forest; minor mid-height grassland | IIIe, VIe |
| 3 | 5–8 | Precipitous slopes and cliffs, 50–90° | No data. Probably stony land | No data | VIII |
| 4 | 3–6 | Concave slopes, 25–5° | No data. Probably 14, Emo, stony | | VIe,st |

**Geology.**—?Late Cretaceous or ?early Tertiary basic–ultrabasic plutonic rocks. Thin late Pleistocene and Recent andesitic ash layers in west.

**Geomorphology.**—Mountain ridges: of equilibrium type, leading up to a central crestal ridge along the axis of recent up-arching. Shallow and deep immature weathering. Common debris avalanche and occasional slumps. Predominantly very long very steep straight slopes (1), often bouldery, meeting in ridge crests (2) up to 600 ft wide. Moderate to gentle hummocky long concave slopes (4) are associated with slumps, and precipitous slopes and cliffs (3) up to 400 ft high margin the incised streams.

**Soils.**—Predominantly shallow weakly acid dark red-brown to strong brown friable gravelly or stony clay soils (1, probably 4), merging into stony land on the steepest slopes (3). On the broader crests (2) occur rather shallow to deep acid friable stony brown clay soils and yellow-red heavy clay soils with strong brown less clayey surface horizon, except in the western part of the Sibium Range where yellow-brown acid to weakly acid ash soils predominate, ranging from fine sandy clay loam with thick dark topsoil through similar or finer-textured soils with thin topsoil to colluvial clay to clay loam soils with much ash admixture. The last two types of soil generally overlie weathering profiles at about 4 ft depth.

**Drainage Status.**—Drainage status varies with depth of soil, variation in rainfall, and steepness and position of slope. It ranges from excessively drained, particularly on upper slopes and crests with shallow soils in the south and east, to well drained in the west and north and on lower slopes, particularly where soils are deeper.

**Vegetation.**—The bulk of the vegetation appears to be rather small-crowned thin-stemmed hill forest with locally better mid-slope forest. Above the *Castanopsis* forest (especially unit 2) a large area of lower montane forest and, on the highest ridges, stunted lower montane forest occur. Scattered *Araucaria* is found on the long steep slopes with small-crowned hill forest of unit 1. Scrambling and climbing bamboo is very common.

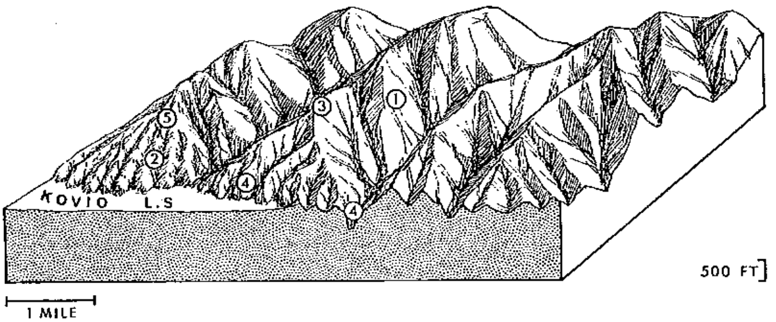
* An additional 20 sq miles in the Wanigela–Cape Vogel area also mapped and included in land unit areas.

## (44) Misima Land System (125 sq miles)

Mountain ridges of Owen Stanley Range on phyllite.

**Altitude.**—2000–9000 ft.

**Relief.**—2500–3500 ft.




Land Units (9 Observations)

| No. | Area (sq miles) | Land Form | Soil Group and Family | Vegetation | Land Class |
|---|---|---|---|---|---|
| 1 | 100–106 | **Straight slopes, 35–40°** | 6, Minawake | Lower montane forest; mid-slope forest | VIII |
| 2 | 6–10 | **Irregular lower slopes, 15–30°** | 14, Emo; 6, Minawake; 16, Kwena | Mid-slope forest; secondary forest | VI–VIIe |
| 3 | 4–6 | **Ridge crests, 5–30°** | 16, Owalama; 14, Kiara | Lower montane and stunted lower montane forest | IIIe, VIe |
| 4 | 2–5 | **Precipitous slopes and cliffs, 50–90°** | No data. Probably stony land and rock outcrop | No data | VIII |
| 5 | 2–5 | **Convex slopes, 5–30°** | 13, Geriwu; 14, Emo, Kiara | Lower montane forest; mid-slope forest; secondary forest | VI–VIIe,$s_2$ |

**Geology.**—?Palaeozoic Owen Stanley Metamorphic rocks, quartz–sericite–chlorite phyllite, commonly calcareous. Isoclinally folded, trending ESE. Late Pleistocene and Recent andesitic ash layers on spurs and crests.

**Geomorphology.**—Mountain ridges: of equilibrium type, terminated by the Owen Stanley fault scarp. Deep stream incision adjacent to this fault. Shallow and deep immature weathering. Predominantly very long very steep straight slopes (1) meeting in narrow convex ridge crests (3) up to 100 ft wide which are locally more deeply weathered and sometimes very sharp. Near the Owen Stanley fault precipitous slopes and cliffs (4) up to 500 ft high occur adjacent to incised stream courses. The mature fault scarps have medium moderate to steep convex upper slopes (5) and long irregular steep lower slopes (2), often with strong seepage near their base.

**Soils.**—Predominantly weakly acid undifferentiated colluvial silty clay loam soils with much gravel (1,2), with locally moderately weathered shallow to moderately deep acid to weakly acid yellow-brown clay soils on fault scarp slopes (2,5) and shallow clay loam soils with thick dark topsoils on upper fault scarp slopes (5). Deep yellow-brown acid to weakly acid friable sandy clay and sandy clay loam ash soils with thick dark topsoils occur on crests (3) and lower fault scarp slopes (2), locally merging into colluvial soils with much ash admixture.

**Drainage Status.**—Well drained, except for mostly excessively drained precipitous lower slopes (4).

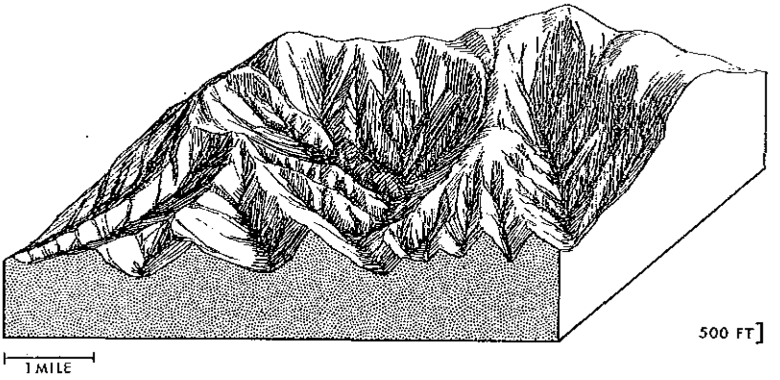
**Vegetation.**—Largely lower montane forest (1,3,5). On lower slopes mid-slope forest with *Lithocarpus* and *Castanopsis* common, irregular and open on hummocky slopes of unit 2. Stunted lower montane forest with pure stands of *Nothofagus* in the highest south-western part (3). Extensive areas of secondary forest along main rivers.

## (45) Suckling Complex Land System (50* sq miles)

*Very high mountain ridges with major slumping (Mt. Suckling).*

**Altitude.**—2000–11,000 ft.

**Relief.**—2500–5000 ft.




**Land Units.**—No land units have been distinguished, because field data are lacking and only a very general description can be given. More detailed study would undoubtedly reveal the necessity to subdivide this mapping unit into two or more land systems. For this reason it has been termed a complex land system.

**Geology.**—?Palaeozoic Goropu Metamorphic rocks, mainly quartz–sericite–chlorite phyllite and calcareous phyllite. Probably isoclinally folded. Very strong up-doming and up-faulting in late Tertiary to Recent time.

**Geomorphology.**—Mountain ridges: with over-steepened slopes and major slumping; very deeply incised streams, shallow immature weathering. Low smooth hills above 9000 ft; very large slumps between 5000 and 9000 ft; otherwise mountain ridges with straight and irregular very long very steep slopes between 35° and 60°. Small slumps, rock slides, and debris avalanches are abundant.

**Soils.**—Probably mainly lithosols and rock outcrop on summit area, slump walls, and steepest straight slopes. Probably calcareous undifferentiated colluvial soils with much gravel on lower slopes and stony land on debris avalanches and screes.

**Vegetation.**—Lower montane and montane forest, scattered to fairly dense *Araucaria cunninghamii*, probably complexes of *Nothofagus*; alpine grassland on summit, minor mid-slope forest on lower slopes.

* An additional 10 sq miles in the Wanigela–Cape Vogel area also mapped.

# PART III. GEOLOGY OF THE SAFIA–PONGANI AREA

By B. P. RUXTON*

## I. INTRODUCTION

### (a) *Regional Setting*

Previous work in north-eastern Papua has shown three geologic zones trending north-west parallel with the coast. From the central high ranges north-eastwards to the coast these are:

(1) The Owen Stanley metamorphic belt of highly folded phyllite and schist;

(2) The Morobe arc of basic–ultrabasic plutonic rocks; and

(3) The Cape Vogel geosyncline of mixed sedimentary and volcanic rocks.

This simple threefold arrangement of metamorphic belt, batholith, and geosyncline making up the regional theme is complicated in the Safia–Pongani area by three factors. Little-altered basalts and sediments occur in a gap between the highly altered rocks of the metamorphic belt forming the Amora block; intramontane depressions, the Musa basin and Kumusi trough, occur south-west of the Morobe arc; and a down-faulted area on the northern margin of the batholith forms the Managalase plateau on which volcanic rocks and sediments have accumulated.

### (b) *Previous Work*

In his geological expedition across the Owen Stanley Range in 1917, Stanley (1919) traversed the upper Kumusi and upper Musa valleys and recorded the schist of the high ranges, the occurrence of intrusive serpentine in the Kumusi and Mamama valleys, and younger volcanic rock near a hot spring on the Awaru River. Recent volcanic activity on the margins of the area, at Waiowa in 1943–44 and Mt. Lamington in 1951, has been described by Baker (1946) and Taylor (1958).

During a reconnaissance of the middle Musa area in 1956, Thompson found traces of garnierite at Wowo Gap associated with basic and ultrabasic rock. In 1958 a Bureau of Mineral Resources geological party mapped the Musa River area (Smith and Green 1961; Green 1961).

General geology of the adjoining survey area of Wanigela–Cape Vogel has been described by Haantjens *et al.* (1964) (after mapping by J. E. Thompson of the Bureau of Mineral Resources); and that of Buna–Kokoda by Paterson (1964) and Paterson and Kicinski (1956).

For other contributions and general discussions that refer to this part of Papua, the reader is referred to Stanley (1923), Glaessner (1950), David (1950), and Fisher (1958).

* Division of Land Research, CSIRO, Canberra, A.C.T.

## II. Regional Description

For descriptive purposes the area is considered as made up of parts of six tectonic regions (Fig. 6), which are treated separately below. The reader is also referred to the geology map.

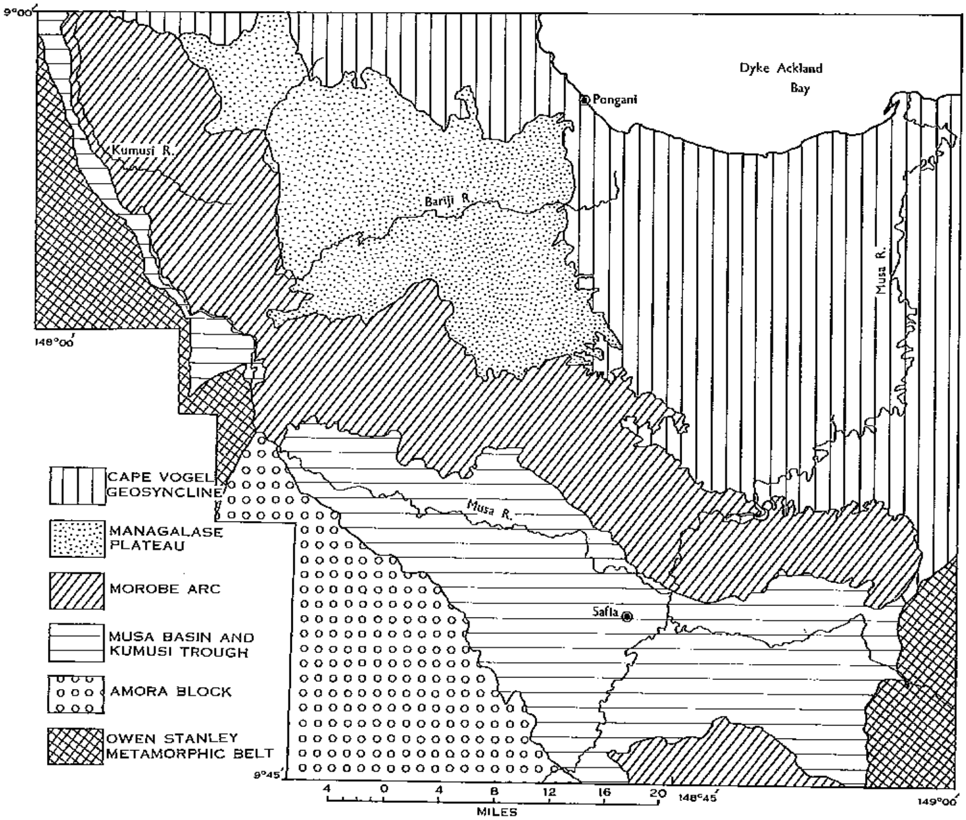



Fig. 6.—Tectonic divisions.

### (a) *Owen Stanley Metamorphic Belt*

Quartz–sericite phyllite, which is commonly calcareous and chloritic, makes up the Niori Mountains on the western edge of the area and the Goropu Mountains on the eastern edge of the area. It is derived by low-grade regional metamorphism of silty, clayey, and calcareous sedimentary rock. The rocks are highly folded, often isoclinally, and fold axes trend north-west and west-north-west. They were named the Owen Stanley Metamorphics by Paterson and Kicinski (1956) and the Goropu Metamorphics by Smith and Green (1961). These workers tentatively placed them as of Palaeozoic age.

### (b) *Amora Block*

A series of broadly folded altered basalt, greywacke conglomerate, and calcareous siltstone with occasional limestone forms a fault-bounded group of mountain ranges and high hills in the south of the survey area adjacent to the Niori Mountains. Smith and Green (1961) named them the Urere Metamorphics. They considered them to be affected by very low-grade thermal metamorphism and probably related to the ?Cretaceous Kaindi series which occurs near Morobe. They have not been seen in contact with the Goropu Metamorphics, but Smith and Green (1961) considered them to overlie these unconformably in the north-west corner of the Amora block.

Several small areas of ultrabasic rock have been discordantly faulted or thrust into the Urere Metamorphics, and represent outlying fragments of the Morobe arc. A series of conglomerate, greywacke, and greywacke siltstone overlies the Urere Metamorphics unconformably in the Bubudi basin between the Amora and Foasi Ranges, and is correlated with the Domara River beds in the Musa basin.

### (c) *Morobe Arc*

The ultrabasic belt forms a narrow mountain and hill chain from north-west to south-east across the survey area. There are three main rock types, an ultrabasic group, a transitional group of interbanded basic and ultrabasic rock, and a gabbroic group, all of which are described in more detail by Smith and Green (1961). The ultrabasic rock group occurs on the south-western side of the Guaya–Owalama Ranges, on the eastern end of the Didana Range, and in isolated masses on the south side of the Musa basin. Most of the Sibium–Didana Ranges consists of transitional and gabbroic rock types.

Smith and Green (1961) reported possible intrusive contacts with the Urere Metamorphics, and the author found a definite intrusive contact in the Gerewu River (a north-flowing tributary of the Pongani River) of the Managalase plateau between the gabbro and altered basalt. The ultrabasic belt, therefore, post-dates the Urere Metamorphics and is probably responsible for the weak, and generally patchy, thermal metamorphism of them. It is generally considered to be late Cretaceous or early Tertiary.

An area of Urere Metamorphics outcrops in the eastern Sibium Range and is made up almost entirely of hornfelsed basalt. No sedimentary rock has been found in the Urere Metamorphics north of the Musa basin.

Late Pleistocene and recent fan-glomerate fills a series of upland basins on the eastern Sibium Range. The origin of the upland basins is obscure; however, their isolated positions at different elevations near the axis of the up-arched hill ranges suggest some form of local subsidences. This range is flanked by basalt that has been up-arched with the range, and it has a patch of basalt remaining on top of it near Kakasa. Pliocene and Pleistocene basalt occurs at the northern end near Sesaru, and basaltic activity also occurred at the eastern end of the Didana Range (Green 1961). It is therefore possible that the East Sibium and Didana Ranges were formerly part of an arc of basaltic activity, now mostly eroded away, and that the upland basins represent subsidences over former magma chambers.

### (d) *Musa Basin and Kumusi Trough*

(i) *Musa Basin.*—The large triangular basin of the Musa valley was probably initiated in the Pliocene by complementary downwarping of the basin and upwarping of the embryonic Didana Range in the north. The cover rocks of the basic–ultrabasic pluton must already have been denuded off, and at least part of the range was covered by basalt lava flows.

Once formed, the basin was the site of a lake in which mudstone and calcareous greywacke siltstone were deposited, partly of Pleistocene age (Smith and Green 1961). Thick coarse and fine fan-glomerate, including abundant pebbles of basic–ultrabasic rock, was deposited on the margins of the lake and eventually spread across the infilled portions of it. Sporadic basaltic and andesitic volcanism preceded and accompanied deposition. These basin-fill sediments were named the Domara River beds by Smith and Green (1961).

At some stage during this aggradation the lake overspilled the growing anticline of the Didana Range, initiating the growth of a delta in the sea on the northern side, later to become the Musa coastal plain.

Renewed earth movement in and around the basin buckled the Domara River beds into broad folds trending west-north-west, and caused sharp bounding marginal faults that form the present framework of the basin structure.

Continued earth movement later in the Pleistocene gave rise to several separate features. A succession of step faults trending east-south-east on the south side of the valley formed a series of benches considerably narrowing the aggrading valley basin. Small blocks of ultrabasic rock were thrust up on the south-east margin of the basin, and layered mudflow fans, the Silimidi beds (Smith and Green 1961), were formed adjacent to the rapidly uprising Goropu massif.

Agglomerate-like breccia, consisting of fragments of ultrabasic rock in a variable matrix, occurs as irregular vent-like bodies in the ultrabasic rock and as interbedded horizontal layers in the Silimidi beds. They are thought to be due to the activity of volcanic gases associated with olivine alkali basalt (Green 1961).

(ii) *Kumusi Trough*.—The narrow fault trough between the Morobe arc and the metamorphic belt in the upper Kumusi and upper Musa valleys is here called the Kumusi trough. At the north end, thick late Pleistocene and Recent andesitic ash layers from Mt. Lamington obscure most of the solid geology; however, a small group of deeply weathered hills — probably dissected scoria mounds and cones — are made up of andesitic basalt near Sirorata. At the south end near Aiare, a series of gently dipping conglomerate, greywacke, and mudstone, probably equivalents of the Urere Metamorphics, are overlain unconformably by thick andesitic mudflow layers that contain an interbedded andesitic basalt lava flow. The andesitic mudflows are similar to those on the Managalase plateau and are thought to be of Pleistocene age.

### (*e*) *Managalase Plateau*

The Managalase plateau is a down-faulted block of basic–ultrabasic and Urere Metamorphic rocks thickly blanketed by terrestrial late Pliocene, Pleistocene, and Recent mixed volcanic and sedimentary rocks. In contrast with the Domara River beds these rocks are not folded, but important block faulting has occurred.

A flat-lying series of mudstone, siltstone, greywacke, and conglomerate appear to form the basal beds. In the north-western Managalase these were named the

Mamama Formation by Stanley (1919) who considered them to be of Pliocene age. In the west they are overlain by andesitic ash and agglomerate and thick andesitic mudflows derived from the Hydrographers Range. In the east they are overlain by the Uoive Volcanics, a late Pleistocene and Recent series of andesitic basalt lava flows, and the Manna Volcanics, mostly rhyodacite ash cones. In the south-east the Mamama Formation appears to overlie the Sesaro Volcanics, a large, deeply denuded Pliocene shield volcano of andesitic basalt agglomerate and lava flows.

In the eastern Managalase the volcanic cones tend to be aligned along north- and west-trending lines that mark the positions of important faults. Thus the north-trending line of five rhyodacite cones, including Mt. Manna, marks a major fault with a large downthrow to the east, and Urere Metamorphic rocks crop out up to 1500 ft above sea level on the western side. Near Uoive a west-trending line of nine cinder cones and two scoria mounds marks the site of a fissure from which a large basalt flow spreads out northwards. The scattered explosion craters, however, do not show any obvious spatial patterns.

In many places within a 30-mile radius of Mt. Lamington late Pleistocene and Recent andesitic ash layers were found, and within a 15-mile radius these layers may aggregate more than 50 ft thick, particularly on broad ridge crests. Most of the layers vary between 1 and 2 ft in thickness and have a sandy silt texture. These ashes are absent over most of the volcanic field of the eastern Managalase where thin rhyodacite ash layers are common.

### (*f*) *Cape Vogel Geosyncline*

Cape Vogel geosyncline is an active linear belt of dominant subsidence in which rocks of from Miocene to Recent age have been deposited. Only a small portion of the south-west margin of this geosyncline is present in the Safia–Pongani area. This includes parts of the andesitic volcanics of the extinct Hydrographers Range and the active Mt. Lamington and Mt. Victory, and the whole of the Recent sediments on the Musa coastal plain.

The Pleistocene Hydrographer Volcanics comprise andesite ash and agglomerate interbedded with andesite and basaltic andesite lava flows. These rest unconformably on Urere Metamorphic rocks at 300 ft above sea level in the Pongani River.

## III. Geology and Land Systems

The six tectonic regions described correlate closely with the six physiographic regions outlined in Part I, and each physiographic region has its own characteristic land systems. Many land system boundaries coincide with geological contacts that are mostly steeply dipping (usually faults) or boundaries of superficial deposits (unconformities). There is therefore a close similarity in pattern between the land system map and the geology map. However, where flat-lying rock groups are combined with pronounced relief, complex land systems are delimited. Thus the Manna land system includes basement Urere Metamorphic rocks overlain by flat-lying Mamama beds and rhyodacite Manna Volcanics.

TABLE 2

LAND SYSTEMS ARRANGED ACCORDING TO ROCK GROUPS

| Age | Name | Rock Group | Land System |
|---|---|---|---|
| Recent | — | Littoral sands | Pawara |
| | — | Paludal clay and peat | Bendorodo, Tortore |
| | — | Alluvium | Dove, Momoiogo, Gobera, Aiare |
| | — | Fan-glomerate | Imo, Nembadi, Korala, Boborobo, Ubo, Safia, Liamu, Sibium |
| | — | Interlayered mudflows and fan-glomerate | Siviai, Ibinambo |
| | — | Interlayered colluvium, mudflow, and fan-glomerate | Kovio |
| Late Pleistocene and Recent | Manna Volcanics | Dacite ash cones | Manna |
| | Uoive Volcanics | Olivine basalt lava, scoria, and cinder cones | Uoive |
| | | Olivine basalt lava and fan-glomerate | Iwuji |
| Pleistocene | Silimidi beds | Interlayered mudflows and fan-glomerate with interbedded ultrabasic breccias | Darumu, Silimidi, Wowo |
| | — | Andesitic mudflows and pyroxene basalt lava | Suwari |
| | — | Andesitic ash and agglomerate and andesitic mudflows | Gorabuna, Tahama |
| | Hydrographers Volcanics | Andesitic ash and agglomerate | Banderi, Hydrographers |
| Plio–Pleistocene | Mamama Formation | Lacustrine beds and andesitic ash and agglomerate | Bariji |
| | Domara River beds | Conglomerate, greywacke, and greywacke siltstone and calcareous mudstone | Asaga, Avikaro, Arumbai, Adau |
| Pliocene | Sesaro Volcanics | Basalt agglomerate and lava | Sesaro |
| ?Late Cretaceous or Early Tertiary | Basic–ultrabasic Batholith | Ultrabasic rocks | Avuru |
| | | Mixed basic–ultrabasic rocks | Fiobobo, Guaya, Owalama, Didana |
| ?Mesozoic | Urere Metamorphics | Altered basalt, greywacke, conglomerate, calcareous siltstone, and limestone | Aimare, Amora, Foasi |
| ?Palaeozoic | Goropu Metamorphics | Quartz–sericite phyllite, commonly calcareous | Misima, Suckling Complex |

The correlation between rock groups and land systems is shown in Table 2. Most rock groups have several land systems developed on them owing to different geomorphic, climatic, and other factors. Thus of the four land systems on the mixed basic–ultrabasic rock group, the Guaya and Didana land systems have greater relief, higher rainfall, and deeper, more mature weathering than the Fiobobo land system. Guaya land system has significant lower concave slopes and sharper ridge crests than Didana land system. Owalama land system is distinguished by its thick andesitic airborne ash layers.

The grouping of land systems is based on similarities of land characteristics, slope, soil, and vegetation that are mainly dependent on geomorphic history and climate. Land system groups cross the boundaries of rock groups and tectonic divisions, thus the group of "mountain ridges with immature weathering" includes phyllites of the Owen Stanley Metamorphic belt, basic–ultrabasic rock of the Morobe arc, and andesitic basalt agglomerate of the Managalase plateau.

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# PART IV. GEOMORPHOLOGY OF THE SAFIA–PONGANI AREA

By B. P. RUXTON*

## I. INTRODUCTION

### (a) *Physical Regions*

The Safia–Pongani area is divided into six physical regions that correspond closely with the tectonic divisions (Fig. 3).

(i) *Owen Stanley Ranges* (185 sq miles).—These high mountains, rising to over 9000 ft, form the main watershed of Papua. They extend into both edges of the survey area as the Niori Mountains in the west and the Goropu Mountains in the south-east.

(ii) *Owen Stanley Foothills* (280 sq miles).—High hills with scattered mountain groups flank the high ranges in the south of the survey area. They include the Amora and Foasi Ranges (3000–5500 ft) and an intervening dissected upland basin between 2000 and 3000 ft.

(iii) *Guaya–Didana Ranges* (660 sq miles).—This arcuate chain of mountains and hills, on basic–ultrabasic plutonic rocks of the Morobe arc, crosses the survey area from north-west to south-east. In the north-west the Guaya and Owalama Ranges are fault-block mountains rising to 5500 ft and include a high hilly plateau. The Sibium Range, in the centre of the survey area, rises to 7164 ft at Mt. Avena. In the east the Didana Range, rising to 4000 ft, forms the eastern end of the Morobe arc. Hilly country between 1300 and 3000 ft forms the eastern margin of the Sibium Range and five small upland basins, aggregating 25 sq miles, are aligned north-north-west within these hills. Block mountains on the south side of the Musa basin are considered as outliers of the Morobe arc; they include Mt. Korioko and Mt. Avuru (2000–5000 ft).

(iv) *Volcanic Mountains and Plateau* (460 sq miles).—An extinct andesitic strato-volcano, the Hydrographers Range rising to 6280 ft, borders the north of the survey area and its southern foot slopes extend south-west to 2000 ft at the Bariji River. Between the Pongani and Bariji Rivers a volcanic plateau between 2000 and 3500 ft is built up of late Pleistocene and Recent andesitic basalt lava flows and rhyodacite ash cones. Mt. Manna, the highest point of this plateau, is a rhyodacite cone and rises to 3698 ft. South of this plateau an extinct andesitic basalt shield volcano forms a rugged mountain range rising to 4400 ft at Mt. Namoa.

(v) *Musa Basin* (510 sq miles).—In the middle reaches of the Musa River between the Owen Stanley foothills and the Sibium–Didana Ranges, a triangular-shaped intramontane trough lies between 400 and 2000 ft above sea level. A narrow, easterly-aligned strip of fans and alluvial terraces is surrounded by a complex of valley benches and intricately dissected hill groups composed of former basin-fill deposits.

* Division of Land Research, CSIRO, Canberra, A.C.T.

(vi) *Musa Coastal Plain* (590 sq miles).—Depositional plains with minor marginal fans form a large, nearly level tract extending 25 miles inland from Dyke Ackland Bay. A central, higher, better-drained area, made up of prior meander tracts of the Musa River, extends north from the Didana Range and leads down on three sides to large marginal freshwater swamps. The meander tract of the present Musa River forms a low alluvial rise through the eastern marginal swamp. Two projections of the Bariji fan form low alluvial rises in the western marginal swamp, and one of them cuts across this swamp to join with the terminus of a prior meander tract of the Musa River at Karaisa. A belt of mangrove swamps with minor beach ridges borders Dyke Ackland Bay.

### (*b*) *Drainage*

The Musa River drains three-quarters of the survey area (Fig. 3). It rises on the Owalama divide at 3750 ft and flows south-east in a narrow fault-controlled valley until it reaches the Musa basin. Here at 1200 ft above sea level the valley widens out rapidly and the river swings to an easterly course.

It leaves the Musa basin at 360 ft near Safia and turns abruptly north into a deep gorge in the Didana Range. Steep rapids mark a prominent nick point one mile down the gorge and the river descends to 200 ft at Mamama. From near Mamama to Dove the river flows in an east-north-east direction entering the coastal plain at Embessa as an actively meandering stream. Periodic gauging at the head of the Musa gorge between August 1958 and September 1963 (personal communication from the Commonwealth Department of Works) shows a range in discharge of 2170 to 23,400 cusecs.

The Kumusi River rises on the Owalama divide and flows north-north-west in a fault-controlled valley. Most of its tributary streams join it with discordant junctions. North of Sirorata the Kumusi is joined by a large west-flowing tributary, the Mamama River, which is structurally controlled in its lower reaches where it separates the Guaya Range from Mt. Lamington.

The Bariji River drains most of the Managalase plateau but it has a very restricted mountain catchment. It peters out in the swamps of the coastal plain near Gombari. Several other smaller streams lose their identity in the swamps of the coastal plain, among them the Korala and Imo Rivers which drain the Wororai and Sesaro upland basins respectively.

## II. Geomorphic History

The Safia–Pongani area is characterized by youthful landscapes resulting from very active tectonic movements and volcanism in Pleistocene and Recent time.

### (*a*) *Historical Outline*

Differential fault movements in the north and west, and differential warping in the centre and south at the end of the Tertiary, established the present geomorphic framework (see Part III). Earlier history is obscure but the Owen Stanley Ranges had been a positive area throughout the Tertiary and uplift of the Morobe arc had commenced by the late Tertiary.

During the Pleistocene several stages of powerful uplift affected both the Owen Stanley Ranges and foothills and the Guaya–Didana Ranges. Uplift was accompanied by block-faulting and extensive volcanism in the north and by folding and later step-faulting in the south. In Recent time the main events have been continued fault movements throughout the area, accompanied by tilting, extensive volcanism in the eastern Managalase plateau, and the rapid outgrowth and development of the Musa coastal plain.

### (*b*) *Summit Profiles and Remnant Surfaces*

Subaccordant summit profiles and high-level partly dissected surfaces, in many cases with relict weathering profiles preserved, indicate pulsatory stages of uplift in the erosional history. The various erosion surface remnants are localized in extent and are difficult to correlate across the area. They are here described in four groups in decreasing order of altitude and age.

The dome-shaped crest profiles of the high ridges and summits in the Goropu Mountains are truncated around their margins by recent fault scarps and suggest up-doming of this range before the marginal faulting (cf. Smith and Green 1961). On the same evidence the high Sibium and Didana Ranges have been arched up along west-trending axes. In contrast the Owalama and Guaya Range summit profiles suggest the uplift of a fault block with slight tilting to the east. These very high-level subaccordant profiles probably represent Plio–Pleistocene surfaces.

Remnants of deep mature weathering profiles on subaccordant ridge crests indicate that they were former deeply weathered sloping surfaces. Such forms between 3500 and 4500 ft on the Amora and Foasi Ranges probably relate to an early stage in development of the Musa basin, and have since been uplifted. In contrast, similar features on the Hydrographers Range and its foot slopes are remnants of the original surface of this Pleistocene strato-volcano.

Dissected, deeply weathered valley floors of the Urere and Ikumu Rivers in the Owen Stanley foothills, at present between 2000 and 2400 ft, were formerly graded to the central Musa basin before uplift along the south-bounding fault. Similar features between 1250 and 1400 ft in the Didana Range represent early growth stages of this anticlinal range prior to uplift along the north-bounding fault.

A series of little-weathered valley benches on the north and south sides of the Musa basin are the result of late Pleistocene and Recent step-faulting mostly trending west-north-west. The oldest valley benches on the south side of the basin are now completely dissected into hills of ridge and ravine type with a relief of 1500 to 2000 ft. The proportion of accordant summit flats in the landscape increases, and relief decreases towards the centre of the basin.

### (*c*) *Recent Landscape Development*

Late Pleistocene and Recent volcanism, tilting, and aggradation have left clear signs of their effects on the landscape. Such features, no doubt, were also important earlier in the Pleistocene but their effects have been largely erased by later developments, often of a similar nature in the same area.

(i) *Volcanism.*—The eastern Managalase plateau has been built up by late Pleistocene and Recent andesitic basalt lava flows, lava cones, and cinder cones, and subordinate rhyodacite ash cones. Weathering is skeletal or shallow and drainage is disorganized with few permanently flowing streams. The basalt lava flows have repeatedly caused temporary blockages of the Pongani and Bariji Rivers, and lacustrine deposits, now forming terraces, were formed. Other lavas flowing down steep tributary valleys have formed long narrow tongues with the complementary development of twin lateral streams. The deeply dissected rhyodacite ash cones and partly dissected basalt lava cones (in the west) are probably older features, while the west-trending lines of basalt cinder cones near Uoive are undissected and one of them has been active in village memory.

Late Pleistocene and Recent heavy falls of andesitic ash aggregate 50 ft in thickness up to 15 miles from Mt. Lamington. In the Guaya Range, valleys have been partly filled in and very broad lower concave slopes have developed as a result. In the Owalama Range, thick layers of andesitic ash from Mt. Lamington have been dissected into a maze of precipitous ridges with a relief corresponding closely to the depth of the ash cover (30–100 ft).

(ii) *Tilting.*—Recent tilting downwards to the north-east has affected the whole of the eastern Sibium Range, causing drowning of the margins beneath the coastal plain sediments. Barbed tributary patterns in the Wororai basin in this range suggest that it formerly drained south into the Nuaro basin before tilting took place.

Recent easterly tilting has also affected the Owalama Range, and Savaro Creek has been captured by the Bariji River as a result. Prior to diversion, Savaro Creek flowed through a wide valley south of Umwate to join the Musa River. Andesitic mudflows derived from the Hydrographers Range occur north of Aiare (in the upper Musa valley), and westerly-flowing barbed tributary patterns east of Umwate confirm this diversion.

Recent strong tilting has also affected the Silimidi beds at the eastern end of the Musa basin, causing very deep mass movement of them.

(iii) *Outgrowth of the Musa Coastal Plain.*—Rapid outgrowth of the Musa coastal plain in Recent time is the result of the large quantities of sediment transported through the Musa gorge from the very rapidly eroding Sibium–Didana and Owen Stanley Ranges. Seaward growth of deltas and the deposition of alluvium by meander tracts of prior Musa River courses have been complicated by relative changes in the levels of land and sea.

The long profile of the coastal plain from Embessa north-north-west to the coast (Fig. 7) shows three prominent convexities, 2, 8, and 19 miles from the mouth of the Musa gorge, which are backed by platforms at about 190, 100, and 30 ft above sea level respectively. Prior break-through channels and splays with relatively steep slopes are spaced along the seaward margins of the upper and middle platforms and lead down to long linear meander tracts of prior Musa River course. These platforms probably represent growth stages of the coastal plain at former sea levels. The platform near the coast varies from 10 to 30 ft above sea level and has a very abrupt straight margin, in places adjacent to the mangrove belt. The presence of prominent rapids, even in the swamps near Karaisa, near this margin, and of paired terraces south of it, suggests very recent faulting with up-throw on the inland side.

The present Musa River has built a delta that protrudes two miles beyond the general shoreline. Active wave currents and beach drift have transported large quantities of sand westwards from this delta, adding to the fringing coastal beaches, spits, and bars along the coast as far west as Songadi.

In 1943, the Musa River broke its bank at Garagarata and cut a channel north, emptying about half of the flow into the eastern marginal swamp with outlet to the sea via the Foru River. The slackening of flow down the Musa River has led to severe curtailment of the sand supplied to the present delta. As a result the fringing coastal beaches to the west are being actively degraded and in places have already been removed.

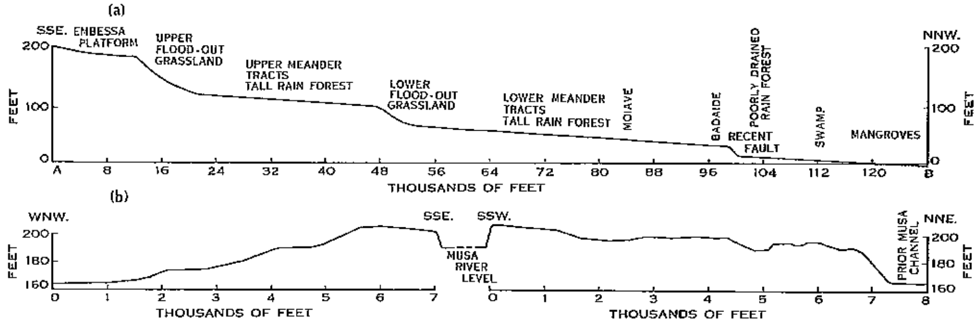


Fig. 7.—Sections of the Musa coastal plain. (*a*) Long profile from Embessa NNW. to the sea. Vertical exaggeration × 80. (Section line *A–B* shown on geomorphology map.) (*b*) Details of high platform and upper flood-out near Embessa. Vertical exaggeration × 50.

## III. Land-forming Processes

In this tectonically mobile area differential rapid uplift has produced a high relief. With a high rainfall, downward corrasion has cut deep ravines and the very rapid weathering and vigorous slope erosion have graded the interfluves to ridges with sharp crests and very steep straight slopes. Rock debris from slope denudation has been rapidly transported by the streams from the mountains and deposited as alluvial fans and alluvial plains.

### (*a*) *Weathering*

In general, the very steep slopes of the mountain and hill ridges have shallow immature weathering profiles with abundant unstable primary minerals remaining in them.

Deep mature weathering is confined to remnant surfaces where an upper reddish clayey zone between 10 and 40 ft thick has little or no unstable primary minerals in it. On dissection, small-scale slumping and debris avalanche commonly develop on the margins of such relic weathering profiles, and knife-edge ridges are formed between the slumps.

### (*b*) *Mass Movement*

Very deep mass movement, active to over 200 ft depth, has affected several large, gently sloping areas of deeply weathered rock, including Pleistocene and early Recent inter-layered mudflow fans. Buckled and corrugated surfaces with deep fissures form a pattern of aligned ridges, and in places flow patterns have developed. These secondary deformations are probably caused by earthquake shocks and may be assisted by tilting.

Deep mass movement, active to over 50 ft depth, displacing large quantities of weathered rock downslope, is an important process on over-steepened slopes of most of the mountain areas. Thus the Goropu Mountains are characterized by very large slumps, the Sibium–Didana Ranges by debris avalanches, and the Hydrographers Range by debris slides. Debris flow and earth flow (Sharpe 1938), involving the slow flowage of wet gravelly clay, are characteristic of some very deeply but immaturely weathered hilly areas in the Owen Stanley foothills.

Although less spectacular, slow superficial mass movement affecting only the soil layer is probably a more important process of denudation on the steep and very steep mountain and hill slopes. Thus soil flow (White 1949) and soil slips, forming terracettes, were noted on many mountain slopes in the wet climatic zone. Here, as elsewhere on forested slopes, tree fall is an important process assisting the normal forms of downslope creep (Denny 1956).

Layered mudflow fan-glomerate results when the material from very large slumps travels out from the mountains onto adjoining plains. Most of the initial slump material flows out to form large mudflow tongues while the remainder chokes the headwater valleys to depths of several hundred feet. Material from the slump scars aggrades these valleys still further, and this valley fill is then transported by the torrential streams to form a fan-glomerate layer on top of the mudflow.

### (*c*) *Slope Wash*

Slope wash is an important, if not major, process of erosion under hill forest with open canopies on steep and very steep slopes. It includes rain-drop and water-drop erosion and unconcentrated wash. Its effects are seen in the absence or paucity of leaf litter and duff, and the presence of small-scale earth pillars, scoured surfaces, and lag gravel. Openings in the forest canopy on steep slopes are caused mainly by tree fall caused by mass movement, undermining of roots by caving, and in exposed situations by wind.

In the grassland and savannah of the dry climatic zone, slope wash appears to be the dominant agent of slope erosion and may be responsible for the very fine pattern of dissection of the hill ridges.

### (*d*) *Stream Action*

Most streams in the hills and mountains are perennial, poorly graded torrents with bouldery or cobbly beds. The abundance of steeper lower slope facets and the common presence of gorges point to very rapid vertical down-cutting.

The detritus supplied by mass movement and slope wash to the streams is rapidly transported from the mountains and hills and is supplemented by the products of vertical corrasion. In general the coarser debris, consisting mostly of unweathered rock fragments, is deposited as alluvial fans at the mountain and hill fronts. Alluvium on the plains, especially in meander tracts, is composed dominantly of unstable primary minerals of sand and coarse silt grades.

## IV. Land Forms and Land Systems

The land systems correspond with particular patterns on the aerial photographs and most of them are readily distinguishable land form types. The land form classification adopted is shown in Table 3 and the relationship to land systems is indicated.

In the Safia–Pongani area, differential strong uplift and vigorous constructional volcanism have provided a high relief. The high rainfall, coupled with rapid weathering, has led to rapid morphogenesis, and steep mountain and hill ridges contrast sharply with low-angle alluvial fans and nearly flat alluvial plains. Recent undissected lava flows, cones, and explosion craters form an additional group of constructional land forms.

### (a) *Denudational Land Forms*

The continual supply of erosional energy has maintained a steady state of dynamic equilibrium typical of an open energy system (Chorley 1962), and this is expressed in the predominance of erosionally graded ridge and ravine topography. The ridges have typically sharp crests, straight slopes, and narrow valleys, and all parts of such land surfaces waste downward at a uniform rate (Hack 1960).

Differential up-arching and up-faulting have produced numerous independent mountain and hill blocks, each of which forms a single dynamic system. Despite their differences in rate and type of uplift, and in relief, rock type, and rainfall, they all show similar ridge and ravine topography with the straight slopes mainly between 35 and 40°.

Most of the denudational land forms are of the equilibrium ridge and ravine type, and they occur in two orders of magnitude: as mountain ranges with relief usually well over 2000 ft, and as scattered hill groups with a lower relief. Some of these land forms have only recently attained an equilibrium form and still have minor unconsumed remnant surfaces, e.g. Foasi and Tahama land systems. Others more advanced have only patches of relict weathering profiles on their more prominent ridge crests, e.g. Gorabuna and Hydrographers land systems. Some forms which appear to have been in a steady state of dynamic equilibrium for some time may still show local structural control in their slope forms, e.g. Amora and Arumbai land systems.

Oscillations in the rate of stream incision may cause minor transient changes of slope form. Thus, accelerating incision has produced common precipitous lower slope facets in Suwari land system; while decelerating incision in parts of Sesaro and Fiobobo land systems has caused local slope replacement mechanisms to operate adjacent to some streams with the formation of lower concave slopes.

Greatly accelerated stream incision causes a marked divergence from the equilibrium land forms. Precipitous slopes and cliffs are formed, as in Adau land system, and large-scale slumping may occur, as in Suckling Complex land system. Greatly decelerated stream incision probably leads to the formation of lower concave slopes. In Guaya land system most of the northern valleys have been choked with very thick ash falls from Mt. Lamington, and very long, concave, lower slopes developed before recent redissection.

### (*b*) *Constructional Land Forms*

Only little-dissected land forms constructed by Recent volcanism are considered in this section. Volcanoes dissected beyond the early planeze stage have been considered as denudational land forms. Thus the Pleistocene Hydrographer and Pliocene Sesaro Volcanics are mostly in the early and late residual mountain stages respectively (Kear 1957), and the late Pleistocene to Recent Manna Volcanics are mostly in an advanced planeze stage.

Broad fans and flat-lying areas with tumuli, built of andesitic basalt lava, flank the eastern margin of the Managalase plateau as the Iwuji land system. On and near this plateau andesitic basalt lava flows, partially dissected lava cones, and undissected cinder cones make up Uoive land system. The lava flows are of various types including gently sloping lobes with pressure ridges, frilled flow domes, and steep blocky cascades.

### (*c*) *Aggradational Land Forms*

Much of the debris from the denuding hills and mountains has been deposited as fans at the hill fronts and in basins, and as alluvium on the rapidly prograding coastal plain. The older Pleistocene fans and basin-fill have been uplifted and denuded into ridge and ravine land forms as in Arumbai land system, considered above. Many younger Pleistocene and even Recent fans have also been partly dissected, and since these retain a considerable proportion of their original surfaces they are considered as aggradational land forms.

Mudflow fans of late Pleistocene and early Recent age in the Musa basin occur adjacent to the up-arched and up-domed Sibium, Didana, and Goropu Ranges. They have been derived by slumping of the deep weathering profiles on Plio–Pleistocene surfaces after warping, uplift, and dissection of them. In some places they have been tilted and/or have undergone secondary mass movements that have buckled and corrugated their surfaces. Most of them have been variably dissected by throughgoing V-shaped valleys and by smaller subparallel ravines. The untilted and undeformed mudflow fans have low general gradients between 1 and 5°, and in places they may have numerous hillocks on their surfaces (e.g. Darumu land system) similar to those figured on mudflows elsewhere (Verstappen 1963).

Fan-glomerate and alluvium have built cones, fans, piedmont alluvial plains, and basin-fill surfaces with smooth concave slopes ranging from 15° to 1 in 500. They are concentrated mostly near the centre of the Musa basin and around the margins of the coastal plain. The only steep cones and fans are adjacent to the high northern Sibium Range where a series of subparallel ravines with small catchments

TABLE 3

LAND FORM CLASSIFICATION AND LAND SYSTEMS

| Denudational Land Forms | | | | | Land System |
|---|---|---|---|---|---|
| Relief > 2000 ft | Mountain ridges | Predominantly very steep straight slopes (equilibrium forms) | Very long straight slopes | Developed on calcareous and chloritic phyllite | Misima |
| Relief > 2000 ft | Mountain ridges | Predominantly very steep straight slopes (equilibrium forms) | Very long straight slopes | Developed on basic–ultrabasic plutonic rock | Didana |
| Relief > 2000 ft | Mountain ridges | Predominantly very steep straight slopes (equilibrium forms) | Long straight slopes | Local broad crests, with relict weathering profiles | Foasi |
| Relief > 2000 ft | Mountain ridges | Predominantly very steep straight slopes (equilibrium forms) | Long straight slopes | Local hummocky concave slopes due to slumping | Amora |
| Relief > 2000 ft | Mountain ridges | Predominantly very steep straight slopes (equilibrium forms) | Medium straight slopes | Early residual stage of dissected volcano | Hydrographers |
| Relief > 2000 ft | Mountain ridges | Predominantly very steep straight slopes (equilibrium forms) | Medium straight slopes | Late residual stage of dissected volcano | Sesaro |
| Relief > 2000 ft | Mountain ridges | Oversteepened slopes with major slumping | | | Suckling Complex |
| Relief > 2000 ft | Mountain ridges | Lower concave slopes formed by thick ash fill in valleys | | | Guaya |
| Relief > 2000 ft | Block mountains; subdued land forms surrounded by recent fault scarps | | | | Avuru |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Almost entirely of ridge and ravine form | Medium and long straight slopes | Fiobobo |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Almost entirely of ridge and ravine form | Medium and short straight slopes | Manna |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Almost entirely of ridge and ravine form | Short straight slopes | Gorabuna |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Common upper precipitous slopes and cliffs, on basalt | | Bariji |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Common broad ridge crests with deep weathering and/or andesitic ash cover | Accordant ridge crests | Tahama |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Common broad ridge crests with deep weathering and/or andesitic ash cover | High relief | Kovio |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Common broad ridge crests with deep weathering and/or andesitic ash cover | Local precipitous lower slopes | Suwari |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Very fine dendritic drainage | At high altitude | Owalama |
| Relief < 2000 ft | Hill ridges | Predominantly very steep straight slopes (equilibrium forms) | Very fine dendritic drainage | Local upper gentle slopes and dip slopes | Arumbai |
| Relief < 2000 ft | Hill ridges | Predominantly irregular hummocky slopes due to strong debris flow and earth flow | High relief; 1000–2000 ft | | Aimare |
| Relief < 2000 ft | Hill ridges | Predominantly irregular hummocky slopes due to strong debris flow and earth flow | Low relief; 200–1000 ft | | Avikaro |
| Relief < 2000 ft | Hill ridges | Precipitous slopes and abundant cliffs | | | Adau |
| Relief < 2000 ft | Low hills and undulating surfaces | | Concavo–convex slopes, planezes of Hydrographers volcano | | Banderi |
| Relief < 2000 ft | Low hills and undulating surfaces | | Predominantly concave slopes and dip slopes | | Asaga |

| | | | | | |
|---|---|---|---|---|---|
| | | Constructional Land Forms | | | |
| Volcanic land forms | | Broad lava fans; of andesitic basalt<br>Lava flows; lava cones; cinder cones and explosion craters, mostly of andesitic basalt | | | Iwuji<br>Uoive |
| | | Aggradational Land Forms | | | |
| Mudflow *and fans* | Undissected gently undulating surface | | | | Ibinambo |
| | Little-dissected hummocky | Corrugated surface<br>Abundant hillocks | | | *Silimidi*<br>Darumu |
| | Strongly dissected | Irregular hummocky dissection slopes<br>Strongly tilted | | | Siviai<br>*Wowo* |
| Alluvial fans | Undissected | Fans of gentle gradient, 1 in 25 to 1 in 500 | Seasonally and periodically flooded lower fan segments | | Imo |
| | | | Composite fans, well drained | Sandy volcanic detritus<br>Gravelly detritus | Nembadi<br>Safia |
| | | Fans of moderate gradient, swampy termini | Mainly 2° to 0° 15′, basin fill fans<br>Mainly 3° to 1°, coalescing piedmont fans<br>Mainly 5° to 1°, single fans | | Liamu<br>Korala<br>Ubo |
| | Strongly dissected | Concavo–convex dissection slopes<br>Steep cones and aprons 15° to 2° | | | Boborobo<br>Sibium |
| Alluvial terraces | | Gentle, mostly 1 in 200 to 1 in 400<br>Steep, mostly 3° to 0° 30′ | | | Gobera<br>Aiare |
| Alluvial plains | | Stable, well drained. Mostly prior meander tracts with gradients 1 in 80 to 1 in 500<br>Unstable, poorly drained. Gradients 1 in 200 to 1 in 2000 | | | Momoiogo<br>Dove |
| Freshwater swamps | | Permanently or seasonally flooded | | | Tortore |
| Littoral plains | | Beach ridges above high sea level<br>Mangrove swamps below high sea level | | | Pawara<br>Bendorodo |

disgorge onto the Managalase plateau. Elsewhere, larger streams build lower-angled fans at the hill fronts. Most fans have active and inactive portions. The active portions are interlaced by numerous distributary channels which are constantly shifting their positions on the fan surface. The inactive parts have more permanent, usually incised channels and between these the surface is often mantled with a more weathered soil layer. Thus, in Korala land system weathered plastic clay soils, often with microrelief, are common. In Safia land system, in the central Musa basin, active fans of the major stream distributaries have been inlaid into older inactive fans whose termini have been truncated by former Musa River (Fig. 8) courses that now form slightly raised flood-plain terraces (Gobera land system).

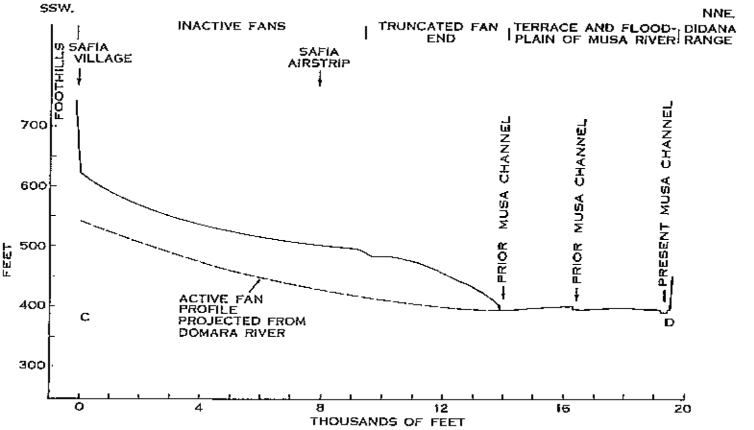


Fig. 8.—Cross-section of Musa valley at Safia, showing profiles of active and inactive fans of Safia land system, and the terrace and flood-plain of the Musa River in Gobera land system. Vertical exaggeration × 20. (Section line *C–D* shown on geomorphology map.)

Flat, nearly level, depositional surfaces built mostly of alluvium of prior meander tracts of the Musa River make up the centre of the coastal plain. The stable well-drained plains with gradients between 1 in 80 and 1 in 500 form Momoiogo land system. Dove land system mostly surrounds the higher ground as unstable poorly drained land with gradients between 1 in 200 and 1 in 2000, and is subject to periodic flooding. It includes the present meander tract of the Musa River.

Seasonally and permanently flooded alluvial land with gradients mostly less than 1 in 1000 margins most of the coastal plain as Tortore land system. The eastern marginal swamp is fed by Musa River flow diverted at Garagarata, and water levels fluctuate over a wide range. This swamp has abrupt meridional contacts with well-drained land in the west and the low alluvial rise of the Musa River meander tract in the east. Its presence is probably due to the recent up-fault near Foru, mentioned above. The western marginal swamp is probably a down-warped area connected with the easterly tilt of the Sibium Range and it is fed largely by the Korala and Imo Rivers. Most of its margins are also abrupt and in the west the very steep mountain slopes of Sesaro land system plunge straight into the swamp with no development of intermediate slopes.

Mangrove swamps, of Bendorodo land system, in the intertidal zone consist of undisturbed prior deltas of the Musa River and the present delta, with intervening strips of degraded beach ridges. Minor low beaches, spits, and off-shore bars are also included. Crab mounds, up to 4 ft in height, form a prominent microrelief in the lower tidal flats.

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# PART V. PEDOLOGY OF THE SAFIA–PONGANI AREA

By H. A. HAANTJENS*

## I. INTRODUCTION

### (a) General

As in many other parts of New Guinea, there is a striking preponderance of unweathered to moderately weathered soils in the Safia–Pongani area. Compared with an estimated 850 sq miles of undifferentiated alluvial, colluvial, and lithosolic soils (Entisols), 500 sq miles of unweathered to moderately weathered neutral soils with thick dark topsoil (Mollisols), and 800 sq miles of other kinds of slightly to moderately weathered soils (Inceptisols), there are only some 100 sq miles of moderately to strongly weathered texture-contrast soils (Alfisols and Ultisols) and less than 200 sq miles of strongly weathered tropical red and brown clay soils (Oxisols). This is remarkable for a region where a warm humid climate acting on mostly basic parent rocks should have resulted in rapid and pronounced weathering. Tectonic instability and Recent volcanism, however, have produced youthful land forms and in most instances only little time has been available for soil formation. The great variety of parent rock and land forms, together with marked differences in climate and types of weathering, have resulted in many different trends and stages in soil formation, producing a highly complex soil pattern.

### (b) System of Classification

The soils of the Safia–Pongani area have been classified by applying the 7th Approximation of the comprehensive system of soil classification developed by the U.S. Soil Conservation Service (1960). They have been placed into 7 orders, subdivided into 14 suborders (one undefined), 20 great groups (one undefined), 38 subgroups (three undefined), and 74 families. This classification is shown in the first five columns of Table 4. The relationships between families and great groups are further illustrated in Figure 9, in which the connecting lines indicate observed or expected intergradations between families and between great groups.

The soil families were given locality names.† The higher soil categories have been given 7th Approximation names and are further indicated by brief distinguishing descriptions. It should be stressed that the 7th Approximation names are used only tentatively, because in many instances the soils could either not be identified with these names with complete confidence, or it is known that they do not precisely comply with the criteria set out for the classes in the 7th Approximation. A detailed discussion of the use of the 7th Approximation in this report is given in Appendix I.

In cases where no proper soil cover exists or the soils are dominated by extraneous features, such as stones, the nature of the land surface has been described as dark

* Division of Land Research, CSIRO, Canberra, A.C.T.

†Correlation with families in adjoining areas is available in an unpublished report (Division of Land Research Technical Memorandum 66/1).

beach sand, rock outcrop, lava rubble land, stony land, and river wash (including some alluvial land). These miscellaneous land types are defined in accordance with the Soil Survey Manual of the U.S. Department of Agriculture (1951) and will not be further discussed in this Part.

## II. Soil Description*

Moderately detailed descriptions are given in the land systems (Part II), in many cases emphasizing soil properties that are of particular significance in particular land systems.

In this Part, Table 4, apart from setting out the soil classification, also serves as a systematic brief morphological description† of the soils at any categorical level. Additional chemical data are provided in Table 5. The descriptions in Table 4 are obtained by reading through the classification part of the table up to and including the categorical level in which one is interested. For example, a summarized but exclusive description of the Pawara family is obtained by first noting at the order level that these are undifferentiated (undeveloped) soils. At the suborder level it is learned that these soils are sandy. Under the great group heading the information is added that they are non-quartzitic and under the subgroup that they are well-drained and deep soils. In the Pawara family, finally, such soils are well sorted and dark. Thus the Pawara family comprises deep, well-drained and well-sorted, dark, non-quartzitic, sandy, undifferentiated soils. As explained in the footnotes of Table 4, the term "well drained" implies in a particular case like this that these soils may in fact be rather excessively drained. In some instances, the description at a certain categorical level allows a choice of properties, which is resolved at some lower categorical level. For instance, great group 6 includes well to poorly drained soils. Of the component families, Gobera and Toma are defined at subgroup level as poorly drained, Gorabunina at family level as well drained. The others are defined at subgroup level as well to imperfectly drained. Where a choice like this is *not* resolved lower in the classification, this means that the soil family in question is variable in this particular respect. For instance the Foru and Abimboro families (great group 4) include very poorly drained and swampy soils as defined at the suborder level.

To check rapidly for each family on a number of agronomically important morphological characteristics, as well as to determine the similarities and dissimilarities between soil families with respect to these properties, Figures 10–13 have been prepared; they illustrate the relationships between families and soil depth, drainage status, texture and consistence, and topsoil characteristics. The relationship between soil families and reaction, based on field and laboratory pH measurements, is illustrated in Figure 14. The layout of the families in these figures is the same as that in Figure 9 and represents their arrangement according to great groups.

*All soil descriptions are based on the terminology set out in the Soil Survey Manual of the U.S. Department of Agriculture (1951). Colour names are those indicated in the Munsell Soil Color Chart and refer to the moist condition.

† Detailed descriptions of type profiles of the soil families are available in an unpublished report (Division of Land Research Technical Memorandum 66/7).

Table 4

classification, characteristics,* and distribution of the soils

The soils have been tentatively classified according to the comprehensive system (7th Approximation) of the U.S. Soil Conservation Service. Newly coined names not occurring in the 7th Approximation are given in brackets

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| **1.** Histosols: organic soils | — | — | — | **Sebaga** (25 sq miles): saline mangrove peat soils | Organic residue over deltaic sand and sandy alluvium. Tidal swamp. Mangroves | S: Bendorodo |
| | | | | ‖**Karaisa** (20 sq miles): shallow freshwater peat soils | Organic residue over swamp clay. Swamp. *Phragmites* and sago–*Pandanus* woodland | M: Boborobo, Tortore |
| Entisols: undifferentiated soils | Aquents: very poorly drained and swampy soils | **2.** Hydraquents: soft alluvial swamp soils | — | **Songada** (30 sq miles): saline muds | Calcareous deltaic deposits with organic residue. Tidal swamp and depressions; upper tidal flats. Mangroves, *Nypa*, and mangrove–*Pandanus* woodland | D: Bendorodo |
| | | | | **Yupuru** (70 sq miles): grey-green medium- to very fine-textured soils | Calcareous and non-calcareous swamp clay and more sandy deltaic deposits. Flood-plain swamps. Herbaceous vegetation and *Pandanus* woodland | S: Tortore |
| | | **3.** Haplaquents: very poorly drained alluvial soils | Uncertain | **Musa** (40 sq miles): calcareous medium-textured soils | Calcareous alluvium, locally over sandy deltaic deposits. Swampy flood-plains, and scrolls. Irregular tall alluvium forest with sago, *Pandanus* woodland, *Saccharum* successions | S: Dove<br>M: Tortore, Ubo |
| | | | | **Moiave** (70 sq miles): calcareous plastic heavy clay soils | Calcareous alluvium. Swampy flood-plains. Irregular tall alluvium forest with sago; *Pandanus* swamp with dead trees | S: Dove, Tortore |
| | | | | **Bariji** (15 sq miles): medium-textured soils | Alluvium, mainly of volcanic derivation. Swampy flood-plains and local low river terraces. Irregular tall alluvium forest with sago; sago woodland; locally secondary | D: Imo<br>M: Gorabuna, Tortore |

| | | | | | |
|---|---|---|---|---|---|
| | | | **Botame** (30 sq miles): plastic heavy clay soils | Alluvium, locally over deltaic sand; minor colluvium in Avikaro land system. Swampy flood-plains and local low terraces; small depressions on slumped slopes. Irregular tall alluvium forest, swamp forest with *Pandanus*, and sago woodland; locally *Phragmites* | S: Gobera, Imo, Tortore<br>M: Avikaro, Boborobo |
| | 4. Psammaquents: sandy soils | Orthic Psammaquents: non-quartzitic soils | **Foru** (5 sq miles): saline soils | Deltaic sand. Tidal swamp. Mangroves | M: Bendorodo |
| | | | **Abimboro** (1 sq mile): soils with thin alluvial surface soil | Beach sand with very thin veneer of alluvium or organic residue. Swampy swales between beach ridges. Sago woodland | S: Pawara |
| Psamments: sandy soils | 5. Orthopsamments: non-quartzitic soils | Orthic Orthopsamments: well-drained deep soils | **Ibau** (1 sq mile): calcareous, poorly sorted soils | Calcareous fan deposits. Lower fan terrace. Secondary forest | M: Ubo |
| | | | **Pawara** (1 sq mile): well-sorted, dark soils | Beach sand, rich in dark minerals. Undulating frontal beach ridge. Beach forest, commonly secondary | M: Pawara |
| Udents: medium-textured soils | 6. Hapludents: well to poorly drained soils | Aquic Hapludents: poorly drained alluvial soils | **Gobera** (30 sq miles): calcareous, very silty soils | Calcareous alluvium. Flood-plains, low terraces, and scrolls. Irregular tall alluvium forest, commonly with sago; seral woodland; locally regrowth | S: Dove<br>M: Gobera |
| | | | ‖**Toma** (5 sq miles): stratified, mainly clay to heavy clay soils | Alluvium and lacustrine deposits. Flood-plains and lacustrine terrace. Irregular tall alluvium forest locally with much *Pandanus*; regrowth | M: Aiare, Imo, Nembadi |
| | | Andeptic Hapludents: alluvial volcanic-ash soils | **Gorabunina** (2 sq miles): well-drained, brown soils | Alluvium of andesitic ash. River and fan terraces. Foothill forest, regrowth | M: Aiare, Guaya, Tahama |
| | | Orthic Hapludents: well to imperfectly drained alluvial and regosolic soils | ‖**Taruma** (G) (40 sq miles): calcareous silty to fine sandy alluvial soils | Calcareous alluvium and fan deposits, locally gravelly. Flood-plains, locally with flood microrelief, level fan surfaces. Tall alluvium and fan forest; locally *Casuarina* fan forest, tall grassland | S: Dove, Ibinambo, Ubo |

TABLE 4 (*Continued*)

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| Entisols (*continued*) | Udents (*continued*) | **6.** Haplu-dents (*continued*) | Orthic Hapludents (*continued*) | ‖**Ovessa** (G) (140 sq miles): stratified loamy to clayey alluvial soils | Alluvium and fan deposits, locally gravelly. Flood-plains and prior flood-plains, level fan surfaces, and low terraces. Tall alluvium and fan forest; locally irregular tall alluvium forest, regrowth; very locally tall grassland | D: Aiare, Korala<br>S: Gobera, Liamu, Momoiogo, Safia<br>M: Imo |
| | | | | **Gombara** (G) (20 sq miles): dark brown loamy to clayey alluvial soils | Alluvium derived mainly from volcanics, also from basic–ultrabasic rock, locally gravelly. Prior flood-plains, flood-plains, level fan surfaces. Tall fan forest, secondary forest, regrowth, mid-height grassland | S: Boborobo, Nembadi<br>M: Korala, Liamu |
| | | | | ‖**Minawaka** (260 sq miles): more or less gravelly regosolic soils | Colluvium derived mainly from hornfelsed basalt, also from schist and greywacke–siltstone and basic–ultrabasic rock. Generally steep to very steep, straight or very irregular hill and mountain slopes. Mixed deciduous and evergreen hill forest, commonly poor; locally regrowth, lower montane forest | D: Aimare, Amora, Misima<br>S: Avikaro, Manna<br>M: Arumbai, Avuru, ?Darumu, Foasi, Kovio |
| | | | Lithic Hapludents: well-drained shallow soils | ‖**Sisiworo** (75 sq miles): overlying soft weathered rock | Calcareous greywacke–siltstone, pelite, gabbro, microdiorite, dacitic ash, and ash–siltstone. Very steep hill slopes, locally structural short gentle upper slopes. Mixed deciduous and evergreen hill forest, commonly poor; eucalypt savannah | S: Arumbai, Bariji, Fiobobo, Manna<br>M: Aimare, Avikaro |
| | | | | **Kosiwara** (25 sq miles): overlying hard weathered rock | Greywacke, volcanic breccia. Very steep hill slopes. Eucalypt savannah and hill forest, mostly poor | S: Arumbai, Bariji |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mollisols: neutral¶ soils with thick dark topsoil | Udolls: well to imperfectly drained soils | 7. Hapludolls: slightly weathered or unweathered soils | Entic Hapludolls: alluvial soils | ‖**Ubo** (G) (30 sq miles): calcareous, commonly very silty soils | Calcareous alluvium and fan deposits, locally sandy or gravelly. Prior flood-plains, levees, and break-through splays; level to very gently undulating fan surfaces. Tall alluvium and fan forest; also tall grassland and secondary forest | S: Ubo<br>M: Momoiogo |
| | | | | **Embessa** (15 sq miles): sandy or very gravelly soils, well drained | Gravelly or sandy fan deposits and alluvium of volcanic and mixed derivation. Level fan surfaces and river terraces. Tall to mid-height grassland, tall eucalypt savannah, tall fan and alluvium forest, some regrowth | S: Gobera, Nembadi<br>M: Gorabuna, ?Iwuji, Momoiogo |
| | | | | ‖**Kinjaki** (25 sq miles): dark brown loam to clay soils | Alluvium of volcanic derivation, fan deposits derived from hornfelsed basalt. Level to slightly undulating fan surfaces, river terraces, and prior flood-plains. Tall to mid-height grassland, tall fan forest | S: Liamu, Nembadi<br>M: ?Iwuji, Uoive |
| | | | | ‖**Safia** (G) (110 sq miles): sandy clay loam to clay soils | Alluvium, fan deposits, locally gravelly; very locally colluvial deposits. Prior flood-plains, levees, and break-through splays; level fan surfaces and terraces; very locally gentle colluvial slopes. Tall grassland, locally tall alluvium and fan forest, secondary forest, regrowth | D: Safia<br>S: Liamu, Momoiogo<br>M: Aiare, Avuru, Gobera, ?*Sibium*, Ubo |
| | | | | **Bibira** (G) (10 sq miles): heavy clay soils | Alluvium; locally colluvium of greywacke–siltstone. Level fan surfaces, mostly lower parts; locally gentle colluvial slopes. Tall grassland, tall fan forest, mixed deciduous hill forest | M: Avikaro, Avuru, Safia |
| | | | Cumulic Hapludolls: soils with very thick topsoil | ‖**Foasi** (3 sq miles): mainly heavy clay soils, deep | Colluvio-alluvial deposits derived mainly from greywacke–siltstone and ultrabasic rock. Lower coalescing fan surfaces; gentle colluvial slopes which locally form broad low ridge crests. Tall fan forest, mixed deciduous hill forest; locally eucalypt savannah | M: Avikaro, Avuru, Safia |

TABLE 4 (*Continued*)

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| Mollisols (*continued*) | Udolls (*continued*) | 7. Haplu-dolls (*continued*) | (Lithic Hapludolls): well-drained shallow soils | **Asaga** (30 sq miles): clay to heavy clay soils on gravelly weathered rock | Gravelly greywacke, commonly with strong volcanic element. Very steep hill slopes; locally gentle to steep crestal and lower slopes. Eucalypt savannah; poor deciduous hill forest; locally secondary forest | S: Arumbai, Avikaro<br>M: Aimare, Asaga |
| | | | | **Ariari** (30 sq miles): clay soils overlying soft weathered rock | Greywacke–siltstone and hornfelsed basalt, mostly colluvium thereof. Steep to very steep hill slopes and locally gentle broad crests of low ridges. Eucalypt savannah, mixed deciduous hill forest, mostly poor | M: Aimare, Asaga |
| | | | | **Avikaro** (120 sq miles): clay to clay loam soils overlying hard weathered rock | Basic–ultrabasic plutonic rock, basalt, hornfelsed basalt, dacite, greywacke with strong andesitic element. Steep to very steep hill slopes; locally gentle crest slopes and basaltic tumuli. Eucalypt savannah. Poor mixed deciduous evergreen hill forest; locally mixed *Casuarina* hill forest, and short grassland | D: Avuru<br>S: Arumbai, Fiobobo, Manna<br>M: Iwuji, Sesaro |
| | | | Orthic Hapludolls: slightly weathered soils | ‖**Moikodi** (30 sq miles): moderately deep, clay to heavy clay soils | Calcareous greywacke–siltstone, rarely colluvium of hornfelsed basalt. Gentle to steep upper hill slopes and crests; locally very gentle lower slopes. Eucalypt savannah, mixed deciduous hill forest | S: Avikaro<br>M: Aimare, Arumbai, Asaga |
| | | 8. Argudolls: moderately weathered soils with coarser-textured surface horizons | Orthic Argudolls: well-drained soils with heavy clay subsoil | **Berudi** (50 sq miles): shallow to moderately deep soils with clay surface soils | Basic–ultrabasic plutonic rock and agglomerate, greywacke, some hornfelsed basalt. Moderate crest slopes and steep upper hill slopes. Eucalypt savannah, poor to moderate hill forest, mixed *Araucaria* hill forest; very locally mixed deciduous hill forest, short grassland | D: Darumu<br>S: ?Avikaro, Bariji<br>M: Aimare, Arumbai, Avuru, Fiobobo |

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|---|---|---|---|---|---|
| | | | ‖**Domara** (G) (7 sq miles): soils with sandy clay loam to gravelly clay surface horizons and of variable depth; commonly concretions | Calcareous greywacke–siltstone and alluvial and fan deposits. Gentle dissected slopes, foot slopes and level broad crests, level fan terraces and local rises in inactive fan surface. Eucalypt savannah; locally mixed deciduous hill forest | M: ?Adau, Asaga, Korala |
| | | | ‖**Bua** (20 sq miles): moderately deep, dark brown soils with sandy clay loam to sandy clay surface horizons | Basalt, possibly with thin veneer of dacitic ash. Gently undulating or concave surfaces; steep slopes of broad, slightly dissected cones. Mid-height grassland, eucalypt savannah, mid-height fan forest, hill forest, regrowth | D: Iwuji<br>S: Uoive |
| Aquolls: poorly to very poorly drained soils | **9**. Haplaquolls: unweathered medium-textured soils | Orthic Haplaquolls: poorly drained alluvial soils | **Obeia** (10 sq miles): calcareous, stratified soils | Calcareous alluvium. Level lower fan surfaces, prior flood-plains, and prior channels. Tall grassland with scattered *Phragmites*, irregular tall alluvium forest, *Pandanus* woodland | S: Ubo<br>M: Momoiogo |
| | | | **Feroroda** (10 sq miles): stratified soils | Alluvium and fan deposits of volcanic derivation; thin alluvium over deltaic and beach sand. Level lower fan surfaces with local microrelief; flood-plains, low degraded beach ridges. *Pandanus* and sago woodland, secondary forest, *Antidesma* savannah, tall grassland | S: Pawara<br>M: Nembadi, Tortore |
| | **10**. Argaquolls: moderately weathered soils with coarser-textured surface horizons | Udollic Argaquolls: poorly drained soils with heavy clay subsoil | **Mamana** (G) (10 sq miles): deep soils with clay loam to clay surface horizons | Alluvial and fan deposits. Level fan terraces and lower fan surfaces with some microrelief. Low fan forest, *Nauclea–Antidesma*, and *Eucalyptus–Melaleuca* savannah | S: Korala<br>M: Asaga |
| | | Albollic Argaquolls: very poorly drained soils with abrupt texture contrast and heavy clay subsoil | **Awala** (3 sq miles): moderately deep soils with sandy clay loam to clay surface horizons | Calcareous siltstone–mudstone, locally colluvio-alluvial deposits thereof. Level broad slight depressions, commonly with microrelief; gently sloping valley-side strips. Mid-height grassland with scattered *Nauclea* and *Antidesma* trees, or with many sedges and scattered eucalypts | M: Arumbai, Asaga |

TABLE 4 (*Continued*)

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| Alfisols: moderately weathered neutral texture-contrast soils | Udalfs: not gleyed or moderately gleyed soils | **11.** Typudalfs: soils with heavy clay subsoils, but without bleached eluvial horizon | Mollic Typudalfs: brown soils with thin to moderately thick topsoil | ‖**Fiobobo** (G) (40 sq miles): moderately deep soils with clay surface horizons | Calcareous greywacke–siltstone, basic–ultrabasic rock, hornfelsed basalt, commonly colluvium thereof. Generally moderate hill slopes; mostly upper slopes and crests or foot slopes. Hill forest, secondary forest, regrowth; locally eucalypt savannah and mixed deciduous hill forest | S: ?Amora<br>M: Arumbai, Asaga, Fiobobo |
| | | | Aquollic Typudalfs: gleyed soils with moderately thick dark topsoil | ‖**Urere** (20 sq miles): moderately deep soils with sandy clay loam to clay surface horizons | Calcareous greywacke–siltstone, locally below thin fan-glomerate. Gently undulating high surfaces, broad level crests. Eucalypt savannah; locally poor mixed deciduous hill forest, secondary forest, regrowth | S: Asaga<br>M: Aimare, Avikaro |
| | | | Aquic Typudalfs: gleyed soils with abrupt texture contrast | **Dowai** (20 sq miles): moderately deep to deep soils with sandy clay loam to gravelly clay loam surface horizons | Calcareous greywacke–siltstone. Gently undulating high surfaces and broad valley-side strips; locally irregular broad moderate slopes. Eucalypt savannah; very locally mixed deciduous hill forest | S: Asaga<br>M: Aimare, Arumbai |
| | Aqualfs: strongly gleyed soils | **12.** Ochraqualfs: soils with heavy clay subsoils and weakly developed bleached eluvial horizon | Orthic Ochraqualfs: soils with alkaline subsoils | ‖**Nuaro** (10 sq miles): deep soils with sandy clay loam to clay, weakly acid surface horizons | Fan deposits derived from basic–ultrabasic rocks. Level lower inactive fan surfaces. Low fan forest, locally degrading into scrub with *Pandanus* and sedges | S: Korala<br>M: Boborobo |

| | | | | | | |
|---|---|---|---|---|---|---|
| Inceptisols: soils with minor to moderate *profile* development | Umbrepts: acid soils with thick dark topsoils | **13.** Haplumbrepts: medium-textured soils | Aquentic Haplumbrepts: poorly drained alluvial soils | ‖**Kaevi** (2 sq miles): sandy soils with sandy loam topsoil | Beach sand of volcanic derivation. Level to slightly undulating degraded beach ridges. *Tall grassland, beach ridge forest with palm* understorey | S: Pawara |
| | | | Lithic Haplumbrepts: shallow soils | **Geriwu** (40 sq miles): commonly rather gravelly *clay loam soils overlying* hard weathered rock | Basalt, andesite, hornfelsed basalt, schist. Very steep hill and mountain slopes; locally moderate slopes of narrow spurs. Hill forest, locally poor | D: ?Hydrographers<br>S: Manna<br>M: Banderi, Misima, *Uoive* |
| | | | Orthic Haplumbrepts: slightly weathered soils | **Sesaro** (5 sq miles): deep, clay loam to clay soils with yellow-brown subsoil | Fan deposits of basaltic and (?)basic–ultrabasic derivation. Level to gently sloping, dissected fan surfaces. Tall grassland, mid-*height fan forest, regrowth* | S: Boborobo |
| | Ochrepts: moderately weathered soils with thin dark topsoils | **14.** Dystrochrepts: medium- to fine-textured soils | Eutric Dystrochrepts: well-drained, weakly *acid soils* | **Ibidura** (5 sq miles): shallow, brown heavy clay soils overlying soft *weathered rock* | Calcareous greywacke–siltstone. Gentle to moderate lower hill slopes; locally steep short hill slopes. Eucalypt savannah | M: Arumbai, *Asaga* |
| | | | | **Didana** (170 sq miles): shallow, dark red-brown gravelly clay soils overlying fragmented hard weathered rock | Basic–ultrabasic plutonic rocks, locally hornfelsed basalt, commonly colluvium thereof. Steep to very steep hill and mountain slopes; locally moderate crest slopes. Poor hill forest (locally with *Araucaria*), eucalypt savannah; locally mixed deciduous hill forest, short grassland | D: Didana<br>S: Avuru, Fiobobo<br>M: Aimare |
| | | | | ‖**Afore** (75 sq miles): shallow to moderately deep, dark brown clay to clay loam soils overlying weathered rock | Basalt. Gentle to moderate slopes on lava surfaces; very steep slopes of lava cones, domes, mountain ridges, and below lava escarpments. Mid-height and tall grassland, poor hill forest; locally tall plateau forest | D: ?Sesaro<br>S: Uoive<br>M: Bariji |

TABLE 4 (*Continued*)

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| Inceptisols (*continued*) | Ochrepts (*continued*) | **14.** Dystrochrepts (*continued*) | Eutric Dystrochrepts (*continued*) | **Emo** (70 sq miles): moderately deep, yellow-brown clay soils with gravel, particularly in subsoil | Basic–ultrabasic rocks, basalt, hornfelsed basalt, locally schist; mostly colluvium thereof. Very steep mountain and hill slopes with slump features, moderate to gentle slopes of slumped ridges. Poor hill forest, mixed deciduous hill forest | S: Didana<br>M: Aimare, Misima |
| | | | Orthic or Oxic Dystrochrepts: well-drained, acid to strongly acid soils | ‖**Aiare** (10 sq miles): deep to moderately deep, yellow-brown acid clay soils | Alluvium and colluvium, colluvium of schist. Gently sloping high terraces and foot slopes, very steep mountain slopes with slump features. Foothill forest, poor hill forest, mid-slope forest, regrowth | S: Kovio<br>M: Aiare, Siviai, Wowo |
| | | | | ‖**Kambururu** (70 sq miles): deep, yellow-brown to red-brown strongly acid silty clay loam to silty clay soils | Andesitic agglomerate, andesitic and mixed valley fill and mudflow deposits, hornfelsed basalt, calcareous pelite, locally basic–ultrabasic rocks. Very steep hill and mountain slopes; locally moderate spur slopes. Mid-slope forest, lower montane forest, regrowth; locally mid-height grassland and eucalypt savannah | D: Foasi, Suwari<br>S: Banderi, Gorabuna, Hydrographers, Siviai<br>M: Tahama, Wowo |
| | | | | ‖**Kiara** (90 sq miles): deep to moderately deep, yellow-brown acid clay loam to sandy clay soils with marked influence of volcanic ash | Colluvium mixed with volcanic ash. Very steep and steep hill and mountain slopes; locally moderate narrow crest and bench slopes. Hill forest, *Castanopsis* forest, secondary forest; very locally lower montane forest | S: Gorabuna, Guaya, Kovio, Tahama<br>M: Didana, Misima, Owalama |

| | | | | | |
|---|---|---|---|---|---|
| Andepts: moderately weathered volcanic ash soils, acid to weakly acid | **15**. Ochrandepts: soils with thin dark topsoil | (Orthic Ochrandepts): well-drained soils | **Ondoro** (20 sq miles): moderately deep, sandy loam to sandy clay loam soils | Dacitic ash and locally andesitic ash, mostly shallow over basalt or andesitic mudflow deposits. Gently sloping plateau surfaces, and very steep hill slopes. Tall plateau forest, mid-slope forest, poor *Castanopsis* forest | M: Guaya, Tahama |
| | | | ‖**Sibium** (5 sq miles): deep to moderately deep, fine sandy clay loam to clay soils | Andesitic ash, generally colluvially disturbed. Very steep upper or lower hill slopes, gentle to moderate crest slopes. *Castanopsis* forest, lower montane forest; locally secondary forest | M: Didana, Kovio, Suwari |
| | | (Spodic Ochrandepts): soils with (?)podzolic horizon | ‖**Siurani** (2 sq miles): deep, sandy clay soils | Andesitic ash. Moderate to steep upper crest slopes (5000 ft or higher). Lower montane forest | M: Hydrographers |
| | **16**. Umbrandepts: soils with thick dark topsoil | Orthic Umbrandepts: well-drained deep soils | ‖**Uoive** (50 sq miles): soils with sandy loam texture below 30 in. and yellow-brown subsoil | Andesitic and locally dacitic ash. Very steep to steep hill slopes and locally narrow crests; dissected, slightly undulating plain in Uoive land system. Mid-slope and poor hill forest. *Castanopsis* forest, lower montane forest; locally regrowth | S: Guaya, Owalama<br>M: Kovio, Uoive |
| | | | ‖**Kwena** (100 sq miles): soils with sandy clay *loam texture* | Andesitic and dacitic ash. Gentle to steep rather broad crest slopes and gently sloping to level high terraces and valley-side strips; locally moderate to steep upper and lower hill slopes. Hill forest, secondary forest, regrowth; also *Castanopsis* forest and lower montane forest; very locally tall grassland | S: Owalama, Guaya<br>M: Aiare, Didana, Gorabuna, ?Hydrographers, Kovio, Misima, Tahama, Uoive |

TABLE 4 (*Continued*)

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| Inceptisols (*continued*) | Andepts (*continued*) | **16.** Umbrandepts (*continued*) | Orthic Umbrandepts (*continued*) | **Owalama** (30 sq miles): dominantly sandy clay soils with yellow-brown subsoil | Andesitic ash. Gentle to steep crest and upper hill and mountain slopes; very steep slopes of ash ridges. Lower montane forest, mid-slope forest; locally regrowth | S: Owalama<br>M: Guaya, Kovio, Misima |
| | | | | ‖**Gewoia** (40 sq miles): dominantly sandy clay soils with dark brown subsoil to 20 in. or more | Dacitic ash. Level to gently sloping broad crests and undulating plateau and fan surfaces; locally steep upper hill slopes. Tall plateau forest, regrowth; locally tall grassland | S: Iwuji, Tahama<br>M: ?Sibium |
| Oxisols: strongly weathered friable to firm clay to heavy clay soils | Ustox: weakly acid to neutral soils | **17.** (Ochrustox): soils with thin dark topsoil | (Orthic Ochrustox): uniformly textured soils | ‖**Mioki** (5 sq miles): shallow to moderately deep, dark red-brown to dark brown friable soils overlying hard weathered rock | Basic–ultrabasic plutonic rock, hornfelsed basalt. Steep upper hill slopes and convex crests. Eucalypt savannah, mixed *Casuarina* hill forest | M: Aimare, Avuru |
| | | | | ‖**Jare** (10 sq miles): shallow to moderately deep, yellow-red to red, firm soils overlying thick C horizon | Greywacke–siltstone, hornfelsed basalt, gabbro, andesitic mudflow deposits. Gentle to steep crest and upper hill slopes of low ridges. Eucalypt savannah, hill forest; very locally *Castanopsis* forest | M: Arumbai, Asaga, Fiobobo, Foasi, Tahama |
| | | | | ‖**Silimidi** (15 sq miles): deep, strong brown (in upper part commonly yellow-red) friable soils with very thin topsoil | Mudflow-boulder fan deposits derived from schist, with minor ultrabasic breccia; very locally ultrabasic rock. Gentle to moderate plateau and crest slopes. Mid-slope forest. *Castanopsis* forest; locally regrowth, mixed *Casuarina* hill forest and mid-height grassland | D: Silimidi<br>M: Guaya |

| | | | | | |
|---|---|---|---|---|---|
| | | (Aquic Ochrustox): moderately gleyed, very firm soils | **Busi** (1 sq mile): moderately deep soils, yellow-red, but with depth increasingly brown and olive mottled | Fan deposits. Dissected gentle fan slopes. Low fan forest | M: Boborobo |
| | | (Argillic Ochrustox): soils with coarser-textured surface horizon | ‖**Arumbai** (5 sq miles): moderately deep to deep, brown over yellow-red to red firm to very firm heavy clay soils with sandy clay loam to clay surface horizons | Fan-glomerate, mudflow-boulder deposits, colluvium of greywacke–siltstone. Gentle to moderate crest, fan, and bench slopes; steep upper hill and slump toe slopes. Eucalypt savannah, mixed deciduous hill forest; locally mid-slope forest, regrowth | M: Aimare, Arumbai, Asaga, Liamu, Wowo |
| Udox: acid to strongly acid soils | **18.** (Ochrudox): soils with thin dark topsoils | (Lithic Ochrudox): shallow soils | **Sirorata** (1 sq mile): weak red to red-grey friable soils over strongly weathered rock | Basalt. Very steep crest and hill slopes. Mid-slope forest | M: Guaya |
| | | (Orthic Ochrudox): uniformly textured soils | ‖**Boro** (25 sq miles): moderately deep to deep, strong brown, very friable soils | Ultrabasic rock, andesitic agglomerate, colluvial deposits derived from schist and ultrabasic rock. Steep to very steep upper hill slopes, narrow crests; locally gentle colluvial lower slopes. Mid-slope and poor hill forest, poor *Castanopsis* forest; locally regrowth | S: Banderi<br>M: Amora, Didana, ?Guaya, Owalama |
| | | | ‖**Korua** (50 sq miles): deep yellow-red to red, firm to friable soils | Hornfelsed basalt and calcareous pelite, greywacke, fan deposits, and schistose mudflow-boulder deposits. Level to steep rounded crests; locally gentle irregular lower slopes. Lower montane forest, *Castanopsis* and mixed *Araucaria* hill forest; locally secondary forest and regrowth; very locally eucalypt savannah, mid-height grassland | S: Boborobo, Foasi<br>M: ?Amora, Arumbai, Banderi, ?Bariji, ?Hydrographers, Kovio, Siviai |

TABLE 4 (*Continued*)

| Order | Suborder | Great Group† | Subgroup | Family‡ | Rock, Land Form, and Vegetation | Land System§ |
|---|---|---|---|---|---|---|
| Oxisols (*continued*) | Udox (*continued*) | **18.** Ochrudox (*continued*) | (Ustic Ochrudox): soils with weakly acid to neutral surface horizons | ‖**Wowo** (15 sq miles): deep, friable soils with thick dark brown surface horizons and strong brown subsoil | Mudflow-boulder deposits derived from calcareous schist. Broad moderate upper slopes. Tall fan forest, *Castanopsis* forest | D: Ibinambo<br>S: Wowo |
| | | | (Argillic Ochrudox): soils with coarser-textured surface horizons | **Aimare** (10 sq miles): shallow to moderately deep, mostly strong brown firm heavy clay soils with clay loam to clay surface horizons; overlies thick C horizon | Hornfelsed basalt, basic–ultrabasic plutonic rock, minor andesitic agglomerate, schist, commonly colluvium thereof. Gentle crest slopes, moderate to steep upper hill slopes. *Castanopsis* and mid-slope forest; also eucalypt savannah and locally mixed deciduous hill forest | S: Banderi, Suwari<br>M: Aimare, Avuru, Sesaro |
| | | | | ‖**Togofu** (20 sq miles): moderately deep, dark red firm to friable heavy clay soils with clay surface horizons | Basaltic and locally andesitic lava, minor hornfelsed basalt. Gentle to moderate broad crest slopes, steep to very steep spur slopes. Tall plateau forest, hill forest, *Castanopsis* forest, regrowth | S: Uoive<br>M: Hydrographers, Sesaro |
| | | | | ‖**Siviai** (10 sq miles): deep, strong brown friable heavy clay soils with dark brown to dark red-brown clay loam to clay surface horizons | Basic–ultrabasic fanglomerate. Slightly undulating high surfaces and broad crests. Mid-height fan forest | S: Siviai |
| | | | | **Moni** (15 sq miles): deep, brown over yellow-red to red friable to firm heavy clay soils with sandy clay to clay surface horizons | Basic–ultrabasic rock, also hornfelsed basalt, mixed valley fill and mudflow deposits. Gentle to steep crest and upper hill slopes, locally very steep hill slopes. *Castanopsis* and mid-slope forest, minor eucalypt savannah, mid-height grassland | S: Suwari, Wowo<br>M: Aimare, Didana |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ultisols: strongly weathered, acid, texture-contrast soils | Ochrults: soils with very firm to very plastic heavy clay subsoils | **19.** Rhodochrults: dark-coloured soils with thin topsoils | Orthic Rhodochrults: well-drained soils | **Samage** (10 sq miles): deep dark brown soils with sandy clay loam to sandy clay surface horizons | Basalt, probably with thin veneer of dacitic ash. Gentle to steep upper hill and crest slopes. Tall plateau forest, secondary forest, regrowth | M: Tahama |
| | | **20.** Typochrults: light-coloured soils with thin topsoils | Aquic Typochrults: gleyed soils | **Imuru** (1 sq mile): moderately deep to deep, grey soils with prominent mottles and clay loam to clay surface horizons | Fan deposits, siltstone. Slight depressions in high fan surface, broad crest slopes. Tall grassland, eucalypt savannah | M: Arumbai, Siviai |

*Soil depth to C or D horizon is indicated as deep (> 44 in.), moderately deep (20–44 in.), and shallow (< 20 in.). These terms have not been applied to alluvial soils, which are all pedologically shallow, but for practical purposes deep. Soil reaction is indicated as strongly acid (pH 4–5), acid (pH 5–6), weakly acid (pH 6–6·5), neutral (pH 6·5–7·5), or alkaline (pH > 7·5). Calcareous soils have pH 7·5–8·5, saline soils pH 8–9.

†The great groups (and one order) have been numbered for cross reference with the land unit descriptions in Part II and with Figure 9.

‡The area figures are given to show the relative importance of the soil families. They are only rough approximations. The difference between the sum of all soil areas and the size of the survey area represents the area occupied by miscellaneous land types and open water. The notation (G) indicates the occurrence of a gravelly phase, i.e. profiles with a very high amount of gravel above a depth of 20 in. This notation is *not* applied to soil families that are *normally* gravelly. Gravelly phase profiles of Safia and Bibira families differ from Embessa family in that the non-gravelly horizons of the former two are clay and heavy clay, of the latter sandy loam to loamy sand.

§The area occupied by a soil family in a land system is indicated as D (dominant, 50% or more), S (subdominant, 15–49%), or M (minor, < 15%). A question mark before a land system name indicates that the occurrence of the family in this land system is inferred, or that the area percentage is particularly uncertain.

‖For analytical data see Table 5.

¶These soils occasionally have topsoils with pH 6.

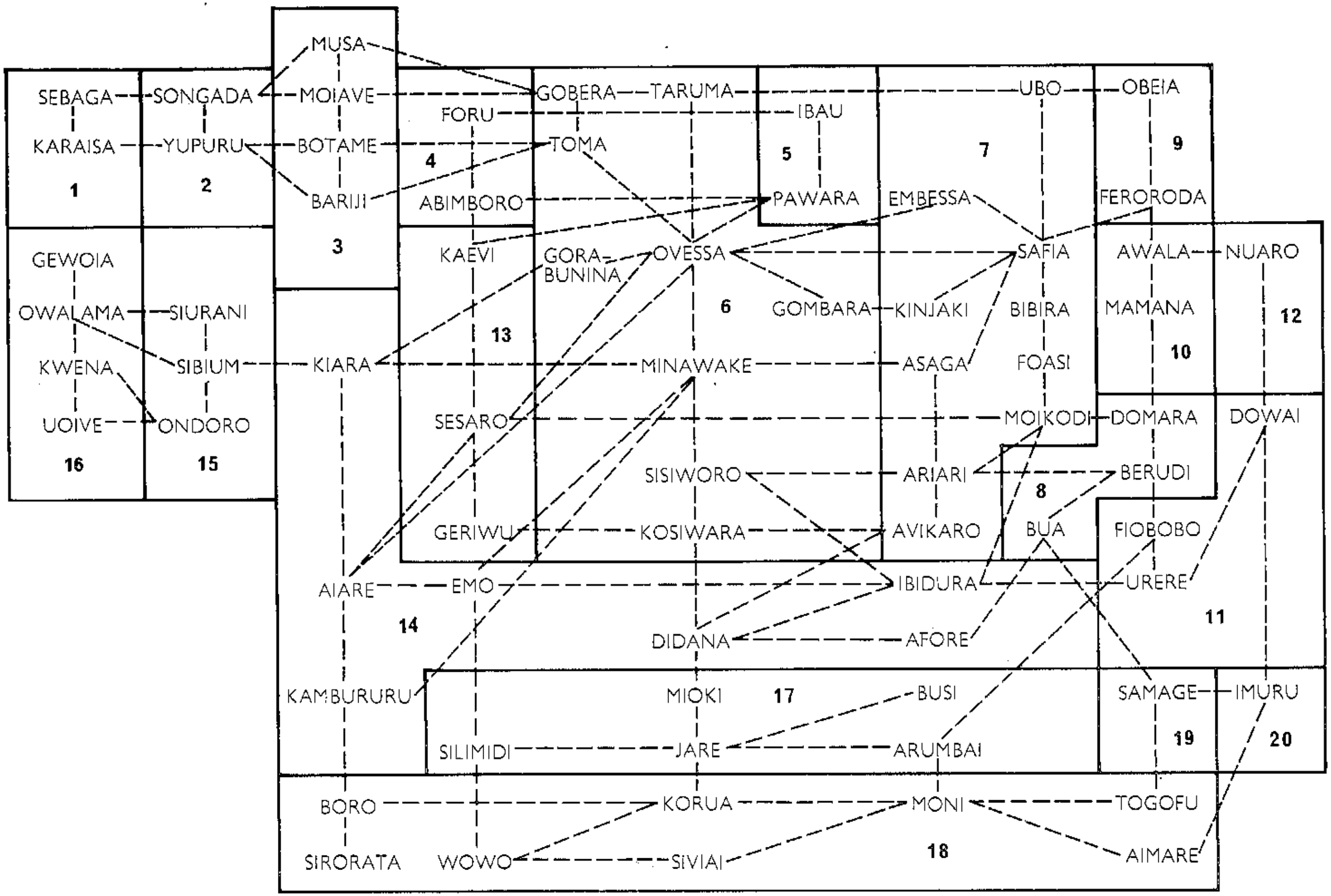


Fig. 9.—Relationship between soil families (names) and great soil groups (numbered blocks). Broken lines indicate intergradational relationships. Tentative equivalent great group names of 7th Approximation are 1, Histosols (order); 2, Hydraquents; 3, Haplaquents; 4, Psammaquents; 5, Orthopsamments; 6, Hapludents; 7, Hapludolls; 8, Argudolls; 9, Haplaquolls; 10, Argaquolls; 11, Typudalfs; 12, Ochraqualfs; 13, Haplumbrepts; 14, Dystrochrepts; 15, Ochrandepts; 16, Umbrandepts; 17, Ochrustox; 18, Ochrudox; 19, Rhodochrults; 20, Typochrults.

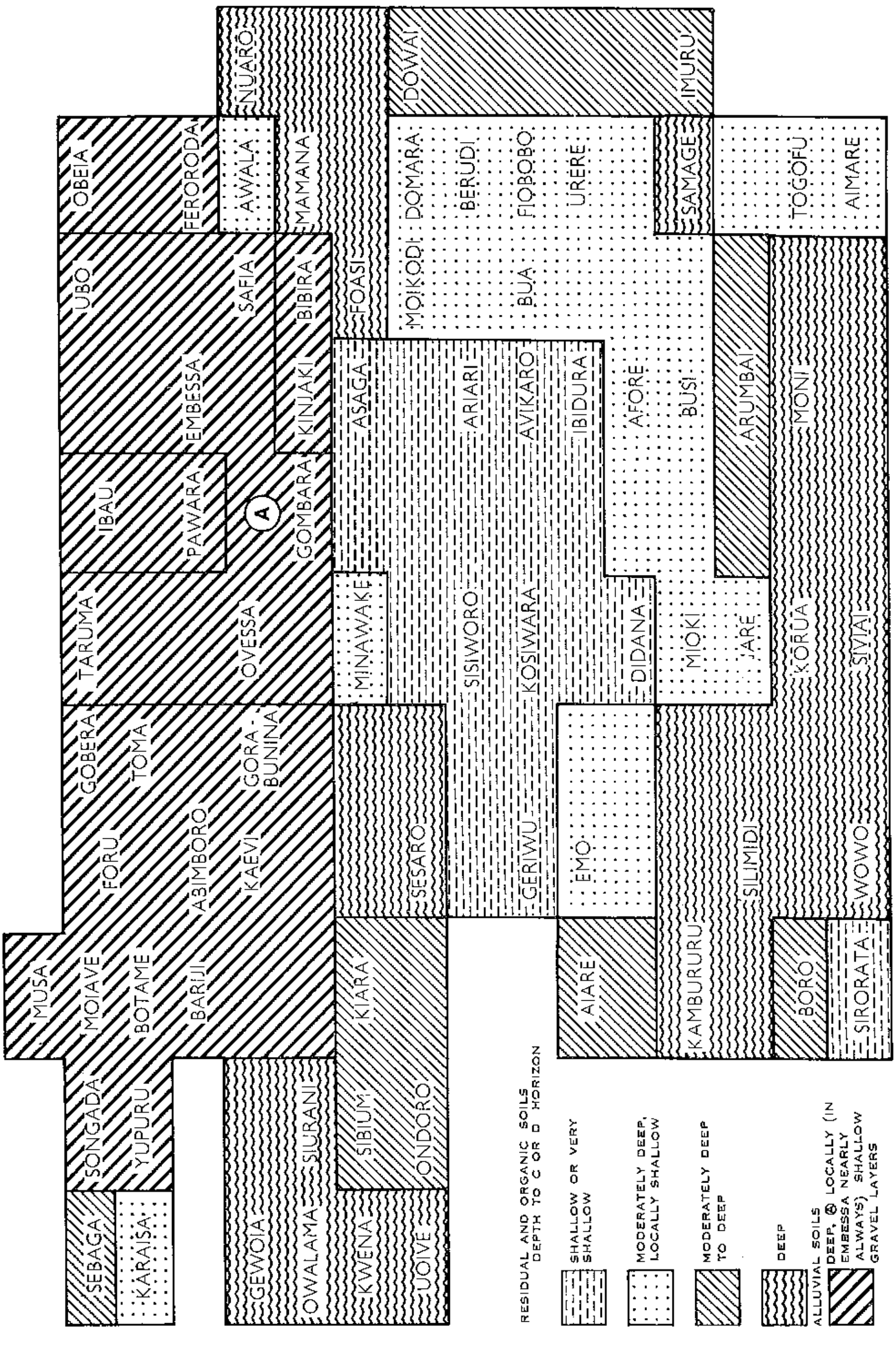


Fig. 10.—Relationship between soil depth and soil families. (Shallow, < 20 in.; moderately deep, 20–44 in.; deep, > 44 in.)

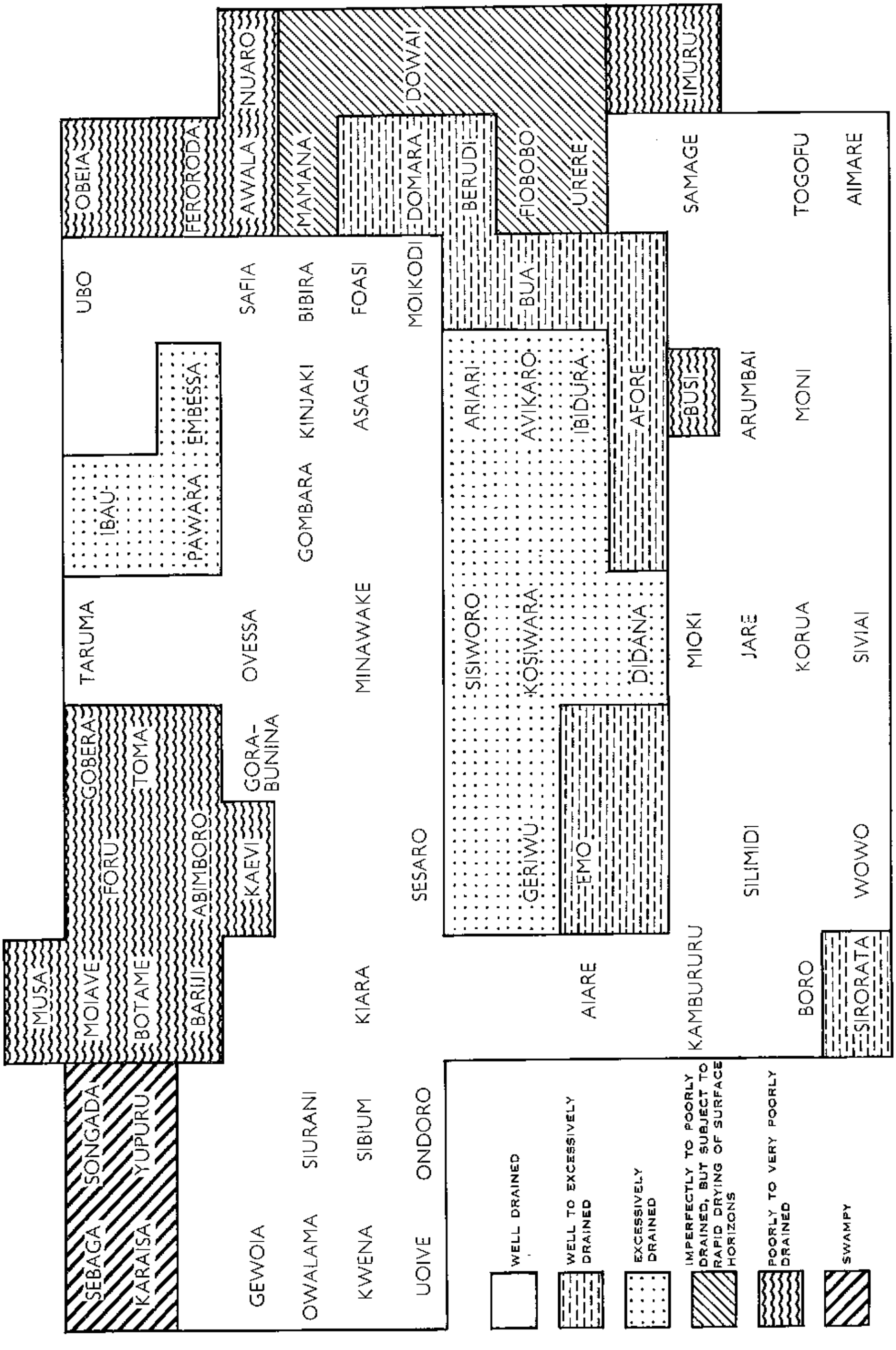


Fig. 11.—Relationship between soil drainage and soil families.

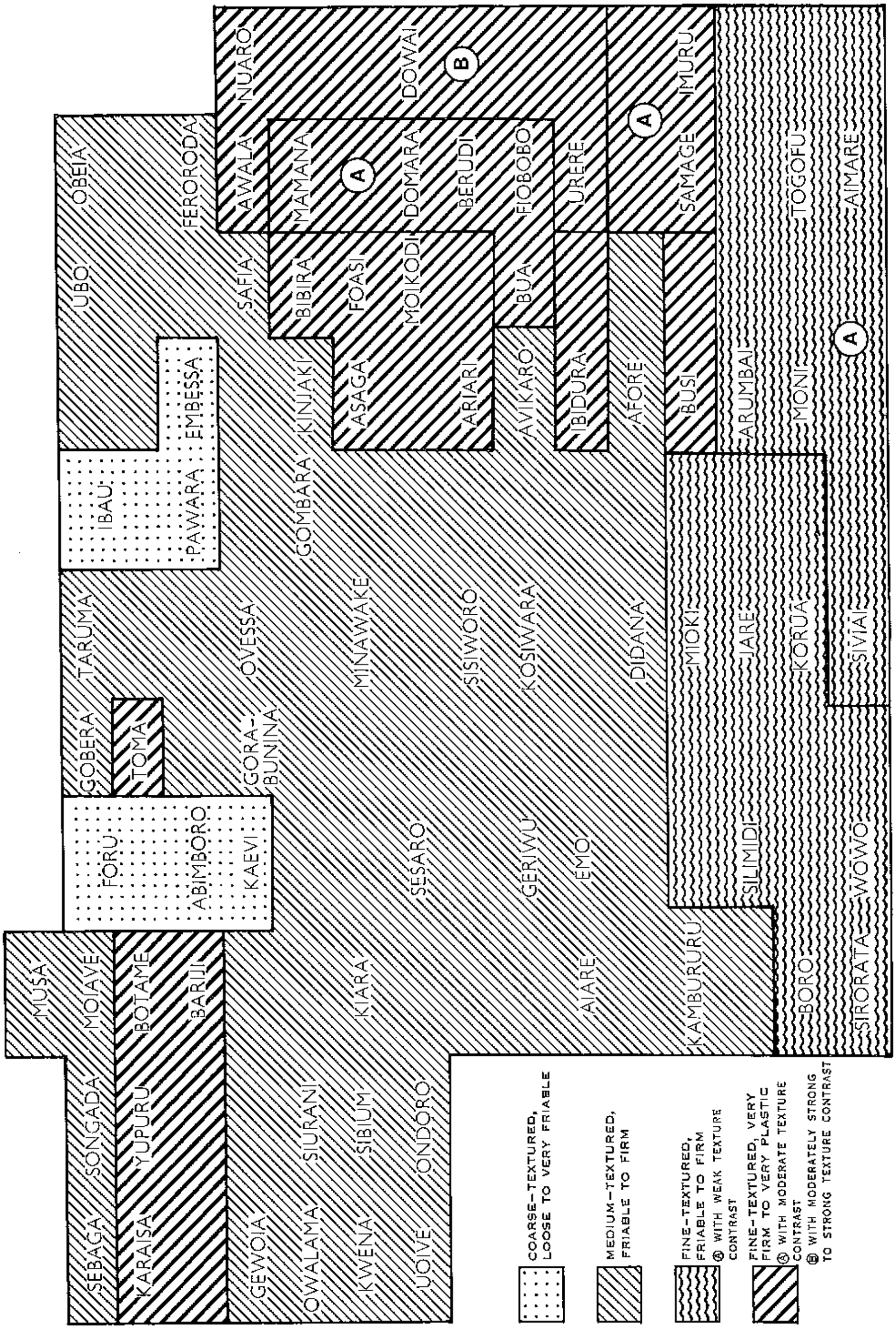


Fig. 12.—Relationship between soil texture and moist consistence, and soil families. (Texture classes: coarse = sand to loamy sand, medium = sandy loam to light clay, fine = medium to heavy clay.)

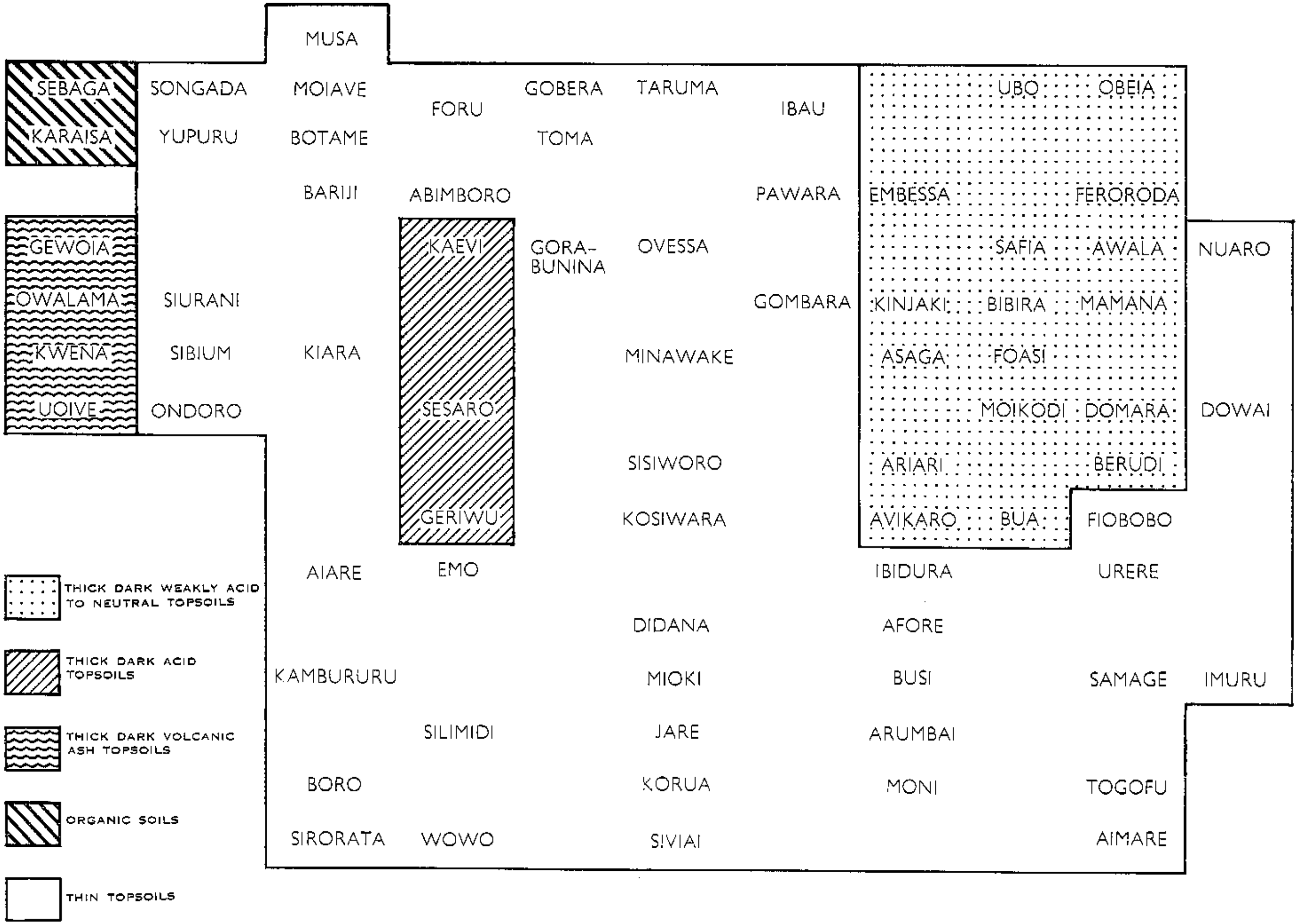


Fig. 13.—Relationship between topsoil characteristics and soil families. (Thick: 10 in. or more in residual soils, 6 in. or more in alluvial soils. Thin: below limits set above. Dark: Munsell chroma and value 3 or less, and at least 1 unit darker than underlying horizon.)

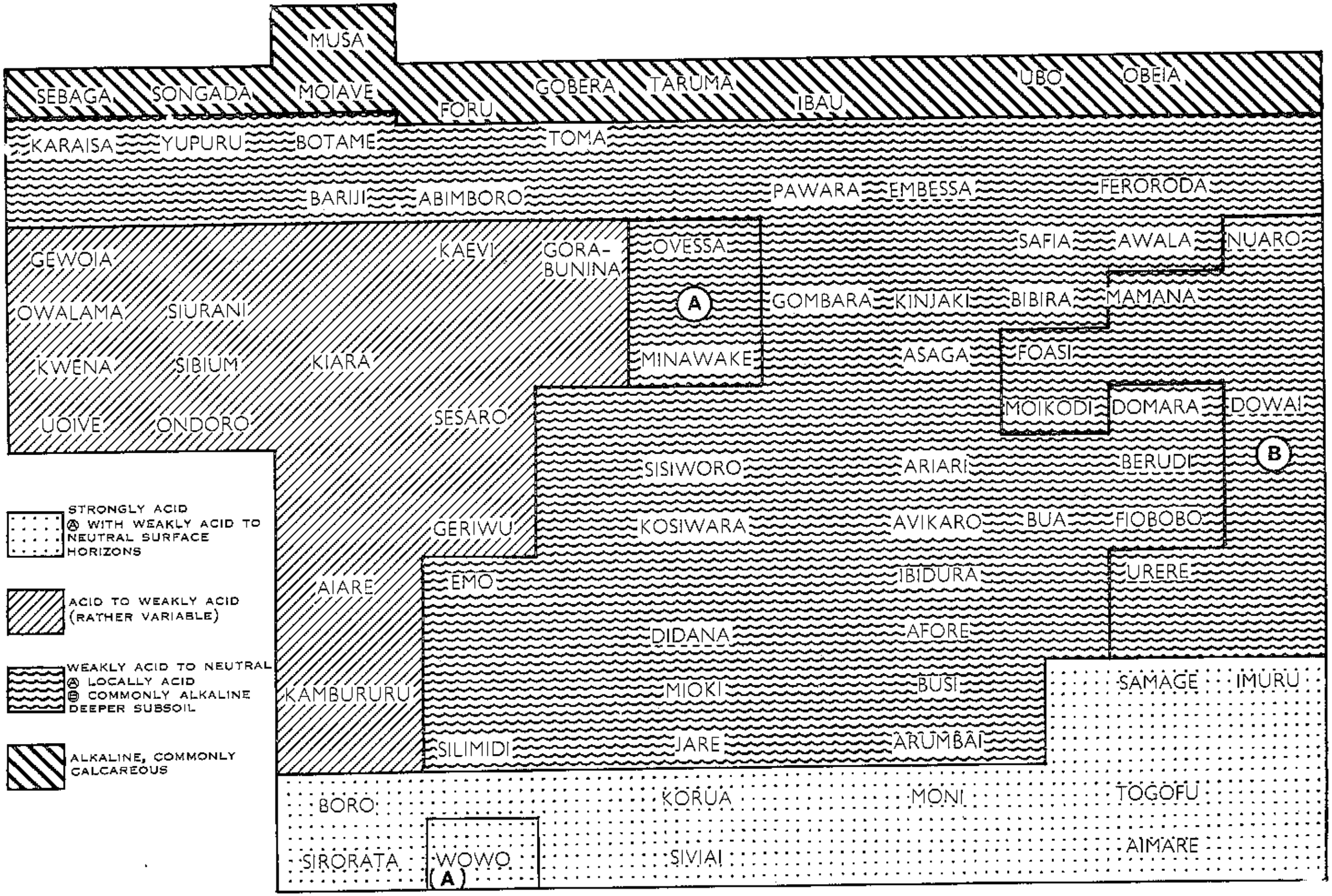


Fig. 14.—Relationship between pH and soil families. (Strongly acid, pH 4–5; acid, pH 5–6; weakly acid, pH 6–6·5; neutral, pH 6·5–7·5; alkaline, pH 7·5–9.)

TABLE 5

RANGES OF SOME CHEMICAL PROPERTIES* FOR GROUPS OF SOIL FAMILIES†

| Horizon | Organic C (%) | N (%) | P–HCl (%) | C.E.C.‡ (m-equiv. %) | Saturation (%) | pH $H_2O$ | Exch. K (m-equiv. %) |
|---|---|---|---|---|---|---|---|
| Organic soils (Histosols). Karaisa (P17) family | | | | | | | |
| Organic horizon | 11 | 1·0 | 0·235 | 74 | 50 | 6·6 | 0·2 |
| Mineral subsoil | 0·4 | 0·1 | 0·178 | 32 | 61 | 8·0(!) | 0·2 |
| Undifferentiated soils (Hapludents); alluvial soils. Ovessa (P18, P38), Taruma (P24), Toma (P3) families | | | | | | | |
| Topsoil | 0·4–2·4 | 0·1–0·3 | — | 27–31 | 65–76 (Taruma > 100) | 6·7–7·1 (Taruma 8·5) | 0·15–0·35 |
| Subsoil | 0·04–0·6 | 0·03–0·1 | 0·133–0·146 | 25 | 72 (Taruma ?100) | 6·7–8·5 | 0·2 |
| Undifferentiated soils (Hapludents); colluvial and residual soils. Minawake (P35), Sisiworo (P37) families | | | | | | | |
| Topsoil | 1·3–2·7 | 0·2–0·4 | 0·065 | 35–40 | 65–70 | 6·4–6·7 | 0·1–0·15 |
| Subsoil (Minawake) | 0·7 | 0·07 | 0·042 | 34 | 70 | 7·0 | 0·1 |
| C horizon (Sisiworo) | — | — | 0·035 | 52 | 93 | 7·0 | 0·1 |
| Soils with neutral thick dark topsoil (Hapludolls); alluvial soils. Kinjaki (P15), Safia (P20, P29), Ubo (P2, P16) families | | | | | | | |
| Topsoil | 1·9–3·9 | 0·2–0·3 | — | 33–47 | 50–90 | 6·1–7·4 | 0·2–0·5 |
| Subsoil | 0·1–0·4 | 0·02–0·1 | 0·134–0·156 | 31–55 | 80–90 | 6·6–8·0 | 0·15–0·2 |
| Soils with neutral thick dark topsoil (Hapludolls); colluvial and residual soils. Foasi (P32), Moikodi (P31, P34) families | | | | | | | |
| Topsoil | 0·9–4·4 | 0·1–0·4 | 0·054 | 48–70 | 55–85 | 6·1–7·4 | 0·2–1·0 |
| Subsoil | 0·3–0·4 | 0·03–0·04 | 0·021–0·045 | 56–57 | 80–90 | 6·5–6·6 | 0·05–0·07 |
| C horizon | — | — | 0·099–0·202 | 44 | 85 | 6·8–8·1 | 0·13 |
| Soils with neutral thick dark topsoil and coarser-textured surface horizon (Argudolls). Bua (P5), Domara (P28) families | | | | | | | |
| Topsoil | 0·6–2·4 | 0·04–0·3 | 0·043–0·120 | 23–38 | 60–70 | 6·0–7·0 | 0·4–0·5 |
| Subsoil | 0·2–0·4 | 0·02–0·04 | 0·022–0·036 | 20(!) | 65 | 7·0 | 0·2–0·3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Neutral texture-contrast soils (Typudalfs, Ochraqualfs). Fiobobo (P21), Nuaro (P19), Urere (P23) families** | | | | | | | |
| Topsoil | 1·1–2·6 | 0·15–0·3 | 0·016–0·050 | 16–19 | 70–75 | 6·4–6·7 | 0·1 |
| Subsoil | 0·1–0·8 | 0·06–0·1 | 0·010–0·015 | 24–51 | 80 | 6·7–7·0 | 0·02–0·1 |
| Deeper subsoil (Nuaro) | 0·1 | 0·03 | 0·061 | 45 | >100 | 8·5 | 0·02 |
| **Soils with acid thick dark topsoil (Haplumbrepts). Kaevi (P1) family** | | | | | | | |
| Topsoil | 2·2 | 0·15 | — | 11 | 5 | 6·1(!) | 0·1 |
| Subsoil | 0·1 | 0·01 | — | — | — | 6·6 | |
| **Moderately weathered soils with thin topsoil (Dystrochrepts); weakly acid soils. Afore (P6) family** | | | | | | | |
| Topsoil | 2·7 | 0·25 | 0·069 | 25 | 35 | 6·1 | 0·4 |
| Subsoil | 0·4 | 0·06 | 0·051 | 21 | 63 | 7·2 | 0·2 |
| C horizon | — | — | 0·124 | — | — | — | |
| **Moderately weathered soils with thin topsoil (Dystrochrepts); acid to strongly acid soils. Aiare (P43), Kambururu (P9), Kiara (P11) families** | | | | | | | |
| Topsoil | 1·8–5·0 | 0·25–0·6 | 0·083 | 29–38 | 0·5–8 | 5·0–5·2 | 0·05–0·85 |
| Subsoil | 0·4–2·3 | 0·1–0·3 | 0·055–0·110 | 16–29 | 2–13 | 5·6–5·8 | 0·1 |
| Deep subsoil | 0·05–0·3 | 0·02–0·04 | 0·039–0·140 | 12–25 | 8–13 | 5·6–6·0 | 0·04–0·07 |
| **Moderately weathered ash soils with thin dark topsoil (Ochrandepts). Sibium (P41), Siurani (P8) families** | | | | | | | |
| Topsoil | 8·7–10·7 | 0·7–0·9 | 0·072 | 45–55 | 1–2 | 4·2–5·3 | 0·1–0·15 |
| Subsoil | 1·6–2·6 | 0·15–0·5 | 0·010–0·040 | 29–37 | 0·5 | 5·4–6·0 | 0·02–0·06 |
| Weathering profile underlying Sibium | 0·4 | 0·05 | 0·010 | 9–15 | 1–2 | 5·6–5·8 | 0·02 |
| **Moderately weathered ash soils with thick dark topsoil (Umbrandepts); soils with dark brown subsurface horizon. Gewoia (P7, P12) family** | | | | | | | |
| Topsoil | 0·6–2·4 | 0·05–0·25 | — | 10–20 | 45–65 | 5·9–6·8 | 0·3 |
| Subsoil | 0·02–0·3 | 0·02–0·1 | 0·010–0·093 | 9–18 | 35–65 | 6·0–6·9 | 0·25–0·4 |
| **Moderately weathered ash soils with thick dark topsoil (Umbrandepts); soils with yellow-brown subsurface horizon. Kwena (P10, P45), Uoive (P44) families** | | | | | | | |
| Topsoil | 1·8–6·7 | 0·4–0·7 | — | 35–45 | 1 | 5·0–5·3 | 0·05–0·1 |
| Subsoil | 0·5–1·1 | 0·04–0·15 | 0·039–0·085, 0·161 in one sample | 15–33 | 1–5 | 5·4–6·1 | 0·03–0·1 |

TABLE 5 (*Continued*)

| Horizon | Organic C (%) | N (%) | P–HCl (%) | C.E.C.‡ (m-equiv. %) | Saturation (%) | pH $H_2O$ | Exch. K (m-equiv. %) |
|---|---|---|---|---|---|---|---|
| Strongly weathered, weakly acid to neutral soils (Ochrustox); soils with high base saturation. Arumbai (P25), Jare (P30) families | | | | | | | |
| Topsoil | 1·4–1·9 | 0·15–0·20 | 0·060 | 13 | 50 | 6·1–6·8 | 0·2 |
| Subsoil | 0·7–0·8 | 0·08–0·1 | 0·037 | 18–28 | 40–80 | 6·4–7·0 | 0·07–0·1 |
| C horizon (Arumbai) | — | — | 0·020 | 16 | 85 | 6·8 | 0·13 |
| Strongly weathered, weakly acid to neutral soils (Ochrustox); soils with low base saturation. Mioki (P36), Silimidi (P26) families | | | | | | | |
| Topsoil | 2·1–2·3 | 0·25 | — | 19–25 | 25–50 | 6·3 | 0·1–0·2 |
| Subsoil | 0·5–0·8 | 0·04–0·09 | 0·050–0·156 | 10–14 | 5–20 | 6·4–7·0 | 0·02–0·03 |
| Strongly weathered, acid to strongly acid soils (Ochrudox); normal soils. Boro (P39, P42), Korua (P33), Siviai (P40), Togofu (P14) families | | | | | | | |
| Topsoil | 1·0–2·3 | 0·15–0·3 | 0·100 | 16–26 | 4–26 | 4·9–5·7 | 0·1–0·3 |
| Subsoil | 0·1–0·4 | 0·03–0·1 | 0·026–0·094 (Togofu 0·124) | 13–28 | 8–17 | 5·2–5·9 | 0·02–0·2 |
| C horizon (Togofu) | — | — | 0·304 | 17 | 4 | 5·3 | 0·01 |
| Strongly weathered, acid to strongly acid soils (Ochrudox); soils with weakly acid to neutral, dark brown surface horizons. Wowo (P27) family | | | | | | | |
| Topsoil | 1·1–3·7 | 0·2–0·45 | 0·120 | 20 | 50 | 6·4–6·8 | 0·15 |
| Subsoil | 0·2–0·3 | 0·03–0·1 | 0·120–0·132 | 14–16 | 6–17 | 5·6 | 0·05–0·1 |

* Analyses by Soil Laboratory, Royal Tropical Institute, Amsterdam.

† Location of sample profiles is shown in Figure 2.

‡ Direct determination.

Some of the environmental conditions under which each soil family was found to occur are given in the right-hand columns of Table 4, the last column of which lists the land systems in which the families have been observed. In order to give some idea of the significance of the various soils in the survey area, tentative areas in square miles are given for each family. These figures are based on estimates of the area occupied by the soil families in the land units and must therefore be judged with great caution. The figures attempt no more than to indicate the order of magnitude.

## III. Chemical Soil Fertility

### *(a) Contents of Nitrogen, Phosphorus, Potassium, and Trace Elements*

Table 5 shows that the variations in N, P, and K content within groups of similar soil families commonly exceed those between the groups.

N contents are moderate to high, with generally little variation from group to group. Really low values do not occur. The consistently lowest values are in the Ochrustox, the sandy soils of the Kaevi family (Haplumbrepts), and, surprisingly, in the Gewoia family of the Umbrandepts. The other Umbrandept families, the Ochrandepts, and the Histosols have the highest N contents.

Total P contents vary rather more than N contents. It is perhaps significant that the highest figures are found in the young alluvial soils of the Histosols, Hapludents, and Hapludolls. Many Oxisols, however, have also above average P contents. The lowest values are found, rather surprisingly, in the colluvial Hapludolls, in the Ochrandepts, but particularly in the Typudalfs and Ochraqualfs. Generally, total P contents are moderate and not indicative of strong P deficiencies, but rarely so high that response to fertilizer is not to be expected.

Exchangeable K contents are rather uniform and neither high nor low. The consistently highest figures occur in the alluvial Hapludolls, the Argudolls, and in the Gewoia family of the Umbrandepts. The lowest values are found in the Typudalfs and Ochraqualfs and in the Ochrandepts and the other families of the Umbrandepts. Peculiarly large variations occur in the residual Hapludolls and the acid Dystrochrepts.

In terms of N, P, and K contents the alluvial Hapludolls appear to be the most fertile soils in the area, closely followed by the alluvial Hapludents, Histosols, and Argudolls. Also above average are the Gewoia family of the Umbrandepts, and the Ochrudox. On the same basis the most infertile soils are the Typudalfs and Ochraqualfs, followed by the Kaevi family of the Haplumbrepts, the colluvial Hapludolls, the Ochrandepts, and the remaining families of the Umbrandepts. This apparently low fertility of most volcanic ash soils is rather surprising because of the luxuriant vegetation and good subsistence crops on these soils. It seems possible that crops on ash soils also obtain plant nutrients from rapidly weathering volcanic glass.

No data are available for trace elements. No series deficiencies are expected in this field in view of the general youthfulness of land forms and soils in the area, the basic composition of the rocks, and the absence of evidence for repeated cycles of weathering. The greatest chance of such deficiencies is in the Typudalfs and Ochraqualfs and in the Ochrudox.

### (b) *pH, Base Saturation, Calcium, and Magnesium*

There is, of course, a good correlation between pH and base saturation with the various kinds of soils in the area, for these properties are important differentiae in the soil classification system. Their significance for soil fertility should probably not be overestimated. It is commonly expected that well-saturated, weakly acid to neutral soils are richer in plant nutrients such as N, P, and K than acid, unsaturated soils. Table 6 shows that this is hardly the case with the soils of the Safia–Pongani area. There is virtually no difference in total P content between the well and poorly saturated soils, whilst the latter are decidedly richer in N. On the other hand, the saturated soils have higher amounts of exchangeable K, but if this were to be expressed as a percentage of total exchangeable bases, the position would be reversed. Thus it is doubtful if the slightly higher K contents will correspond with a greater availability of this element.

TABLE 6

CONTENTS OF NITROGEN, PHOSPHORUS, AND POTASSIUM IN SOILS WITH HIGH (40–100%) AND LOW (1–25%) BASE SATURATION

| | Soils with High Base Saturation | | | Soils with Low Base Saturation | | |
|---|---|---|---|---|---|---|
| | N* (%) | P (%) | K (m-equiv. %) | N* (%) | P (%) | K (m-equiv. %) |
| Normal range | 0·14–0·37 | 0·063–0·105 | 0·14–0·38 | 0·3–0·53 | 0·047–0·131 | 0·04–0·27 |
| Minimum | 0·04 | 0·010 | 0·02 | 0·15 | 0·010 | 0·02 |
| Maximum | 1·0 | 0·235 | 1·0 | 0·9 | 0·161 | 0·85 |

* Data for topsoil only.

The majority of soils with high base saturation have pH values from 6 to 7, a range that appears to be very suitable for a great variety of crops. With saturation percentages from 50 to 90 and fairly high C.E.C. values of 25 to 60 m-equiv. %*, these soils are strongly buffered. Under these conditions any deficiencies in plant nutrients could easily be rectified by fertilizer applications, which can be expected to be very effective, not to be likely to upset the ionic balance in the soil, and to have a good residual effect.

Greater problems can be expected in fully saturated alkaline soils (several soil families, mainly in Hydraquents, Haplaquents, Hapludents, Hapludolls, and Haplaquolls), as well as in acid to strongly acid soils with very low base saturation (particularly Ochrandepts and most Umbrandepts, also acid Dystrochrepts and Ochrudox). In the calcareous, alkaline soils there is a possibility of reduced availability of K and P as well as minor elements. The high pH renders these soils less

* Only 10–25 m-equiv. % in Afore family (weakly acid Dystrochrepts), Gewoia family (Umbrandepts), and Ochrustox. These soils are morphologically more similar to the acid soils of low base saturation than to the normal high base saturation soils.

suitable for many crops, particularly tree crops. Only fertilizers that increase soil acidity should be used. Crop response to fertilizer application and residual effect of fertilizers may be smaller than on weakly acid to neutral soils. The ionic balance on the strongly acid soils of low base saturation may easily be disturbed by fertilizer applications, which could result in Ca or Mg deficiencies or in Mn or Al toxicity. Liming would probably be beneficial and increase the effectiveness of other fertilizer applications but may also cause deficiencies in minor elements. There are strong possibilities of P fixation on these soils. Rock phosphate or basic slag, and sodium or ammonium nitrate, which tends to decrease soil acidity, would be the most suitable P and N fertilizers. The strong soil acidity is likely to reduce the number of crops that can be successfully grown on these soils.

## IV. Soil Formation and Distribution

### (*a*) *Introduction*

The object of this section is to discuss some pedological aspects emerging from the descriptive material presented in Tables 4 and 5 and Figures 9–14, and from the maps of land systems and associations of great soil groups. The soil association map has been prepared by estimating the proportions of great soil groups in each land system and by grouping those land systems that are sufficiently similar in great soil group content. All soil association boundaries correspond with land system boundaries.

The discussion has been organized under the headings of several soil sequences, each characterized by particular trends and stages of soil formation, all of which originate from the pedologically most simple, undifferentiated soils (Hapludents). In order to avoid repetition, this great group will be first separately discussed. The soil sequences can easily be followed in Figure 9, where the Hapludents have been centrally placed.

### (*b*) *Hapludents*

The Hapludents, with nine soil families, constitute the central concept of the Entisols — undifferentiated soils with a virtual lack of horizon differentiation. The first six families are alluvial soils. Of these the Ovessa family, as a medium-textured, well to imperfectly drained soil of generally mixed mineralogical composition and occurring in 11 alluvial plain land systems widely distributed throughout the area, can be considered as the "normal" representative. Where it occurs in Momoiogo land system, the Ovessa family is generally calcareous below a depth of 3 to 5 ft. This can be taken as an indication that carbonates have been leached out of the upper part of the profile of these soils, which here occur on slightly older, stable alluvial plains. But it is also possible that there have been alternations in the deposition of calcareous and non-calcareous sediments. The Musa River, which built up the plain, acquires calcareous deposits from its eastern tributaries above the Musa gorge and non-calcareous materials from its western branches. Variations in denudation rate in these two source areas could alter the nature of the river sediments from time to time and cause the lime content to fluctuate with depth in the coastal plain.

The importance of the highly calcareous (up to 25% $CaCO_3$) Taruma and Gobera families in Ubo and Dove land systems clearly illustrates the present dominance of the eastern Musa tributaries on the character of the sediment load.

Morphologically similar to the Ovessa family but utterly different in geographic distribution is the Minawake family, which comprises regosolic soils on unstable, steep colluvial slopes in 10 mountainous and hilly land systems. Where denudation is particularly strong and weathering very shallow, this family is associated with or replaced by the lithosolic Sisiworo and Kosiwara families. The P contents of these soils are much lower and the exchangeable K contents somewhat lower than those of the alluvial families. This could be caused by their residual position on deeply though immaturely weathered rocks. The alluvial soil parent materials were probably enriched in these elements during their transport by water.

The wide distribution of Hapludents both on depositional plains and on erosional hill slopes causes marked similarities between great soil group associations on strongly contrasting land forms. Of the 10 associations in which Hapludents are dominant or subdominant, one (4) includes both mountains (Misima land system) and terraces (Aiare land system), four (3, 8, 10, 13) consist of flood-plains, terraces, and alluvial fans, whilst five (5, 6, 7, 9, 12) comprise hills and mountains. In many of these associations the Hapludents occur together with slightly more developed, well-drained Hapludolls, whilst the major difference between plain and hill associations commonly lies in the presence of many poorly drained soils in the plain associations, and of well-drained, more weathered soils in the hill and mountain associations. Generally, Hapludents are more often dominant in soil associations of the hills than in those of the plains. This indicates that whilst many hill environments in the area are still strongly denudational, there is an overall decrease in the aggradation of erosion products on the plains. This has led to widespread initial soil development on the plains, resulting mainly in the formation of well-developed $A_1$ horizons.

The Hapludents are very largely covered with forest. The hill forest on the colluvial Minawake soils is commonly irregular in structure, a further indication of the instability of the slopes on which these soils occur. The forest on the lithosolic Sisiworo and Kosiwara families is commonly poorly developed and locally gives way to eucalypt savannah. These poorer vegetation types are probably a reflection of lower available moisture in these soils, which is accentuated by the fact that they occur most commonly in areas with lower rainfall. Although some or all of the savannah may have resulted from man's clearing of the forest, the preponderance of forest vegetation on these soils suggests that their shallowness is due to lack of weathering and to rapid natural erosion, rather than to degradation caused by man as a result of cultivation. They are virtually unused for gardens at the present time.

### (*c*) *Hapludents–Haplaquents–Hydraquents–Histosols Sequence*

The Toma and Gobera families of the Hapludents form the starting point of this soil sequence, which is characterized by increasingly poor drainage — finally leading to strong accumulation of organic matter — in soils that otherwise lack any horizon differentiation. Poor drainage is evidenced by gleying and mottling owing to seasonally or permanently high water-tables, but this can take place even during the process of deposition of the sediments and therefore cannot be considered as a strictly pedological process. Furthermore, there are many gradual transitions between well and poorly drained alluvial soils in deposits of exactly the same age and composition, owing to slight differences in elevation, water-table fluctuations, and flooding regimes.

(i) *Aquic Hapludents*.—The Toma and Gobera families are poorly drained but gleying is restricted to the subsoil and so these families still must be classified as Hapludents. Gleying in these soils may be caused by relatively high water-tables, but in several cases there is no evidence for this and the poor drainage is probably largely due to slow permeability. One profile included in the Gobera family has a water-table at only 7 in., but very weak gleying. This concerns a small area in Dove land system where a minor breakthrough of the Musa River has raised the water-table, but time has been too short for this to be reflected in gleying of the previously better-drained soils.

(ii) *Haplaquents*.—Where gleying extends throughout most or all of the profile but the alluvial soils are firm underfoot, these soils have been separated as Haplaquents.

On poorly drained alluvial plains and fans (soil associations 3, 10), the Haplaquents are associated with better-drained alluvial soils on higher ground. They occur together with more swampy soils in the swamps of soil association 2. An interesting minor occurrence of the Botame family is in small depressions on strongly slumped slopes of Avikaro land system. Thus the Haplaquents are partly true swamp soils, but occur for the greater part in a semi-swampy environment. A surprisingly large range of water-table depths was observed in these soils in the dry season. The vegetation also ranges rather widely, but without clear correlations with the observed depth of water-tables. These data suggest that strong fluctuations in water-table occur in many of these soils, with also rather large variations in the duration of periods of high water levels. It is also possible that in some cases the gleying is caused by long inundations with flood water rather than by rising ground water, particularly in back plain depressions of Imo and Dove land systems.

(iii) *Hydraquents*.—Further deterioration of the drainage status, caused by permanent water-tables close to or above the surface in the dry season, gives rise to very strongly gleyed soils which commonly have little cohesion owing to permanent saturation with water. Such soils have been separated as Hydraquents. The Songada family consisting of soft, and commonly rather fine-sandy, saline muds normally containing much organic matter, occurs widely on the tidal mangrove flats of Bendorodo land system; the Yupuru family of greenish or bluish grey clays is found in the most swampy parts of Tortore land system under a herbaceous or stunted swamp woodland vegetation. Although normally soft, some profiles of the Yupuru family, particularly under woodland, are very plastic and solid, and relatively dry even though they are permanently covered with several feet of water. Apparently the vegetation absorbs much moisture from these soils which is not readily replenished because of their very slow permeability.

Hydraquents are associated with mangrove peats (Histosols) and very poorly drained sandy soils (Psammaquents) in the mangrove belt of soil association 1, and with Haplaquents and minor Histosols in freshwater swamps of soil association 2. There commonly is a gradual transition between both associations. On the upper tidal flats inland the surface horizons of the alkaline muds (Songada family) have been leached and become slightly acid, whilst Yupuru clays in freshwater swamps bordering the mangrove belt have strongly alkaline and commonly sandy subsoils.

No chemical data are available for these soils and the salinity of the Songada family is only deduced from the tidal environment, the salty taste of the ground water, and the high field pH.

(iv) *Histosols*.—The peaty soils are discussed here as if they were the final products in the sequence of soils influenced solely by increasingly poor drainage. This is not strictly so, however, as the drainage conditions of the Histosols appear to be no worse and in some cases even better than those of the Hydraquents and some Psammaquents. More significant in the formation of these soils appears to be the lack or cessation of alluvial aggradation, allowing plant residues to accumulate and become peat under conditions of permanent waterlogging. Because of the generally vigorous alluvial aggradation in the area favourable conditions for peat formation occur only locally. The largest areas of Histosols are found away from active river mouths on tidal flats sheltered behind beach ridges. Here alkaline peat soils of the Sebaga family are derived mainly from roots and leaves of mangroves and are very raw and fibrous (soil association 1). Shallow peat soils of the Karaisa family, which are commonly layered and rather poorly decomposed, containing recognizable leaf material, and which overlie mineral subsoils identical to those of the Yupuru family, occur locally in freshwater *Phragmites* swamps (soil association 2).

The Karaisa samples have the highest conductivity (260 micromhos/cm) and some of the highest exchangeable Na contents (up to 1 m-equiv. %) in the area,* which could have resulted from accumulation of Na from the large quantities of flood water that accumulate each year in the swamp basins. There is, however, no question of salinity in these soils.

*(d) Hapludents–Orthopsamments and Psammaquents–Haplumbrepts (Kaevi Family) Sequence*

This is a soil sequence involving strong differences in texture and drainage status as well as minor differences in profile differentiation.

(i) *Orthopsamments and Psammaquents*.—Whilst the Hapludents encompass a wide variety of textures in the component families, those undifferentiated soils that have a sand to loamy sand texture are separated from them as Orthopsamments. Similarly, very sandy poorly drained soils have been separated from the Haplaquents as Psammaquents. These are all dark-coloured soils that consist of feldspars, dark minerals, and locally calcite, with relatively small amounts of quartz. There are no quartzitic rocks in the area and weathering produces much clay, gravel, and boulders,

* Presumably with the exception of the saline soils of the mangrove belt, which have not been analysed.

but little sand. It is therefore not surprising that sandy soils are rare. The Orthopsamments and Psammaquents are largely confined to sandy deposits accumulated by wave and wind action along the coast (soil association 11). The Foru family occurs on completely degraded, drowned beach ridges in the mangrove zone behind the present coastline. It is characterized by conspicuous crab mounds, which also occur on shallow mangrove peat soils of the Sebaga family that overlie marine sand (soil association 1). The Abimboro family is the least typical in this great group, because the sand is generally covered by a veneer of finer-textured alluvium or organic residue deposited in the swales as the coastline advanced seawards.

(ii) *Haplumbrepts* (*Kaevi Family*).—Whilst the Pawara sands on the frontal beach ridge are still clearly Entisols — with only a minor development of a more acid $A_1$ horizon distinguishing them from the present beach sands — soil development is more marked on the wider beach ridges behind the coast. In the Kaevi family (soil association 11) there is a decrease in pH, accompanied by marked development of a black $A_1$ horizon (umbric epipedon) and a brown colouring of the subsoil (embryonic cambic horizon) above deeper layers that are strongly influenced by the water-table. This remains fairly high, because the beach ridges are only a few feet above sea level. The natural vegetation of beach-ridge forest has been largely replaced by man-made tall grassland, a factor that may have contributed to the formation of the black $A_1$ horizon in these soils.

### (*e*) *Hapludents–Hapludolls–Argudolls–Typudalfs Sequence*

This sequence is concerned with the development of a thick dark $A_1$ horizon and texture differentiation in soils of high base saturation, and the subsequent degradation of the dark topsoils accompanied by a stronger expression of the texture contrast. It deals with the transitions between Entisols, Mollisols, and Alfisols, in which soil horizon differentiation and weathering are becoming increasingly important factors of soil formation.

(i) *Hapludolls*.—There is a striking parallelism between the Hapludents and the Hapludolls as a whole as well as between many of the component families, the essential difference being in every case the presence of a thick, neutral, dark $A_1$ horizon (mollic epipedon) in the Hapludolls and its absence in the Hapludents. The first five Hapludoll families have developed in recent alluvial deposits on flood-plains, terraces, and fans. Of these the Safia family represents the "normal" concept, equivalent to the Ovessa family in the Hapludents. In Momoiogo land system it has similar calcareous deeper subsoils. The Kinjaki family runs parallel with the Gombara family on sediments derived from basalt, and the calcareous Ubo family with the Taruma family on fan deposits derived from Goropu Metamorphics. The sandy Embessa and very clayey Bibira families represent two textural extremes that are less clearly represented in the Hapludents. Embessa family includes the largest extent of coarse-textured soils in the area, which are related to sudden, rapid deposition of fanglomerates by rivers emerging from gorges in hills, and to terrace deposits along steeper upper reaches of the larger rivers. Foasi family is transitional between the alluvial and residual families, and largely colluvial in nature. Its extremely thick $A_1$

horizon appears to have been gradually built up by colluvial aggradation. All these soil families have in common the fact that they occur on stable surfaces, mainly fans, but also alluvial plains and terraces and more rarely colluvial hill slopes.

Similarly to the Hapludents, the Hapludolls also comprise a number of residual soil families occurring on steep denudational hill slopes. These are mainly shallow soils occurring largely in the dry belt of the Musa basin under a vegetation of eucalypt savannah and poor hill forest that reflects the inadequate moisture storage in these soils. With increased weathering, particularly on calcareous sedimentary rocks, similar soils (Moikodi family) develop a B horizon with clearly defined structure and colour (cambic horizon).

Soil associations in which the Hapludolls are dominant or subdominant show the same parallelism between depositional and erosional surfaces as the Hapludents. The alluvial families (soil associations 10, 13, 18) are mainly associated with other well and poorly drained alluvial soils except in association 18, which appears to be dominated by more weathered residual soils and ash soils. The residual and colluvial Hapludoll families (soil associations 12, 14, 15) are generally associated with more weathered soils, but residual families of the Hapludents are very important associated soils in the highly denudational environment of association 12.

The factors that have led to the formation of the mollic epipedon — apart from the prerequisite of surface stability — are probably complex and may vary from place to place. The most important reason is probably youthful soil development on little-weathered or unweathered calcareous or basic parent materials. There has not been sufficient time for strong leaching, which would take longer on these rocks because of the large amount of bases present. Secondly, soils with thick, neutral, dark topsoils are particularly common in the Musa basin with its relatively low rainfall of 60–70 in. They are also common in areas with apparently somewhat higher rainfall, such as the coastal plain and eastern and central Managalase, but appear to be absent from the wettest parts of the area. It is interesting to note that no Hapludoll profiles were observed above 3000 ft. These soils as well as the other great groups comprising the Mollisols appear to be essentially confined to low elevations. Thus, a drier environment appears to be an important contributing factor by slowing down the leaching process. Thirdly, most of these soils occur predominantly under tall grassland. Although this represents a man-made secondary vegetation, it may have been there long enough to aid in the formation of the mollic epipedon.* These soils occur sufficiently often under forest, however, to postulate that a grassland vegetation is not essential for their development.

The Hapludolls show the same striking difference in P content between the alluvial and hill slope families† as the Hapludents. The strong dominance of montmorillonite in the clay fractions‡ agrees with the resemblance of some profiles

* It seems probable that the dark colour of grassland topsoils is at least partly due to the incorporation of charcoal from the regular grass fires.

† The Foasi profile was sampled on a hill slope.

‡ These and other clay mineral data given for non-volcanic ash soils are based on X-ray analyses carried out by J. M. Worden, Australian Mineral Development Laboratories, Adelaide.

of the Foasi, Bibira, and Moikodi families with tropical black earths (Grumusterts), although these soils could not be classified as such because they have a mollic epipedon and lack slickensides, strong cracking, and self-mulching properties.

(ii) *Argudolls.*—The Argudolls differ from the hill slope families of the Hapludolls mainly in having distinct, plastic, heavy clay B horizons and coarser-textured, friable surface soils. Together with a generally greater depth of the solum, these features suggest that greater soil maturity has led to more pronounced horizon differentiation. The Berudi family (dominant in soil association 17) represents initial stages of textural differentiation, which is more pronounced in the Domara family (soil association 19), in which concentrations of iron–manganese concretions common in the transition between $A_1$ and B horizons testify to the alternation of wetting and drying. This latter family commonly also contains streaks of pale silt and fine sand, which are indicative of a breakdown of structural aggregates in the $A_1$ horizon and movement of clay to the B horizon. Because of the rapid methods of soil observation it was difficult to establish with certainty the presence of illuviation cutans in the B horizon, although thick cutans around gravel in the C horizon of the Domara family were found. The Argudolls have consistently lower organic carbon contents than the Hapludolls, a trend which is continued in a decrease in the thickness of the topsoil in the Typudalfs.

Whilst the possibility cannot be discounted that the texture contrast in the Berudi and Domara families has been at least partly caused by deposition of more recent sheet-wash deposits over an existing soil (the mollic epipedon generally is not confined to the coarser-textured surface soil but often includes the upper portion of the heavy clay subsoil), the possibility of a polygenetic origin is much more likely for the Bua family. These moderately weathered soils, developed on basalt under what appears to be a wetter climate than in the case of the two previous families, may well owe their coarser-textured surface soils to admixtures of volcanic ash. These soils occur in soil associations 18 and 20 together with uniformly textured soils on basalt (Dystrochrepts) and deep volcanic ash soils (Umbrandepts). No sand mineralogy data are available to throw more light on the genesis of the Bua family, but the predominance of kaolin in the clay suggests affinity with other, uniformly textured soils on basalt, such as the Afore family (Dystrochrepts).

(iii) *Typudalfs.*—Morphologically the only essential difference between the Argudolls and Typudalfs is that the latter lack a thick dark topsoil (mollic epipedon). Thus there are indications that the organic matter content builds up rapidly in the Hapludents, reaches a peak in the Hapludolls, and then declines with further soil development in the Argudolls and Typudalfs.

The Fiobobo family represents minimal development in this great group. By contrast, Urere and Dowai families have a marked texture contrast between surface and subsoil horizons. The uniform thickness of the coarser-textured surface soil (approximately 9 in.), slight signs of bleaching below the $A_1$ horizon, local evidence of bleached silt or fine sand in the upper B horizon, and locally observed thick cutans in the C horizon all indicate that the horizon differentiation is caused by clay movement and that the soils represent a further stage in soil development from the Argudolls.

In fact there appears to be a clear sequence from Berudi and Domara to Fiobobo to Urere to Dowai family, marked by a decrease in the thickness of the dark $A_1$ horizon and an increase in the degree and sharpness of the texture contrast. This trend is accompanied by a deterioration of the water regime in the soil. This is reflected on the gently sloping surfaces of Urere and Dowai families by increased gleying and the presence of concretions, as well as by a poorer vegetation.

The evidence for stronger weathering of the Typudalfs appears to be confirmed by low P and K contents. A notable feature is the general dominance of Mg over Ca and of Na over K in the exchange complex. These may contribute to the poor physical properties of the Typudalfs. Since the conductivity is invariably low (< 100 micromhos/cm) and the exchangeable sodium, though increasing with depth, remains below 1 m-equiv. %, there is no indication of salinity and the soils are not solodized. They appear to be more related to planosols.

Typudalfs are not widespread in the survey area. They dominate only in soil association 19, comprising areas of shallowly weathered Pleistocene terraces and benches in the relatively dry Musa basin.

### (*f*) *Hapludolls–Haplaquolls–Argaquolls–Ochraqualfs–Aquic Typochrults Sequence*

This sequence deals with the same trends in soil formation as the previous one, but under conditions of poor drainage. It is extended to include the most strongly weathered, acid, texture-contrast soils in the area.

(i) *Haplaquolls*.—The Haplaquolls are simply poorly drained variants of the alluvial Hapludolls. As such they are directly comparable with the Haplaquents, although they are normally somewhat less gleyed. They occur on stable surfaces no longer subject to flooding and aggradation, but owe their poor drainage to strong seepage on lower fan slopes (Ubo, Nembadi land systems) or to ground-water flow in sandy sediments (Pawara, Tortore, Momoiogo land systems). The seepage water in Ubo land system is highly calcareous and has led locally to deposition of lime concretions in soils of the Obeia family. Such profiles are akin to rendzinas (Rendolls), sharing with these also a typical strong crumb or granular structure.

(ii) *Argaquolls*.—Parallel to the grading of Hapludolls into Argudolls is the gradation from Haplaquolls to Argaquolls with increased soil maturity on sub-Recent or older sediments, under conditions of poor drainage and in a relatively dry climate. Gleying in these soils is not due to high water-tables, but to slow permeability of the B horizon, which consists of the most plastic heavy clays in the area.

The Argaquolls (soil associations 8 and 19 and locally in Arumbai land system) carry several specific types of vegetation that reflect their poor physical environment. A common feature of these soils as well as of the Feroroda family of the Haplaquolls in Nembadi land system is the presence of a pothole or trench micro-relief, generally 4 to 9 in. deep. The discontinuity of the depressions as well as the gentle slopes seem to rule out surface erosion as a cause, but subsurface erosion owing to over-saturation of sandy substrata by seepage water may play a role in the Feroroda family. Volume changes or biological causes (earthworms, crabs, tussocky nature of the grassland vegetation) may be dominant in the Argaquolls.

As with the Argudolls, there is as yet no conclusive evidence for the pedogenetic nature of the texture contrast. There are no indications of the development of a bleached $A_2$ horizon (albic horizon) and no data about illuviation cutans. Circumstantial evidence for a pedogenetic origin includes the following points.

(1) Like the Argudolls the Argaquolls fit in well in a soil sequence based on increased horizon differentiation with increase in maturity.

(2) These soils occur locally on sites where deposition of sheet-wash material over an existing, older soil seems unlikely.

(3) The coarser-textured surface horizons are of a uniform depth (12–18 in.) and are lacking in gravel. Their sand content appears to be related to that in the C horizon.

(4) The presence of iron concretions in the lower $A_1$ and upper B horizons points to a relatively advanced age of the soils and appears to be related to the presence of black and brown mottles in the lower B and upper C horizons. The concretions probably have developed from such mottles by irreversible drying during gradual down-wearing of the land surface. They are subsequently concentrated in the lower part of the $A_1$ horizon by gravity during biological churning of the topsoil, particularly when this is saturated after rain. They are, however, unable to penetrate into the massive B horizon.

There are no analytical data for the Argaquolls, but field pH is never very high and there is no indication of solodization.

(iii) *Ochraqualfs*.—The Ochraqualfs are here considered as a stage in a sequence leading from the Haplaquolls through the Argaquolls, but they could equally well be discussed as strongly gleyed variants of the Typudalfs, being related to the Dowai family. They are covered with the same or similar poor types of forest as the Argaquolls and differ from these essentially only in their lack of a mollic epipedon. The decrease in thickness of the $A_1$ horizon is accompanied by the development of a weak $A_2$ horizon, as well as some bleaching of fine sand and silt within the $A_1$ horizon. In Nuaro family (soil associations 8 and 26) the pH rises from 6 to 6·5 in the $A_1$ horizon to 8·5 in the deeper B horizon, which contains soft lime concretions. This trend may reflect leaching of the surface horizons of rather strongly weathered soils occurring outside the dry Musa basin, combined with seepage of calcareous ground water in the rather stratified basic–ultrabasic fan deposits. Seepage influence may also account for the relatively high conductivity (up to 250 micromhos/cm) and exchangeable Na content (1 m-equiv. %) in the deeper subsoil, which remain, however, too low for these soils to be called saline. Thus there appears to be a stronger trend to solodization than in any other soil in the survey area. The dominance of montmorillonite with some increase of kaolin in the surface horizons, as well as the presence of minor slickensides in the subsoil, point in the same direction.

(iv) *Typochrults*.—Strongly weathered, acid soils with pronounced texture contrast and very plastic heavy clay B horizon are extremely rare in the area. Occurring in Siviai land system in local depressions, associated with strongly weathered Ochrudox soils on surrounding higher ground, and in Arumbai land system on local crests on fine-textured sedimentary rock, these gleyed soils have been separated as the Imuru family and classified as Typochrults, although even in this case no proof can be given that the texture contrast is due purely to horizon differentiation.

### (g) *Hapludents (Gorabunina)–Dystrochrepts (Kiara)–Ochrandepts–Umbrandepts Sequence*

This sequence deals with the development of soils on volcanic ash. It is concerned with the effects of time, nature and purity of the ash parent material, mode of deposition, and climatic influence. All soils wholly or partly derived from volcanic ash occur in the north-western sector of the survey area, which was influenced by eruptions of Mt. Lamington as well as minor eruptive centres in Uoive and Manna land systems.

(i) *Gorabunina.*—Volcanic ash, presumably of andesitic composition, has locally been transported, and deposited by streams on low and intermediate terraces. No profile differentiation has taken place and soils on such deposits, which are locally underlain by cobble beds, have therefore been included in the Hapludents as the Gorabunina family.

(ii) *Kiara.*—More weathered soils with ash influence occur widely on hill slopes in areas that have been blanketed with airborne volcanic ash. Such ash layers have commonly been deposited on existing moderately to strongly weathered soils or saprolite and are thickest on crests and upper slopes, whilst they have often been completely removed by erosion from the lower slopes. In between these two extremes generally occurs a zone in which volcanic ash has been colluvially mixed with older soil material and has been subjected to a certain amount of weathering. The amount of ash admixture varies widely, commonly within the same profile. Soils in which it appears significant have been grouped together in the Kiara family. Because these soils have a poorly developed $A_1$ horizon, but a clearly defined colour B horizon (cambic horizon) due to weathering, and because they largely lack the typical properties of pure ash soils, they have been included with the Dystrochrepts. As inferred above, the Dystrochrepts of the Kiara family always occur in association with typical ash soils (Andepts) and generally with weathered non-ash soils (other Dystrochrepts and Oxisols).

(iii) *Ochrandepts.*—The Ochrandepts are soils developed in pure volcanic ash but which lack the thick, very dark $A_1$ horizon commonly associated with such soils. They are of small extent. Two of the families, Sibium and Ondoro, are generally associated with thin ash covers and their poor $A_1$ horizon development commonly appears to be due to the colluvial nature of these soils on steep slopes. The coarser-textured Ondoro soils appear to be little weathered and in Uoive land system have developed in dacite ash, which may be of very recent origin as it is found in places on unweathered basalt. Profiles of both families, however, commonly merge with very gradual transitions into older, residual weathering profiles, a further indication of the influence of colluvial mixing on these soils.

Siurani family shows a horizon differentiation that has been interpreted as a humus podzol. Below a thick, very acid root and litter layer, a well-developed black $A_1$ horizon merges into a dark grey-brown, rather smeary layer, which at 15 in. depth rests on a 3-in.-thick very dark brown smeary horizon. Below this there is a normal brown sandy clay B horizon merging gradually into a yellow-brown sandier C horizon below 40 in. depth. Such a profile could also have resulted from superposition of two ash layers. Where in a few cases buried topsoils were found in volcanic ash soils, these occurred at greater depth and were thicker. Moreover, detailed mineralogical analysis suggests that all horizons have developed in one homogeneous ash layer (Ruxton, personal communication). Since the Siurani family occurs only on local flat crests at 5000 ft or higher in a very wet cool climate, the interpretation of the profile as a podzol is preferred.

The Ochrandepts have chemical and mineralogical properties that are typical of volcanic ash soils. Notwithstanding the poor morphological development of $A_1$ horizon, the organic carbon contents are very high, owing to the presence of allophane* and probably also to the fact that the samples were collected in wet areas above 3000 ft altitude. The percentages may give an exaggerated impression of the amount of organic matter present, because these soils are likely to have a low bulk density. Typical of volcanic ash soils also is that the organic carbon content remains relatively high in the subsoil, whilst it declines sharply in the reddish soil of any underlying weathering profiles. Equally characteristic are the high exchange capacities (none of these soils has a high clay content) and very low base saturation, which is not reflected in very low pH values. The reduction in C.E.C. in underlying oxisolic weathering profiles (which is accompanied by an increase in clay content) is marked and accompanied by a change to kaolinitic clay, but the base saturation remains unexpectedly low. Leaching of Ca and Mg from these ash soils has been so severe that K has become the dominant metal ion in some subsoil horizons. In most profiles the amorphous clay causes serious dispersion difficulties.

(iv) *Umbrandepts*.—The only essential difference between the Umbrandepts and Ochrandepts is the presence of a thick, very dark, crumbly to fine subangular blocky $A_1$ horizon in the former. Morphologically the Umbrandepts are the central concept of the Andepts (Andosols). They occur in association with the Ochrandepts, but are much more extensive throughout the large area of thick ash cover in the mountains and hills.

Of the four families in this great group, the Gewoia family was separated not only on the basis of more clayey texture, but also on the presence of a dark brown B horizon between the $A_1$ horizon and the yellow-brown lower B and C horizons. The other three families are based on textural differences and range from sandy clay to sandy loam. Such texture differences may signify differences in age as well as composition of the ash parent material, but few conclusions can be drawn from their distribution, except that in some positions where young soils are expected, such

* The author gratefully acknowledges the assistance of Dr. M. Fieldes, Soil Bureau, D.S.I.R., Wellington, N.Z., who carried out detailed clay mineral analyses of samples of the Siurani, Sibium, Kwena, Gewoia, and Bua families by means of X-ray diffraction, differential thermal analysis, electron microscopy, and infrared absorption.

as valley benches and terraces in Aiare and Tahama land systems and alluvial flats in Uoive land system, only coarser-textured soils do in fact occur. The separation of the dark brown Gewoia family proved to be very significant when analytical data became available. It has a consistently higher pH, lower C.E.C., higher base saturation, and lower organic carbon content than the other Umbrandept families. Clay mineral determinations further indicate that these soils are dominated by kaolin rather than allophane. The conclusion from these observations is that Gewoia family, although undoubtedly developed on pure volcanic ash, does not exhibit typical andosolic characteristics. They are Mollandepts rather than Umbrandepts, but this distinction was not yet made in the 7th Approximation. Both profile morphology and clay mineralogy indicate a greater degree of weathering of the Gewoia family in comparison with the other Umbrandepts. It is interesting to note that a similar difference exists between Sangara and Higatura families developed from andesitic ash on the slopes of Mt. Lamington (Haantjens 1964*a*), whilst most andesitic ash soils on Mt. Victory (Haantjens 1964*b*) appear to exhibit characteristics similar to the Gewoia family.

The dominance of kaolin in ash soils of the Gewoia family does not help in deciding whether the texture contrast in some soils on basalt is due to horizon differentiation or to addition of volcanic ash. Samples of the Bua family of the Argudolls are dominated by kaolin in the surface horizon as well as in the subsoil, but this cannot now be advanced as evidence that ash admixture has been of no significance in the formation of these soils.

Ochrandepts as well as Umbrandepts are very largely covered by forest or regrowth. Even in densely populated areas man-made grassland is not quickly established on these physically excellent and reasonably fertile soils.

### (*h*) *Hapludents–Haplumbrepts–Dystrochrepts–Ochrustox and Ochrudox Sequence*

This sequence is concerned with the zonal trend in soil formation in the area, leading to strongly weathered soils formed on a variety of parent materials under influence of time and a humid warm climate, under conditions of good drainage. The sequence chosen is the most direct, as well as one that can be repeatedly observed in the field. Some of the sequences discussed above could conceivably be extrapolated to the same mature soils as final stages, for instance the Hapludents to Haplumbrepts sequence and the Hapludents to Umbrandepts sequence. As can be seen from Figure 9, there are also indications that the Hapludents to Typudalfs sequence can be deflected to Oxisols in the early stages (Hapludolls, Argudolls), but continued weathering of the Typudalfs is more likely to lead to the formation of Ultisols, such as great groups 19 and 20.

(i) *Haplumbrepts.*—These soils are the acid equivalents of the Hapludolls and are characterized by the presence of a thick, dark, acid $A_1$ horizon (umbric epipedon). They are comparatively rare soils, as most immature soils in the area tend to have a high base saturation. They are generally confined to the wetter part of the area, occurring on easily leached sands (Kaevi family, see Section (*d*)(ii)), but mostly as shallow soils on hard, but chemically leached rocks (Geriwu family, mainly soil associations 6 and 16). More weathered soils of the Sesaro family with a well-developed colour and structure B horizon (cambic horizon) occur on sub-Recent dissected fan slopes in association with undifferentiated Hapludents on younger undissected fans and highly weathered Ochrudox on older strongly dissected fans (soil association 26).

(ii) *Dystrochrepts.*—The Dystrochrepts include all soils that have a colour or structure B horizon (cambic horizon), which is the result of *in situ* clay formation due to weathering, but that lack a textural (argillic) or latosolic (oxic) B horizon, and do not have a thick dark $A_1$ horizon. They occur extensively throughout the hilly and mountainous parts of the area, generally on steep slopes, where they are associated with shallow rock weathering or with the lower zones of deep weathering profiles. Indications of colluvial disturbance in the profile, such as scattered rock fragments or stone lines, are common and are in fact used as criteria in the separation of some of these soils from the Oxisols. The Dystrochrepts include four weakly acid and three acid to strongly acid families.

The weakly acid Dystrochrepts are invariably associated with shallow residual weathering on recently uplifted, denudational, hilly and mountainous land forms. They appear to represent more advanced stages of soil formation as compared with the colluvial and lithosolic Hapludents and Hapludolls as well as some Argudolls. They are generally shallow soils with a strong relationship to underlying rock, except the Emo family of somewhat deeper soils which is principally colluvial in origin.

Although these soils are commonly found in the relatively dry zone of the Musa basin, they also occur frequently in wetter areas. They are associated mainly with Hapludents and/or Hapludolls and/or Argudolls, all immaturely weathered or unweathered soils of high base saturation. Other minor associate soils are Ochrustox (high base saturation latosols) in drier areas (soil associations 14, 15) and Ochrudox (low base saturation latosols) in wetter areas (soil associations 20, 24). Thus the lack of leaching in these soils is thought to be due more to immature weathering on basic rocks than to lower rainfall.

The presence of these generally shallow and commonly rather gravelly soils on steep slopes, in many places in relatively dry areas, constitutes a rather unfavourable environment for plant growth, which is reflected in the predominance of poor hill forest vegetation, in several localities replaced by eucalypt savannah or short grassland. Deeper soils of the Afore family on almost level basalt flow surfaces in Uoive land system, with more luxuriant forest, form an exception.

The acid to strongly acid Dystrochrepts are generally deep soils. The Kambururu family occurs widely, on different kinds of rocks, where it is typically associated with the lower zones of deep weathering profiles that have been exposed on steep side slopes by dissection. It is therefore characteristically associated with more strongly weathered soils (Ochrudox) on upper slopes, and with less-weathered soils (Haplumbrepts, Hapludents) on lower slopes (Foasi, Siviai, Banderi land systems). The first association may be obscured by thick ash mantling of the upper slopes, as in Tahama and Kovio land systems. The second association may be lost if dissection has not proceeded much beyond the depth of weathering, as in large parts of Suwari and Wowo land systems. Finally, dissection may have been so rigorous that nearly the whole of the upper zone of the weathering profile with its Ochrudox soils has been destroyed, as appears to be the case in Hydrographers and Gorabuna land systems.

The Kiara family, with admixtures of volcanic ash, was discussed in Section (*g*)(ii) and will not be further considered here, except to say that it merges imperceptibly with the Kambururu family. The Aiare family has developed on older alluvial and colluvial terrace deposits within the hilly zones. It is related to the Sesaro family of the Haplumbrepts, but has probably developed directly by weathering from alluvial Hapludents such as the Ovessa family.

The acid Dystrochrepts occur in the wet parts of the survey area under forest vegetation (mainly soil associations 16, 22, 23, 25, 28). Their presence in Banderi land system, however, where a vegetation of poor forest, eucalypt savannah, and mid-height grassland indicates a drier climate, suggests that deep weathering is a more essential factor in the distribution of these soils than the amount of rainfall.

(iii) *Ochrustox and Ochrudox*.—Because only differences in pH are essential for the separation of these two great groups in this report, and because many morphological characteristics are common to both, the Ochrustox and Ochrudox can be conveniently discussed together.

The difficulties in the classification of these soils as Oxisols in the 7th Approximation and the reasons why they have been retained as such are discussed in Appendix I. Whatever the merits of this classification, it is clear from mineralogical analyses of the fine sand fraction* that these soils, although not representing an ultimate stage of weathering, are indeed the most strongly weathered in the survey area. This conclusion is supported by the strong dominance of kaolin in the clay fraction and by the high clay content of these soils, apparently largely resulting from clay formation by weathering *in situ*. Their distribution points in the same direction. They are absent on young depositional plains and fans, as well as on strongly denudational slopes. They occur predominantly in association with the upper zones of extensively developed deep weathering profiles on alluvial and mudflow fans and low hills (soil associations 25 to 29); and in association with relict deep weathering profiles on mountain spurs (soil associations 9, 16, 25). Very locally they occur in hills and mountains with shallower or less-intensive weathering where they are again found mostly on stable gentle crest slopes, but also on steep spur crests, on lower benches and foot slopes, and on old stabilized slump toes (soil associations 12, 14, 15, 19, 20, 24). Lastly, these soils are found very locally in most of the ash-covered hills and mountains, where their scarcity is due not so much to lack of weathering as to the fact that they are mostly buried beneath a thick blanket of volcanic ash. This very wide distribution is in itself an indication that these soils can be considered as advanced stages of development towards what can be termed the zonal soils of the area. Further evidence for this is found in the fact that many of the component soil families show little affiliation with a particular kind of parent rock. As weathering proceeds towards maturity, the influence of parent rock on soil morphology decreases.

* Carried out by R. Townend, Australian Mineral Development Laboratories, Adelaide.

The separation of the Ochrustox from the Ochrudox was intended to correspond with a marked difference in base saturation, the weakly acid to neutral Ochrustox having a percentage saturation between 25 and 50, the acid to strongly acid Ochrudox below 25. This worked out satisfactorily for the Ochrudox, but not for the Ochrustox. The Arumbai profile fits, but the saturation of the Jare profile is too high and that of the Mioki and Silimidi profiles too low in the subsoil. No explanation can be offered for the low values, but attention is drawn to the fact that both these soils have apparently only small amounts of crystalline clay minerals, because X-ray data give incomplete results. These soils appear to react in a similar way to the Andepts (great groups 15, 16), where extremely low base saturation is accompanied by only moderate acidity and a large proportion of amorphous clay. It seems possible that the Mioki and Silimidi families, which markedly exhibit the typical friability of the Oxisols, contain considerable amounts of amorphous hydroxides of Fe and Al.

The importance attached in the 7th Approximation to the base saturation in subdividing the Oxisols is based on the supposition that differences in saturation are associated with marked differences in climate resulting in continual wetness and leaching of the Ochrudox and periodic dryness and decreased leaching of the Ochrustox. In the Safia–Pongani area the Ochrustox are indeed largely found in the lower-rainfall belt of the Musa basin, and here may be expected to dry out on rare occasions to a depth of 2 to 3 ft. The annual rainfall of 60–80 in. still seems to be rather high, however, to account solely for big differences in base saturation. Highly unsaturated Oxisols occur in many parts of the tropics in such rainfall regimes. Moreover, a number of Ochrustox soils was found in higher-rainfall zones, and occasional Ochrudox profiles occur within the lower-rainfall belt. Thus it seems that other factors may either aid or override climatic differences in producing Oxisols of different base saturation. It was noticed, for instance, that deep weathering profiles are generally associated with Ochrudox soils of low base saturation whilst shallow weathering profiles have Ochrustox soils of moderate to high base saturation. But this relationship does not always hold. Particularly intriguing are the properties of the Wowo family, found on very deeply weathered mudflow fan deposits in Ibinambo and Wowo land systems. This family has been classified with the Ochrudox on the basis of the low pH and base saturation in the subsoil, but it possesses thick to very thick, dark brown surface horizons with high pH and saturation, yet with the texture, structure, and consistence typical of latosols (Oxisols). The rapidly decreasing organic carbon content indicates that the dark colour is not solely due to organic matter. These soils are thought to be polygenetic in origin, having younger surface horizons of largely pre-weathered mudflow material enriched in bases during the process of deposition, and strongly leached subsoils developed on older mudflow deposits.

Both within the Ochrustox and the Ochrudox great groups the main subgroups distinguished are those with uniform texture and those in which the texture becomes finer with depth. The causes of this texture differentiation — which is gradual and not very pronounced — may vary and are largely uncertain. Admixture of volcanic ash appears to have contributed to it in some cases. Dark minerals such as are common in the volcanic ash soils were observed in the surface horizons of the

Siviai family and in some profiles of the Moni family. The marked increase in weatherable minerals in the surface horizons of Togofu family is due to hornblende and some sanidine, which are common in volcanic ash but absent from the basalt parent rock. Addition of coarser material from sheet-wash deposits is generally unlikely, because most Oxisols occur in positions not commanded by higher slopes. There is as yet no positive evidence for clay illuviation. Well-defined illuviation cutans were not observed and there is no marked increase in blocky structure and compaction or unusual decrease in porosity and friability in the finer-textured subsoils. Neither is there evidence of a "clay bulge" in the B horizon that could not be explained by residual clay formation by weathering. On the other hand, some degree of texture differentiation is such a universal feature of all Oxisols—even those classified as uniformly textured —that only a pedological process can probably account for it. In many places there is evidence of slope wash. Texture differentiation in such cases may be caused by selective downslope removal of fines. Such a process could be aided by structure collapse under rain-drop impact on sites where the soil is disturbed by tree fall.

The central concept of the Oxisols consists of deep, friable, red soils. No families excel in all three respects. The deepest soils range from red to strong brown and from friable to firm, the most friable soils are all predominantly brown and range from shallow to deep, whilst the reddest soils are generally rather firm in consistence and range from shallow to deep. Colour differences between predominantly red and predominantly brown families cannot be properly explained. Parent rock, stage of soil maturity, and degree of wetness could all play a role. There is certainly no systematic change from red to brown with increasing elevation, some of the best-developed red Oxisols having been observed between 3500 and 4000 ft altitude. Most Oxisol families become redder in colour with depth. It is not known whether this is the result of redistribution of iron in the profile, reflects differences in the hydration of the iron oxides, or is caused by masking of the red colour by organic matter. The fact that this change in colour with depth is best displayed by the Arumbai and Moni families with relatively strong texture differentiation would suggest eluviation of iron as an important cause.

The least typical Oxisols are the gleyed, very firm Busi family, the very shallow Sirorata family, and the Wowo family with its unusual dark brown, high base saturation surface horizons. The Mioki family shows the peculiarity that although the solum has typical Oxisol characteristics, it is underlain at shallow depth by almost fresh ultrabasic rock. In contrast to this the even shallower solum of the Sirorata family rests on very strongly and deeply weathered basalt.

### (*i*) *Soil Sequence on Basaltic Parent Materials*

Six soil families are virtually restricted to basalt parent rock or alluvium derived from basalt. These show an interesting sequence of soils that are all separated from comparable soils on other parent materials, because of their dark colour. They range from the alluvial Gombara family in the Hapludents to older alluvial soils with a well-developed $A_1$ horizon (Kinjaki family of the Hapludolls) to immature residual soils with high base saturation (Afore family of the Dystrochrepts) and similar soils with coarser-textured very dark surface horizons (Bua family of the Argudolls) to more weathered, acid, texture-contrast soils (Samage family of the Rhodochrults) to the strongly weathered, but still relatively shallow, reddish residual soils of the Togofu family of the Ochrudox.

The problem of whether or not the textural differentiation in the Bua family is due to admixture of volcanic ash has already been discussed in Sections (*e*)(ii) and (*g*)(iii). The Samage family has been classified with great group 19, Rhodochrults, because of its rather pronounced texture contrast together with a very firm to plastic consistence of the clay B horizon, as well as because of its apparently low base saturation,* dark brown colour, and lack of a thick very dark $A_1$ horizon. The evidence in favour of ash admixture in Togofu family (see Section (*g*)), in a profile sampled at much greater distance from the source of volcanic ash, makes it reasonable to suppose that the texture differentiation in the Samage family, which occurs in an area where ash blanketing is more evident, is due to the same cause.

The four families of residual soils on basalt have in common that their solum is generally rather thin and merges rapidly into weathered, but relatively hard and recognizable basalt parent material. The rather marked differences between these soils on what appears to be a very uniform parent rock, are probably related to differences in age of the basalt flows, and could possibly be used as an aid in the relative dating of these. The shallow to moderately deep Afore soils without evidence of ash cover appear to be the youngest and are probably restricted to flows which post-date any significant ash deposition. The moderately deep Bua soils with ash admixture are probably only slightly older. The acid, very clayey, and somewhat deeper Samage and Togofu families appear to be more mature soils and would therefore seem to represent soil formation on older flows. It is somewhat difficult to differentiate in age between the Samage and Togofu families, particularly because no analytical data are available for the former. Although the Samage soils are commonly deeper, the Togofu profile is more acid, redder in colour, and more latosolic in nature. It would therefore seem to represent the oldest soils formed on basalt in the area.

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* This statement is based solely on the strength of low pH values measured in the field. No samples were collected.

# PART VI. VEGETATION OF THE SAFIA–PONGANI AREA

By K. Paijmans*

## I. Introduction

Although great variations in altitude (from sea level to over 10,000 ft) and annual rainfall (probably between 60 and 150 in.) have a considerable modifying influence, the climax type of vegetation over most of the area is tropical evergreen rain forest, grading with altitude from lowland to montane forest. In the Musa basin a seasonality more marked than elsewhere is most probably responsible for the occurrence of an unusually high percentage of deciduous trees.

A coastal belt of mangrove and extensive freshwater swamp communities in the coastal plain are largely edaphically controlled.

Natural seral communities form a minor portion of the vegetation. They occur on new land, e.g. aggrading beaches, mudbanks, and river scrolls, or in areas where the original vegetation has been destroyed by fire or floods.

Man's activities have caused large-scale disturbance of the original vegetation, as borne out by the presence of vast areas of secondary forest and garden regrowth, grassland, and in the drier areas, particularly the Musa basin, of eucalypt savannah.

Photo-typing, based on structure and habitat, supported by field observations, has been the basis for the vegetation classification used in this report.

In the classification of forest types the use of floristics has been kept to a minimum, and emphasis laid on structural description and classification. In the first place the complexity of the forest vegetation, insufficient knowledge of genera and species, lack of dominant and faithful species, the often seemingly haphazard species distribution (Richards 1963), and lack of time would make any forest classification based on floristics of doubtful ecological value. In the second place, the description and classification of vegetation types must be compatible with photo-mapping, which is intrinsically based on structural differences.

In this Part, the methods used are discussed first. The next two sections deal with the resulting vegetation classification and vegetation–forest resources map, and with the distribution and description of the vegetation types. A section on ecology lays emphasis on the interrelationships of the vegetation types. Separate sections deal with the relationship of land systems to vegetation, and the influence of man on the vegetation. This Part concludes with additional notes on special features and some common tree species.

## II. Methods

Prior to field work a broad typing was done on the aerial photographs, scale approx. 1 : 50,000, in cooperation with the forest botanist and the geomorphologist. The interpretation, mainly based on photo-aspect and habitat, resulted in the delineation of a number of distinct photo-types.

* Division of Land Research, CSIRO, Canberra, A.C.T.

For consistency and ease of comparison the observations taken at every site in the field included the following set of characteristics, either estimated or measured:

(1) For trees — height, density and/or cover percentage, distribution, stem form, girth distribution, frequency and height of buttresses, occurrence of stilt roots, and occurrence and frequency of (semi-)deciduousness.

(2) For shrubs and herb layer — height, cover percentage, density, distribution, and visibility.

(3) For climbers, epiphytes, palms, bamboo, *Pandanus*, and tree ferns — frequency, height, and type.

In describing forest types a distinction was made between emergents, canopy trees, and lower trees. Description of more tree layers was not found to be feasible, and even the fairly simple stratification used is in practice often difficult to apply and arbitrary.

In descriptions, if no height figures for canopy or individual trees are given, tall means >115 ft, medium between 80 and 115 ft, and low <80 ft.

Girth distribution was estimated in the categories: small, <30 in.; medium, between 30 in. and 70 in.; and large, >70 in. In support of the estimate, the girths of some 25–30 trees were measured at each observation site.

Frequency and height of buttresses were estimated in the categories: low, <1·5 ft; medium, between 1·5 and 4 ft; and high, >4 ft.

Visibility gives another means of expressing density and type of shrub layer.

To express frequency, the following terms are used in order of increasing frequency: rare; present; fairly common; common; very common; abundant. Density has been estimated either as a percentage figure or according to the scale: nearly absent; very sparse or very scattered; sparse or scattered; rather open; fairly dense; dense; very dense.

Grasslands have been subdivided according to height into the categories: tall grassland, >5 ft high; mid-height grassland, between 5 and 1·5 ft; short grassland, <1·5 ft high. In grasslands and savannahs, cover percentage and distribution of the grasses were recorded.

Common or conspicuous species at and around each observation site were recorded. For field identification the knowledge of the native assistants was often of great help. Where necessary, herbarium material and/or wood samples were collected. The specimens were identified where possible, mostly to genus level, through comparison in the Herbarium Australiense, Canberra. Wood samples were identified partly by the forest botanist, partly by the Division of Forest Products, CSIRO, Melbourne.

## III. Classification

The original photo-types have been maintained as vegetation types. Field observations showed them to be sufficiently different in structure and species composition to justify this.

Where within a forest type a sufficient number of observations was available, the observations have been integrated into an overall description for the type. For these abbreviated structural descriptions the reader is referred to Appendix II.

### (*a*) *Vegetation Types*

Vegetation types recognized in the survey area are described in Section IV. Names of the major groups are based on structure, those of the vegetation types on structure, habitat, or dominant or most conspicuous species. Where structural differences are closely related to habitat, forest types have been named after the habitat concerned, this being the most obvious and simplest way to differentiate them by name. Where in a few instances photo-type proved to be correlated with dominance of one or two species, these have been used to name the vegetation type.

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

The vegetation–forest resources map, scale 1 : 250,000, is largely based on the original photo-interpretation, modified and somewhat refined by means of the field observations. Forest-type boundaries have been established in cooperation with the forest botanist, and their timber potential is indicated in three grades by different patterns of stippling. Unstippled areas comprise non-forested areas and forests with a stocking rate of less than 3500 super ft per acre.

Although most vegetation types described in Section IV have been mapped, this was not possible in all cases. The scale sets a limit to the mapping of small or fringing communities, or those forming a very intricate pattern. Thus, in the major group mixed herbaceous–tall grass vegetation, the *Ipomoea–Canavalia* and *Saccharum* subtypes are not mapped and the remainder are indicated with one colour. Similarly, mangrove has been given one colour and includes mangrove forest, mangrove and fern scrub, *Casuarina equisetifolia* forest, and *Nypa* palm vegetation. Within the swamp woodland only the sago swamp woodland is mapped separately, in view of its economic importance. Eucalypt savannah includes scattered small areas of *Nauclea–Antidesma* savannah. The types foothill forest and mid-slope forest have not been separated.

Only a few larger occurrences of *Castanopsis* forest have been mapped where the dominance of *Castanopsis* has been established without doubt from photo-aspect and field observations.

Three small areas of nearly pure *Rhus taitensis*, falling under the category "very small-crowned hill forest", have been mapped separately.

The most important areas of secondary forest have the symbol S printed over the colour of the original forest type.

In view of its economic importance *Araucaria* has been given a symbol. The symbol density broadly indicates the relative density of the genus as established by photo-interpretation and field observations.

In the map reference, vegetation types are grouped according to habitat, of which five major types are distinguished in the area: coastal, swamp, alluvium, fan, and hill and mountain.

The broad correlation between vegetation types and land systems becomes evident on comparison of the vegetation–forest resources map and the land system map.

## IV. Distribution and Description of the Vegetation Types

### (*a*) *Mixed Herbaceous and Tall Grass Vegetation*

This group comprises all low herbaceous vegetation types. Grasses play a part that can vary from dominant to subordinate. Low palms and *Pandanus* also occur. Although some of the types are more or less clearly seral, it was considered best to include them in the present major group.

(i) Ipomoea–Canavalia *Mixed Herbaceous Vegetation*.—This community consists of pioneer sand-binding herbs and low grasses and sedges. The habitat is recent sandy beaches, just above the high tide line (Pawara land system). Nearest the sea are the characteristic and pan-tropic species *Ipomoea pes-caprae* and *Canavalia maritima* with long, trailing, rooting stems.

(ii) *Aquatic Mixed Herbaceous Vegetation*.—This type consists of floating and semi-submerged water plants, partly covering standing water in lakes, oxbows, etc. Small areas occur in Tortore, Dove, and Momoiogo land systems.

(iii) Leersia–Hanguana *Mixed Herbaceous Vegetation*.—*Hanguana malayana* forms a thick, dense, more or less floating mat in the deeper parts of the western swamp (Tortore land system), the part above the water being about 5 ft high. *Leersia hexandra* forms rather large, almost pure patches (except for some *Polygonum*). It mainly lines waterways in the western swamp and trails in the water or grows to about 1 ft above it.

(iv) *Fern Mixed Herbaceous Vegetation*.—Ferns and other low, unidentified, herbaceous vegetation including clumps of very low sago were seen from helicopter to cover permanently swampy areas in the western swamp (Tortore land system).

(v) Phragmites *Tall Grass Vegetation*.—*Phragmites* to 13 ft high covers large areas in nearly pure stands in more or less permanently swampy environment surrounding deeper swamps (Tortore land system). Scattered low trees of genera such as *Nauclea* and *Glochidion* are generally present. *Leersia* is one of the grasses sparsely mixed with the *Phragmites*.

(vi) Saccharum *Tall Grass Vegetation*.—Tall, dense, nearly pure stands of *Saccharum* occur on rapidly accreting river scrolls near the water's edge (Dove land system) and in braided river channels (Ubo land system).

### (*b*) *Grassland*

(i) *Tall Grassland*.—Being a fire disclimax vegetation the type is most widespread in regions with a comparatively dense population and a marked dry season, i.e. the Musa valley, particularly around Safia, Obeia, and Ubo (Gobera, Safia, and Ubo land systems). Further areas occur in the Pongani–Kinjaki region (Nembadi land system) and, locally, in the coastal plain (Momoiogo land system) and the Managalase (Uoive land system).

The height varies from 5 to 13 ft and averages 9 ft. The main genera are *Saccharum* and *Coelorachis*, usually in mosaic with *Imperata* and *Ophiuros* very common and locally dominant. *Cymbopogon*, *Sorghum*, and *Apluda* are present to common. Shortly after burning, *Imperata*, quick in sprouting from its rhizomes and flowering, can be completely dominant. *Saccharum* would appear to favour somewhat wetter sites and grows to 13 ft high, often mixed with some *Phragmites*.

Widely scattered low trees and shrubs, often aligned along narrow depressions and shallow drainage courses, are usually present, as are ferns, climbing or otherwise, and a few forbs amongst the grasses. The shrub–tree component, limited in number of species because few can stand the regular burning, mainly consists of the genera *Nauclea*, *Antidesma*, *Albizia*, *Terminalia*, *Cycas*, and *Ficus*.

Tall grassland often contains small patches where the tall grass has died, now partly bare, partly covered with short grasses, e.g. *Chrysopogon*, *Eragrostis*, *Elyonurus*. Lack of aeration in the wet season is a possible explanation.

(ii) *Mid-height Grassland*.—On shallow soils of terraces and hill slopes and under less favourable moisture conditions, grasses are mid-height (Banderi and Avuru land systems). The main species are *Themeda australis* and *Imperata cylindrica*, with an admixture or local dominance of a host of other grass species. Sedges, always present, locally come into prominence on wetter sites, accompanied by moisture-loving grasses.

Under impeded drainage conditions grasses tend to become tussocky or patchy, thus emphasizing the already existing microrelief. This results in a lower cover, particularly conspicuous just after burning.

(iii) *Short Grassland*.—This is a depauperate form of mid-height grassland, occurring on very shallow soils on stony ridges and very steep slopes (Avuru land system). The main genera are *Themeda* and *Imperata*; *Arundinella* occurs locally. Accompanying shrubs are *Commersonia bartramea*, *Dodonaea viscosa*, *Grevillea papuana*, Myrtaceae, and shrubby *Casuarina*.

Alpine grassland occurs on the summit of Mt. Suckling and was not visited in the field.

### (*c*) *Scrub*

(i) *Mangrove Scrub*.—Within the mangrove a dense scrub occurs away from the creeks draining the tidal flats. The type was not visited in the field.

(ii) *Fern Scrub*.—To landward of the mangrove a dense low thicket occurs locally, which in a few instances (observed from helicopter) was found to consist of ferns.

### (*d*) *Palm Vegetation*

(i) Nypa *Vegetation*.—*Nypa* palm locally forms pure dense stands in brackish environment in depressions and very shallow creeks, and commonly occurs in discontinuous fringes lining the borders of sluggish creeks draining the mangrove.

### (*e*) *Woodland*

(i) *Mixed Swamp Woodland*.—This type occurs in slightly brackish environment in a discontinuous belt on the landward side of the mangrove (Tortore land system). The tree canopy, to 80 ft high, is open to very open. Mangrove species occur but gradually give way to freshwater species. *Pandanus* is usually abundant in shrub and lower tree layer, also sago may be locally plentiful. The herb layer is generally sparse, comprising *Crinum*, and *Acrostichum* and other ferns. Epiphytes and climbers become more common with distance from the mangrove. *Heritiera littoralis* is locally dominant, also *Sapium* sp., as was found near the Musa River.

(ii) *Sago Swamp Woodland.*—This type, in which sago dominates, occurs in a freshwater environment, mainly in the permanent back swamps of the coastal plain (Tortore land system). Sago grows best in relatively well-drained swamp, e.g. in the north of the Musa River back swamp around the upper courses of the Foru River and its tributaries. Other larger sago complexes are found in the south and south-west of the western marginal swamp. Minor occurrences are in the central part of some of the upland basins (Boborobo land system) and in the Musa valley in seepage areas and along rivers in the lower Ubo fan (Ubo land system).

The ground cover, moderately dense to dense sago, is topped by a layer of low trees, e.g. *Nauclea* and *Mitragyna*, varying in density from open to widely scattered. The herb layer is scanty and consists of ferns and gingers. *Pandanus* is usually present and is locally abundant.

(iii) Pandanus *Swamp Woodland.*—This type, in which *Pandanus* is prominent, occurs in a habitat similar to that of sago swamp woodland. *Pandanus*, varying in density, is topped by scattered trees, e.g. *Nauclea*. Very occasionally almost pure stands of *Pandanus* occur, e.g. in prior river channels of Momoiogo land system. The ground layer commonly consists of dense high gingers.

### (*f*) *Savannah*

(i) *Eucalypt Savannah.*—The main areas of eucalypt savannah, by far the most important type of savannah in the survey area, are found in the hills and terraces surrounding the Musa valley (Asaga and Arumbai, and also Adau and Avuru land systems), with the greatest extent to the south of the valley. Minor occurences are on the eastern slopes of the Hydrographers Range and Managalase plateau (Iwuji land system). In the hills eucalypt savannah mainly occupies ridges and upper slopes.

The upper storey consists of eucalypt trees, from 30 to 115 ft high, usually more or less widely scattered, often also in fairly dense groups.

The shrub layer is usually scarce to almost absent. *Cycas* is commonly present, particularly along the border with the forest. Common shrubs are *Desmodium*, *Timonius*, and *Clerodendrum*; higher up in the hills are *Grevillea ?papuana* and *Myrtella*. There are no climbers. Epiphytes are scarce; at higher altitudes *Usnea*, ferns, *Dischidia*, and others are occasionally fairly common.

The ground layer consists of grasses, usually mid-height, occasionally short, on poor stony crests. The main species is *Themeda australis*, the next most important being *Imperata cylindrica*. The latter shows a slight tendency to be more common than *Themeda* under the canopy of eucalypt trees. Many other grasses, e.g. *Saccharum*, *Coelorachis*, *Ophiuros*, *Arundinella*, *Capillipedium*, and *Eulalia leptostachys* are locally dominant, *Coelorachis* often near the edge of the forest. Other common grasses are *Apluda*, *Sorghum*, *Eragrostis*, and *Cymbopogon*. Cyperaceae, always present, usually dominate on wetter sites.

The aspect of the grass cover under eucalypts depends on the stage it is in after burning. A grassland dominated by *Capillipedium* shortly after burning is often completely dominated by *Themeda* at a later stage. Coverage depends on burning and position on the slope. Generally, side slopes have a greater coverage than crests and upper slopes. A cover of nearly 100% may drop to 30–40% after burning when the grass appears tussocky. Young grass regrowth is in places moderately to strongly grazed by wallabies.

A great many forbs, especially legumes, are mixed with the grasses, particularly where frequent burning occurs. Some very low species flower just after burning, e.g. *Pygmaeopremna sessilifolia* and *Curculigo orchioides*.

Four species of *Eucalyptus* have been found in the survey area, *E. tereticornis*, *E. alba*, *E. papuana*, and *E. confertiflora*. *Melaleuca ?cajaputi*, indicating poor drainage conditions, was found mixed with widely scattered, low *E. papuana* on the fan slopes of the Sibium Range west of Embessa. Individual eucalypts showing features of both *E. papuana* and *E. confertiflora* were found and it is possible that some hybridization has taken place.

(ii) Nauclea–Antidesma *Savannah*.—This type occurs within the eucalypt savannah in shallow depressions in terraces and in seepage areas at the foot of hills and terrace scarps (Asaga land system).

The upper storey consists of scattered low trees of *Nauclea* and *Antidesma*, the frequency of either species varying considerably. The ground layer of mid-height grasses contains many sedges, *Phragmites* is locally present, and *Alloteropsis* is locally dominant. Grasses tend to be tussocky, in places patchy with bare patches between; coverage is generally less than on slopes under eucalypts.

### (g) *Low Forest*

(i) *Montane Forest*.—This is a low stunted forest, (according to the aerial photographs) occurring on the upper slopes and summit of Mt. Suckling, roughly above 9000 ft. The type was not visited. *Araucaria cunninghamii* is locally common, its height has not been established.

(ii) *Stunted Lower Montane Forest*.—In the higher parts of the lower montane zone, roughly above 4800 ft, the forest, often enveloped in clouds, consists of gnarled trees with a canopy 65 to 80 ft high, open, and with large gaps. Climbers and epiphytes are very abundant, and thin climbing bamboo is common to abundant. As in the zone below, *Lithocarpus* is common, but *Castanopsis* was not found. *Nothofagus*, tending to be gregarious, occurs locally and trees of the Sapotaceae family are common. The type was visited on only two occasions. According to the aerial photographs large areas occur in the high hills of Misima land system in the extreme west of the survey area, where it is characterized by complexes of *Nothofagus*.

(iii) *Very Small-crowned Hill Forest*.—This type is a usually dense, uniformly very small-crowned, very thin-stemmed, low forest, occurring in the Sibium and Didana Ranges mainly in Fiobobo but also in Darumu land systems on shallow soils. Climbing and scrambling bamboo is often very common. Emergent *Araucaria* occurs locally. Along the middle Bariji River, three small lava block flows are covered with nearly pure low *Rhus taitensis*, with a dense ground cover mainly of ferns and many species of orchids.

(iv) *Small-crowned Hill Forest.*—This type covers large portions of the Sibium and Didana Ranges mainly in Fiobobo and Didana land systems. It is a thin-stemmed low forest with a dense to rather open, rather uniformly small-crowned canopy.

Three genera found to be common are *Anisoptera* and *Syzygium* at a lower altitude, *Calophyllum*, *Lithocarpus*, and *Syzygium* at a higher altitude. As in the foregoing type, *Araucaria* may occur, usually widely scattered, occasionally fairly dense.

(v) *Low Fan Forest.*—This is a thin-stemmed, small-crowned forest occurring in upland basins of the Sibium Range (Boborobo land system) and on fans sloping down into the basin between Musa River and Didana Range (Korala land system). As in the small-crowned hill forest, the average crown diameter is small, but larger crowns do occur, and where the type's occurrence is due to poor drainage there are locally patches of dense sago and *Pandanus* swamp woodland. Occasionally *Casuarina* forms a very open upper storey. Palms, climbers, *Pandanus*, and climbing bamboo are locally abundant.

(vi) *Mangrove Forest.*—From Songada eastward to the Musa River and beyond stretches a belt of mangrove 1½–3 miles in depth (Bendorodo land system). From Songada to the north-west the belt of coastal vegetation narrows as the plain wedges out against the fan slopes of the Hydrographers Range, and only pockets of mangrove occur along a few small rivers.

Mangrove grows right down to the beach except for about a mile to the west of the mouth of Foru River where a system of beach ridges has been and is still being developed.

Although mangrove commonly shows seral stages, it was considered best to treat the four main genera capable of developing into forest under the present heading.

(1) Avicennia *Mangrove.*—*Avicennia* is, like *Casuarina equisetifolia*, a pioneer on offshore sand bars immediately above high tide level; it also occurs on the landward side of the mangrove belt. When young it forms a dense, low, scrubby vegetation. At a later stage the *Avicennia* thins out and other mangrove species such as *Sonneratia* begin to appear. In a further stage of development, after silty material has been deposited, *Avicennia* and *Sonneratia* locally form an open upper canopy with a dense ground layer of young *Rhizophora*, *Bruguiera*, and *Avicennia*.

*Avicennia* is easily recognized by its very pale green leaves and asparagus-like pneumatophores, which together form disk-shaped groups around the stems of older individuals.

(2) Sonneratia *Mangrove.*—This genus was not seen in pure stands but only forming a very open upper storey 65–100 ft high, pure or mixed with *Avicennia*, over young stands of *Bruguiera* and/or *Rhizophora*, mixed with other mangrove species, e.g. *Xylocarpus*, *Lumnitzera*, *Avicennia*, and *Aegiceras*. It also occurs in small groups, or scattered, along river banks. Like *Avicennia* it has asparagus-like pneumato-

phores projecting through the mud at a considerable distance from the stem, out of proportion to its crown size.

Although climbers are normally absent in mangrove they were found to be rather common in the types with old *Sonneratia*.

(3) Rhizophora *Mangrove.—Rhizophora* often forms pure, moderately to well-closed, uniform stands of presumably equal age on tidal flats. The highest stands, to 80 ft or slightly higher and of small uniform girth (30 in. average), invariably occur near rivers and creeks.

Undergrowth in mature stands consists almost solely of young *Rhizophora* with occasional tufts of *Acrostichum* fern; the young *Rhizophora* is mainly between 1 and 7 ft high, only a few rising to 13 ft. The soil, often a deep peat, is usually under shallow water.

A typical feature common in mature stands is more or less circular areas, approximately 1 acre in extent, of dead or dying trees (Plate 1, Fig. 2). *Bruguiera* trees may also be involved. Under the dead trees grows a dense thicket of mainly young *Rhizophora*.

(4) Bruguiera *Mangrove.—Bruguiera*, like *Rhizophora*, often forms almost pure, usually small stands of uniformly small girth. It grows at a slightly higher level than *Rhizophora*. Scattered individuals of *Avicennia* and/or *Rhizophora* are usually present and stands consisting of an approximately equal mixture of *Bruguiera* and *Rhizophora* commonly occur, usually between narrow zones of pure *Rhizophora*. The ground layer consists of *Acrostichum* fern and mangrove seedlings. The layer of *Acrostichum* has a varying density, depending on the amount of light reaching the ground, and is particularly well developed on levees and on hummocks of sandy soil made by crabs. *Bruguiera* is characterized by knee-like pneumatophores.

(vii) *Beach Forest*.—This forest, occurring on present and older beach ridges (Pawara land system), is low to mid-height with an open to very open canopy and palm understorey. A few characteristic species of the coastal fringe forest on the first beach ridge, just behind the *Ipomoea–Canavalia* community, are *Calophyllum inophyllum* with a wide umbrella-shaped crown and shiny leathery leaves, the deciduous *Terminalia catappa*, *Pandanus tectorius*, and *Hibiscus tiliaceus*.

A large part of the beach forest is secondary and near coastal villages has largely been replaced by coconut plantations.

### (*h*) *Mid-height Forest*

(i) *Lower Montane Forest*.—At about 3500 ft there is a gradual, almost imperceptible change from the zone of *Castanopsis* forest below to lower montane forest, where *Castanopsis* is still very common. The beginning of this zone is often more easily recognized on the air photo than in the field. It occurs in many of the hill land systems and is dominant in Owalama, Guaya, Foasi, and Suckling Complex land systems.

Lower montane forest has a canopy at 80–100 ft, with emergents to 115 ft. Climbers are common, epiphytes are very common, mossy epiphytes especially are abundant. Bamboo is often very common. The scattered old trees have thick, crooked, often dying branches completely covered with epiphytes. Trees do not seem to fall as a whole but die off gradually until a stump a couple of metres high is left, which may remain standing for a long time. There is usually a thick springy layer of organic matter and subsurface erosion causes holes to form under the moss-covered surface roots. The forest is moist, very quiet, and birds and even ants are rare. The gloomy aspect may be broken by flowering *Dendrobium* orchids or climbing *Rhododendron*.

Apart from *Castanopsis*, common tree genera are *Lithocarpus*, *Elaeocarpus*, *Podocarpus*, *Syzygium*, *Calophyllum*, and Sapotaceae. Common shrubs are *Psychotria* and Gesneriaceae. The moss *Dawsonia* is conspicuous. On steep slopes the forest is irregular, with large gaps in the canopy; many trees are inclined or have bent bases; climbers are more common and climbing or scrambling bamboo is locally abundant.

(ii) *Mid-height Fan Forest*.—This type is most common on the eastern slopes of the Managalase plateau (Iwuji land system, also Korala land system). It is intermediate between low fan forest and tall evergreen fan forest, has a rather even canopy, and trees are largely of moderate crown size and girth. Species composition is similar to tall evergreen fan forest (see Section (*i*)(x)).

### (*i*) *Tall Forest*

(i) *Mid-slope Forest*.—Mid-slope forest occurs on mid and upper hill slopes roughly below 2500 ft. The canopy, at 115 ft, is generally fairly dense and uniform with rather small crowns, but may vary from open and irregular on steep and unstable slopes to dense. Emergents reach 130 ft, occasionally slightly more. Emergents and canopy trees have long, straight, clear boles; large girths are rare. In the lower tree storeys the number of poles is conspicuous. The shrub layer, although consisting of a great number of individuals, gives the impression of being rather open, since the shrubs are mainly long, thin, slender saplings.

Common tree genera are *Calophyllum*, *Lithocarpus*, *Sloanea*, *Ficus*, *Castanopsis*, *Canarium*, *Elaeocarpus*, and *Pometia*.

(ii) Castanopsis *Forest*.—*Castanopsis* forest forms the transition between lowland hill and lower montane forest roughly between 2500 and 3500 ft. The type is named after *Castanopsis acuminatissima*, which occurs roughly between 2000 and 4800 ft throughout the survey area and is very common to abundant above 2500 ft, especially on ridges where it often dominates the canopy. The species is easily recognized by the more or less dentate, acuminate leaves often forming a carpet on the ground, and by the many coppice shoots around the base of the main trunk. The type has a well-closed canopy, 100–115 ft high. Crowns are small to moderate, 20–40 ft. Emergents reach 130 ft. In contrast to the mid-slope forest, which it resembles in structure, the canopy is somewhat denser and the average crown size smaller, the herb layer has more ferns and surface-root mosses; low epiphytes, stilt roots, and tree ferns are more frequent.

Apart from *Castanopsis* the genera *Lithocarpus*, *Calophyllum*, and *Sloanea* are very common; common also are *Podocarpus*, *Canarium* ("enalgeteget"), and, in the western Sibium Range, *Schizomeria* and *Xanthophyllum*. Common shrubs are *Psychotria* and *Amaracarpus*.

On steep slopes the canopy is irregular, with gaps; tree bases are often bent; climbers and stilt roots are more common; bamboo is often abundant.

(iii) *Foothill Forest*.—This type occurs at the foot of hills and in V-shaped valleys within the mid-slope forest type. The canopy, very irregular in crown size and height, is generally open, occasionally dense, 100–115 ft high, with large gaps. Emergents reach 130 ft. Differences from mid-slope forest are that the canopy is more irregular both in height and in density, that trees of large girth are more common, and that climbers and rattan, also buttresses, are slightly more common and epiphytes slightly less common.

*Pometia pinnata* is usually common, in places abundant. Other common genera are *Ficus*, *Terminalia*, *Alstonia*, *Sloanea*, *Canarium*, and *Pterocymbium*.

(iv) *Plateau Forest*.—Wherever flattish areas occur in the hills, the forest responds with a more luxuriant growth, characterized by increased average girth, height, and crown size. Thus a plateau forest type was recognized, mainly occurring on the plateaux in the Managalase (Tahama land system), and further as scattered patches often too small to be mapped. It is a fairly dense forest if undisturbed. Trees are high and straight with long clear boles. Emergents reach 165 ft. Girths are small to moderate, with scattered trees of large girth present but not as common or as large as in the tall alluvium forest.

Very common genera are *Pometia* and *Ficus*; common genera are *Sloanea* and *Alstonia*.

Large areas have been used for shifting cultivation and are now covered with secondary forest, which if advanced is of the same height as the original forest but with fewer large trees and more climbers and rattan.

(v) *Mixed Deciduous Hill Forest*.—This type, in which up to 40% of the canopy trees can be deciduous, occurs on terraces and hills surrounding the middle Musa River valley in fairly large complexes covering hill-sides (Avikaro and Aimare land systems) or in an irregular, lichen-like pattern on side slopes and in valleys alternating with eucalypt savannah on the ridges (Arumbai and Adau land systems; Plate 6, Fig. 2).

Structurally the type is rather similar to mid-slope forest and, at foothills and in valleys, to foothill forest. The canopy is, generally, somewhat more open, and scrambling bamboo, in places very common to abundant, is a normal feature. Common canopy trees are *Intsia*, *Ficus* (also a deciduous species), *Pometia*, *Anisoptera*, *Celtis*, *Flindersia*, *Erythrina*, *Alstonia scholaris*, *Terminalia*, *Sterculia*, *Pterygota*, *Vitex*, and *Elaeocarpus*. Shrubs generally present and often very common are *Lunasia amara*, *Acalypha* sp., and *Desmodium ormocarpoides*.

(vi) *Mixed* Casuarina *Hill Forest*.—In this type, *Casuarina papuana*, of an otherwise scattered occurrence in the hills, dominates the aspect of the forest. The type occurs in the Owen Stanley foothills from about 2400 ft up into the lower montane zone as small to large complexes covering hill-tops and hill-sides. A large complex lies some 8 miles south of Domara (Avuru land system). It is also found in narrow bands fringing eucalypt savannah and often associated with *Araucaria*, e.g. south of Mioki (Avuru land system; Plate 11, Fig. 1). An occurrence of minor importance and at a lower altitude is above the Namudi savannahs on the south slopes of the Sibium Range (Siviai land system).

*Casuarina papuana* forms an open to very open upper storey of small (20–30 ft), rather dark, rounded crowns at about 100 ft over broad-leaf species. Girths to 60 in. were measured. It is often associated with klinki pine (*Araucaria hunsteinii*), in which case the scattered *Araucaria* trees top the *Casuarina* by some 65 ft. Both *Casuarina* and *Araucaria* were found regenerating, though *Casuarina* only sparsely.

(vii) *Mixed* Araucaria *Hill Forest*.—*Araucaria hunsteinii* occasionally grows gregariously to form fairly dense stands (Plate 5, Fig. 2). The type was found in the foothills of the Owen Stanley Range and in the Sibium and Didana Ranges between 1800 and 3600 ft. Mixed stands of *Araucaria hunsteinii* occur on ridges and steep side slopes with slump topography and shallow soil (Foasi and Aimare land systems) as well as on gentle slopes and plateau surfaces (Sibium land system; Darumu land system). The *Araucaria* trees may reach a height of 180 ft and top the canopy of broad-leaf species by 65 ft. Apart from *Casuarina*, common accompanying genera are *Calophyllum*, *Anisoptera*, and *Sloanea*. *Araucaria cunninghamii* (hoop pine) was on rare occasions found together with the klinki.

(viii) *Tall Alluvium Forest*.—This type occurs on imperfectly to well-drained level sites, not subject to flooding or subject only to occasional flash floods, such as prior Musa River lobes and prior and present levee banks (Momoiogo land system). The type has a fair number of scattered, large, emergent trees 130–150 ft, rarely 165 ft high, and a rather open to moderately dense canopy of medium-sized trees 115–130 ft high. Climbers and palms, also buttresses, are common to very common, rattan and *Pandanus* rather common.

Common tree species are *Pometia pinnata*, *Ficus* sp., *Terminalia* spp., *Alstonia scholaris*, and *Octomeles sumatrana*. In old secondary forest *Canarium acutifolium*, *Elaeocarpus* sp., and *Endospermum* sp. are usually common or even dominant. Myristicaceae are locally prominent in the lower tree storeys.

(ix) *Irregular Tall Alluvium Forest*.—This type occupies poorly drained areas subject to deep seasonal flooding for longer periods and even in the dry season somewhat swampy or with a high water-table, such as depressed back plains (Imo and Dove land systems). It also occurs as scattered remnant patches in the Musa valley, and in seepage areas (Ubo and Gobera land systems). The canopy, about 100 ft high, is very irregular and open, emergents are slightly lower (125–150 ft) and more widely scattered than in the tall alluvium forest type. Climbers, rattan and other palms, *Pandanus*, also buttresses, are very common to abundant. The type has a lower density of trees and a lower cubic content than the tall alluvium forest type; the average girth, however, is higher than in the tall alluvium forest as here it is depressed by the greater number of trees of moderate to low girth.

Species composition was found to be rather similar to tall alluvium forest. *Pometia* is less common. Species especially common include *Bischofia javanica* and *Planchonia papuana*, commonly associated with small groups of sago palms.

(x) *Tall Evergreen Fan Forest.*—The habitat is gentle well-drained fan slopes with usually deep soils. Virtually evergreen tall fan forest occurs south and north-east of Mafu (Ibinambo land system). Although tall forests on the foothill fans of the Hydrographers Range, from south and south-east of Pongani to north and north-east of Kinjaki (Nembadi land system), do contain deciduous trees, they are best classified under the present heading.

The type resembles the tall alluvium forest in structure. Differences are that the canopy is somewhat denser, that emergents are higher (150 ft average, often to 165 ft), that palms are not as abundant and climbers not as common as in tall alluvium forest, and that on the whole the shrub layer is somewhat denser.

Common emergent and canopy tree genera are *Ficus, Pometia, Alstonia, Dracontomelum, Syzygium, Dysoxylum, Vitex, Intsia, Canarium,* and *Octomeles*; at higher altitudes *Calophyllum, Chisocheton,* and Lauraceae. The deciduous *Terminalia canaliculata* is locally common where, under temporary swampy conditions, very gentle fan slopes run out into the coastal plain (Nembadi land system).

As the habitat is generally easy of access and suitable for cultivation, large areas have degraded into tall grassland and secondary forest, locally also eucalypt savannah.

(xi) *Tall Mixed Deciduous Fan Forest.*—This type, in which a fairly large proportion of the canopy trees is deciduous, occurs in the Musa valley (Safia, Liamu, and Ubo land systems). Its structure is similar to that of tall evergreen fan forest. Climbing and scrambling bamboo is usually common, locally abundant. Apart from the genera mentioned under tall evergreen forest the following trees were found to be common: *Anisoptera, Celtis, Maniltoa,* and the deciduous trees *Terminalia, Pterygota, Pterocymbium, Sterculia, Tetrameles,* and *Bombax.*

### (j) *Seral Vegetation Types*

(i) Timonius–Commersonia *Scrub.*—Where for some reason burning of grassland has been discontinued, *Timonius, Commersonia,* and other pioneer regrowth species increase and, where the shrub layer becomes dense, the ground cover of grasses starts to die back. The type was visited on one occasion in Fiobobo land system and seen from helicopter in Momoiogo land system, e.g. north-west of Garagarata.

(ii) Casuarina equisetifolia *Forest.*—Pioneering *Casuarina equisetifolia* forms low to mid-height, usually very dense stands on recent offshore sand bars and accreting sandy coasts commonly right up to high tide mark, and also on sandy strips along the mouths of the larger rivers.

(iii) Casuarina *Fan Forest.*—*Casuarina cunninghamiana* colonizes gravelly and stony stream deposits in dense, pure, low to mid-height stands, usually in narrow discontinuous bands along swift-running creeks from the Goropu Mountains, occasionally in fairly extensive complexes (Ubo land system).

(iv) *Mixed* Casuarina *Fan Forest.*—The same species of *Casuarina* forms an open, in places very high (up to 200 ft) canopy over open to fairly dense lower storeys of broad-leaf species. The old *Casuarina* trees have long, straight, clear boles with buttresses to 13 ft high and 3 ft wide.

## V. Ecology

In view of the strong correlation between vegetation types and environment they are discussed according to the major types of habitat. Savannahs and grasslands, to a degree independent of habitat, are treated separately.

### (a) *Coastal Environment*

Within the mangrove, type and species composition vary at short distance and are apparently very sensitive to environmental factors such as frequency of inundation and age and character of the soil (salinity, drainage, sand, mud, or peat). The highest stands of *Rhizophora* and *Bruguiera* occur in a dendritic pattern along the creeks draining the tidal flats, which is clearly visible on the air photos. Away from the creeks the vegetation rapidly decreases in height, giving way to a low scrub, possibly caused by lack of tidal influence and/or lack of aeration.

The Musa delta merits separate mention. Influenced by changed river course, wind, waves, and sea currents, the landscape and with it the vegetation pattern are continually changing and developing. Aggrading offshore bars and spits near the present river mouth are colonized by *Casuarina* and *Avicennia* whilst on the protected landward side other mangrove species germinate. In sheltered lagoons behind the bars *Rhizophora* finds a favourable habitat. Going inland from the old river outlet one observes various seral stages: young *Rhizophora* along the muddy banks; old *Avicennia* and *Sonneratia* with an understorey of young *Rhizophora*, *Bruguiera*, and *Avicennia*; and mature *Rhizophora* stands. *Avicennia* is the most common pioneer mangrove species. The occurrence of *Sonneratia*, together with *Avicennia*, as an open upper storey over young stands of *Bruguiera* and *Rhizophora* seems to indicate that *Sonneratia* too can be a pioneer species. This agrees with findings in other tropical mangrove areas (Watson 1928).

The "holes" in the mangrove (referred to in the description of mangrove forest), mainly in *Rhizophora* stands, are irregularly spread and look like bomb craters on the air photos. They also appear in 1943 war photographs of the same area, but at other places. Their cause is not understood. In analogy of similar occurrences in coniferous forests one is inclined to think of a circularly spreading fungus disease striking at old less-resistant trees. The areas of dead trees serve a very useful purpose as regeneration centres. Mangrove trees are strong light-demanders and although there apparently is a regular establishment of seedlings under a not too dense canopy of mature trees, this regeneration is short-lived.

Some mangrove genera, e.g. *Sonneratia*, are found rather far inland along river banks, in mixture with freshwater species. Findings on the tolerance of *Rhizophora* to fresh water are controversial. It is considered a facultative halophyte, along with *Avicennia*, and has been found well beyond the salt limit in completely fresh water in Surinam (Lindeman 1953). In South Africa it has been found not to withstand fresh water, in contrast to *Avicennia* and *Bruguiera* (Macnae 1963).

The mangroves of the survey area are rather poor in comparison with other tropical mangrove areas where tree heights to 150 ft and girths to 3 ft have been measured (Watson 1928; Lindeman 1953).

In the *Ipomoea–Canavalia* community all species are of necessity tolerant to salt, wind, high soil temperatures, and strong fluctuations in temperatures, and are mainly restricted to this habitat. An exception is *Cassytha filiformis*, a parasite of the Lauraceae family, common both in the beach front line community and the inland eucalypt savannah. *Ipomoea pes-caprae* is reported to occur on freshwater beaches (Taylor 1963) and on inland river banks (Hoogland, personal communication).

Beach forest is best developed on the highest ridges. In the swales between the ridges it gives way to sago or *Pandanus* swamp woodland. Where occasionally mangrove borders the complex, the vegetation changes through a mixture of freshwater and mangrove species and huge old *Casuarina* trees to pure mangrove. *Hibiscus tiliaceus*, common on the first beach ridge, is also widely distributed along river banks in the mangrove belt and in coastal garden regrowth.

### (*b*) *Swamp Environment*

Drainage conditions determine the distribution of the various swamp communities. Boundaries between swamp communities are characteristically very sharp, as with the *Leersia–Hanguana* boundary, but may range from sharp to gradual, as with the sago–herbaceous boundary. Both minor changes in habitat, and chance, i.e. presence of diaspores, are likely to play a part. Normally the transition from sago swamp woodland to herbaceous swamp vegetation is gradual, sago becomes lower and tends to grow in scattered rounded clumps. Occasionally, e.g. in the southwestern part of the western marginal swamp, a narrow rim of sago at the foot of the hills is sharply defined from the bordering low herbaceous vegetation of the swamp proper. Where sago woodland grades into irregular tall alluvium forest, the tree layer gradually increases in height and becomes denser and more varied in species composition.

A striking difference between the western and the eastern marginal swamp is that in the western swamp the vegetation is predominantly herbaceous, with trees very scarce, whereas in the eastern swamp woodland is prominent. Since the Musa River broke through near Garagarata in 1943, the increased amount of water flowing into the eastern swamp must have considerably influenced the vegetation. Around the actual breakthrough most trees have died (Plate 2, Fig. 1); further away from it and in a belt all along the border of the swamp, especially the western border, many small trees, mainly *Nauclea orientalis*, have died or are dying, the broken branches of their crowns smothered in climbers (Plate 2, Fig. 2). *Nauclea*, though itself a tree of waterlogged habitats, may not have been able to stand the increased swampiness.

### (*c*) *Alluvium*

As in the swamp communities, the type of alluvium forest depends on drainage conditions. Consequently the two types distinguished are not sharply defined, their distribution and boundaries are irregular, and they merge and form transitions (Plate 3, Fig. 2). Where tall alluvium forest grades into tall fan forest, the canopy gradually becomes somewhat denser, the average crown size of emergent and canopy trees somewhat less, and climbers and rattan less numerous.

From where the Musa River emerges from the gorge into the coastal plain it meanders strongly, forming scrolls. Where these accrete rapidly, roughly between Embessa and Taruma, a succession from pure *Saccharum* near the water's edge to tall alluvium forest as the climax type can be clearly seen. More to the north, where growth of scrolls is slower, the forest grows almost to the edge of the water.

### (*d*) *Fans*

Depending on local climate, fan forests are evergreen, e.g. in the Mafu area, or contain some deciduous trees, e.g. in the Pongani–Kinjaki area and around Korala and Kakasa, or have a fair proportion of deciduous trees in the canopy, e.g. in the Musa valley. Across the Ubo–Mafu fan the importance of deciduous trees diminishes towards the east, presumably due to an increase in rainfall, until south of Mafu the fan forest is virtually evergreen.

The occurrence of low fan forest seems to be controlled by shallow stony soils or poor drainage. With improving drainage there is a rapid transition to mid-height fan forest.

In the eastern portion of the Ubo fan pure stands of pioneering *Casuarina cunninghamiana* occur on bouldery fans. With stabilization of the habitat broad-leaf species begin to appear and through various stages of mixed *Casuarina*–broad-leaf forest in which *Casuarina* no longer regenerates, the forest develops to the eventual climax, the tall fan forest.

### (*e*) *Hill and Mountain Environment*

The types of forest distinguished on altitude and position on slope, i.e. foothill and mid-slope forest, *Castanopsis* forest, lower montane forest, and montane forest, have no sharp boundaries, changes are gradual both in structure and in species composition. Another factor influencing the type of forest in the hills is degree of slope. On steep slopes the forest tends to be open and irregular. On flattish areas, average girth, height, and crown size increase and for this type the name plateau forest is used.

The boundary between evergreen and mixed deciduous hill forest is not sharp either. Deciduous trees occur scattered in many hill forest types, locally more conspicuous, e.g. around Manana, Biriri, and Toma, but are strikingly common in certain areas, i.e. the Musa basin. This basin, lying in the rain shadow of the Owen Stanley, Sibium, and Didana Ranges, has a relatively low annual rainfall of probably 60–70 in. The factor governing the frequency of deciduous trees is probably the rather marked dry season and low mean for the driest month, July, which is well below 5 in., giving the local climate a strongly monsoonal aspect. To the south of the Musa valley deciduous trees were found to form an important part of the canopy up to an altitude of 2600 ft. With increasing altitude their number decreases, so that they virtually disappear in the lower montane zone south of Emuruwake, Mioke, and Aimare and east of Silimidi, and in the higher regions of the Sibium and Didana Ranges. It is noteworthy that deciduous trees are common not only in hill forest, on well to excessively drained sites, but also in poorly drained flood-plains of the Musa valley proper, accompanied by such genera as *Bischofia* and *Planchonia*. Temporary water stress in the dry season may account for this occurrence.

Deciduous trees occur almost exclusively in the emergent and canopy layer. Those of the Sterculiaceae family, and also the genus *Terminalia*, are the most important. In many Sterculiaceae flowering precedes flushing of new leaves; in *Terminalia* they go together. On one occasion a *Terminalia* species was found exuding a fluid in the process, evident as a constant dripping on the forest floor under the canopy.

The main reason for the occurrence of small-crowned, and also of strikingly poor very small-crowned, hill forest is likely to be shallowness of soil. Where the types merge into the savannahs and grasslands in and around the Musa valley, temporary drought may further deteriorate growing conditions. The lava block flows covered with *Rhus taitensis* form an extremely unfavourable habitat with hardly any soil at all. Very small-crowned forest occurring on hummocks within mixed *Araucaria* hill forest in Darumu land system was not visited but may be a seral stage in the succession from grassland to forest.

The origin of mixed *Casuarina* hill forest is not clear. A suggested explanation is that *Casuarina papuana* established itself after destruction of the original mixed deciduous forest by fire in one or more excessively dry seasons. Another less likely possibility is earthquake causing large-scale mass movement and destruction of the vegetation. After establishment of the *Casuarina*, broad-leaf species may have gradually returned. Repeated fires may have caused a further degradation of part of the *Casuarina* forest to eucalypt savannah. Regeneration of *Casuarina* was found to be sparse.

The origin and status of the mixed *Araucaria* hill forest also pose a problem. It has been suggested (Womersley 1958) that *Araucaria* forests represent a "living fossil vegetation". In the survey area, extensive areas of mixed *Araucaria hunsteinii* hill forest with healthy natural regeneration of *Araucaria* and with the species represented in all girth classes, give the impression of being able to maintain the community for an indefinite period. No firm correlation has been found between the occurrence of *Araucaria hunsteinii* and soil type, although the species tends to be associated with poor forest on shallow soils. The statement that klinki and hoop pine do not intermingle (Kraemer 1951; Gerry 1954) was found to be incorrect.

### (*f*) *Savannahs*

It is likely that the bulk of the savannahs and also the grasslands in the survey area are disclimax types of vegetation induced after destruction of the original vegetation by fire, which in the hills could start more easily on ridges because of adverse edaphic conditions and strong winds.

It is also likely that in the hills savannahs and grasslands were in many cases not initiated by shifting cultivation but that there are, or have been, patches of natural grassland and eucalypt savannah on stony ridge crests. Repeated burning by the indigenes and subsequent encroachment by the fire upon the surrounding forest may have caused the present-day extensive areas of savannah.

The boundary between eucalypt savannah and the adjacent forest appears to be fairly stable and the change is always abrupt. Though occasional mature eucalypts occur within the forest near the edge of the savannah, the forest was nowhere found to have extended recently at the cost of the savannah. On the other hand, savannah grass fires were seen penetrating into the adjacent forest. Though fires will not normally spread far into the forest, they do destroy the edges. It is not known whether larger areas of forest are occasionally burnt.

Eucalypts often regenerate in groups. Though mature trees are to a large extent fire-resistant, their regeneration is often badly damaged by fire. Normally some individuals will stay alive, grow up, and maintain the community (Plate 5, Fig. 1). Where fires are very frequent a further degradation to grassland will take place.

Little correlation has been found between eucalypt species and general habitat and soil properties. Often two or three species grow at one site. *E. alba* tends to be more common on very gravelly soils, particularly on the terraces around the Musa valley (Asaga land system) and in the valley proper. It is often low, crooked, and of small girth. *E. tereticornis* is the most common and widespread; it is also the tallest of the four, and on gentle fan slopes and occasionally also on favourable hill sites may reach 115 ft. (In the Port Moresby–Kairuku area it is reported to reach 80 ft maximum (Heyligers, personal communication).)

Where drainage is impeded, eucalypts do not grow, giving way to scattered low trees of *Nauclea* and *Antidesma*. A very slight decrease in height of terrain can evoke the change.

### (*g*) *Grasslands*

Grassland, like eucalypt savannah largely a fire disclimax vegetation, is maintained by burning, and variations in structure and composition are largely due to differences in frequency and intensity of burning. Where burning has ceased, scattered shrubs and small trees that are always present become denser and the grassland grades into scrub or savannah and, provided fire does not recur, may eventually revert to forest. The time it takes for large surfaces under seasonal climatic conditions to revert to the climax forest type is estimated in terms of many thousands of years (van Steenis 1961). In lowland regions with high rainfall, small grassland areas surrounded by forest with seed-bearing trees could well be converted far more rapidly.

## VI. Relationship of Land Systems to Vegetation

The distribution of vegetation types in relation to land systems is shown in Table 7.

As noted earlier, man has had and still has considerable influence on the vegetation, and naturally boundaries of induced vegetation types do not necessarily follow land system boundaries. The vegetation–forest resources map shows this quite clearly for grassland and eucalypt savannah. In Table 7 these types occur in 25 and 20 of the 45 land systems respectively.

In the low-lying areas the vegetation sharply responds to changing edaphic conditions and land system boundaries have been mapped on vegetation patterns.

TABLE

DISTRIBUTION OF VEGETATION TYPES

Occurrence of communities is indicated as D (dominant, area occupied

| Vegetation Type | Land | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pawara | Bendorodo | Tortore | Imo | Dove | Momoiogo | Gobera | Aiare | Nembadi | Safia | Liamu | Ubo | Korala | Boborobo | Sibium | Ibinambo |
| **Mixed herbaceous–tall grass vegetation** | | | | | | | | | | | | | | | | |
| *Ipomoea–Canavalia* mixed herbaceous vegetation | m | | | | | | | | | | | | | | | |
| Aquatic mixed herbaceous vegetation | | | m | | m | | | | | | | | | | | |
| *Leersia–Hanguana* mixed herbaceous vegetation | | | m | | | | | | | | | | | | | |
| Fern mixed herbaceous vegetation | | | m | | | | | | | | | | | | | |
| *Phragmites* tall grass vegetation | m | | S | | | | | | | m | | | | | | |
| *Saccharum* tall grass vegetation | | | | | m | | m | | | m | | m | | | | |
| **Grassland** | | | | | | | | | | | | | | | | |
| Tall grassland | m | | | | m | m | D | | S | D | | S | | m | | |
| Mid-height grassland | m | | | | | m | | m | m | m | | | m | m | m | |
| Short grassland | | | | | | | | | | | | | | | | |
| **Scrub** | | | | | | | | | | | | | | | | |
| Mangrove scrub | | m | | | | | | | | | | | | | | |
| Fern scrub | | m | | | | | | | | | | | | | | |
| **Palm vegetation** | | | | | | | | | | | | | | | | |
| *Nypa* vegetation | | m | | | | | | | | | | | | | | |
| **Swamp woodland** | | | | | | | | | | | | | | | | |
| Mixed swamp woodland | | | m | | | | | | | | | | | | | |
| Sago swamp woodland | m | | S | | | | | | | | | | | | | |
| *Pandanus* swamp woodland | m | | D | | | m | m | | m | | | m | | m | | |
| **Savannah** | | | | | | | | | | | | | | | | |
| Eucalypt savannah | | | | | | | m | m | m | | | | m | | m | |
| *Nauclea–Antidesma* savannah | | | | | | | | | m | | | | | | | |
| **Low forest** | | | | | | | | | | | | | | | | |
| Montane forest | | | | | | | | | | | | | | | | |
| Stunted lower montane forest | | | | | | | | | | | | | | | | |
| Very small-crowned hill forest | | | | | | | | | | | | | | | | |
| Small-crowned hill forest | | | | | | | | | | | | | | S | m | |
| Low fan forest | | | | | | | | | | | | | D | S | | |
| Mangrove forest | | D | | | | | | | | | | | | | | |
| Beach forest | D | | | | | | | | | | | | | | | |

7

IN RELATION TO LAND SYSTEMS

> 50% of land system), S (subdominant, 15–50%), or m (minor, < 15%)

System

| Silimidi | Siviai | Wowo | Suwari | Darumu | Iwuji | Uoive | Asaga | Banderi | Avikaro | Aimare | Bariji | Manna | Adau | Arumbai | Fiobobo | Avuru | Tahama | Kovio | Gorabuna | Owalama | Guaya | Foasi | Hydrographers | Amora | Sesaro | Didana | Misima | Suckling Complex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | | | | | m | | | | | | | | | | | m | | m | | | | | | | | | |
| | | | | | m | m | m | S | | | | m | | | | m | | | | | | | | | m | m | | |
| | | | | | | | | | | | | | m | | m | S | | | | | | | | | | | | m |
| | | | | | | | | | | | | | | | | | | | m | | | | | | | | | |
| m | m | | | m | S | m | D | m | m | m | | m | m | D | | S | | | | | | | | m | m | | | |
| | | | | | | | m | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | m |
| | | | | | | | | | | | | | | | | | | | | m | m | m | m | m | | m | S | S |
| | | | | m | | | | | | | | | | | S | | | | | | | | | | | | | |
| | S | | m | S | | m | | | | | S | S | | | D | | | | | | | | | | m | D | | |

TABLE 7

| Vegetation Type | Land | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pawara | Bendorodo | Tortore | Imo | Dove | Momoiogo | Gobera | Aiare | Nembadi | Safia | Liamu | Ubo | Korala | Boborobo | Sibium | Ibinambo |
| Mid-height forest | | | | | | | | | | | | | | | | |
| Lower montane forest | | | | | | | | | | | | | | | | |
| Mid-height fan forest | | | | | | | | | | | | | S | m | | |
| Tall forest | | | | | | | | | | | | | | | | |
| Mid-slope forest | | | | | | | | | | | | | | | S | |
| *Castanopsis* forest | | | | | | | | | | | | | | | | |
| Foothill forest | | | | | | | | | | | | | | | m | |
| Plateau forest | | | | | | | | | | | | | | | S | |
| Mixed deciduous hill forest | | | | | | | | | | | | | | | | |
| Mixed *Casuarina* hill forest | | | | | | | | | | | | | | | | |
| Mixed *Araucaria* hill forest | | | | | | | | | | | | | | | S | |
| Tall alluvium forest | | | | | m | D | m | m | | | | | | | | |
| Irregular tall alluvium forest | | | | D | D | m | | | | m | | m | | | | |
| Tall evergreen fan forest | | | | | | | | D | S | | | | m | | | D |
| Tall mixed deciduous fan forest | | | | | | | | | | S | D | S | | | | |
| Seral vegetation | | | | | | | | | | | | | | | | |
| *Timonius–Commersonia* scrub | | | | | | m | | | | | | | | | | |
| *Casuarina equisetifolia* forest | | m | | | | | | | | | | | | | | |
| *Casuarina* fan forest | | | | | | | | | | | | m | | | | m |
| Mixed *Casuarina* fan forest | | | | | | | | | | | | m | | | | m |

Thus coastal vegetation types are restricted to two land systems only (Bendorodo and Pawara) and swamp vegetation types virtually to one (Tortore), with minor occurrences in Pawara, Dove, Nembadi, Ubo, and Boborobo land systems. The same applies to alluvium forests; the better type is dominant in Imo and Dove land systems, both of similar habitat.

Tall evergreen fan forest is dominant in two land systems (Aiare and Ibinambo) and most probably was dominant originally in Nembadi land system; mid-height fan forest, being an intermediate type, is nowhere dominant; low fan forest, reflecting mechanical or physiological shallowness of soil, is confined to two land systems (Korala and Boborobo); tall mixed deciduous fan forest, restricted to the Musa valley with its seasonally dry climate, is characteristic of three land systems (Safia, Liamu, and Ubo) and would be dominant in all three were it not for man's destructive action.

In the hills and mountains the vegetation tends to reflect differences in altitude and position on slope rather than differences in land form and lithology; thus foothill and mid-slope forest occurs in nearly all the hill and mountain land systems. Although

(*Continued*)

System

| Silimidi | Siviai | Wowo | Suwari | Darumu | Iwuji | Uoive | Asaga | Banderi | Avikaro | Aimare | Bariji | Mamna | Adau | Arumbai | Fiobobo | Avuru | Tahama | Kovio | Gorabuna | Owalama | Guaya | Foasi | Hydrographers | Amora | Sesaro | Didana | Misima | Suckling Complex |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | m | | | | | | | | | | | | | | D | D | D | S | S | m | S | S | D |
| | m | | | | S | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | S | S | D | | | m | | S | | | S | D | | | m | m | m | m | D | m | S | m | D | S | D | S | S | m |
| S | | D | S | | | m | | | | m | | m | | | | | m | m | | S | S | S | m | S | | m | m | m |
| | m | m | m | | | m | | m | | | | m | | | | | m | m | m | m | m | m | m | | m | | | |
| | | | | | | S | | | | | | | | | | | D | | | | | | | | | | | |
| S | | | | m | | | m | | D | D | | | m | S | m | m | | | | | | | | m | | | | |
| m | m | | | | | | | | | | | | | | | S | | | | | | | | | | | | |
| | | | m | S | | | | | | m | | | | | | | | | | | | m | | m | | | | m |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | m | | | | | | m | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | m | | | | | | | | | | | | | |

no special effort was made to make the lower montane zone a separate land system on the various land forms where it occurs, lower montane forest is the dominant vegetation type in four and again subdominant in four of the 10 land systems comprising it.

Of the 45 land systems, 29 have a vegetation type that is dominant for the land system. Where one land system comprises many (seven or more) different vegetation types, this is due to great differences in altitude (e.g. Suckling Complex), a large number of seral or swamp communities (e.g. Pawara, Tortore, and Ubo), human influence (e.g. Uoive and Ubo), or the complexity of the land system (e.g. Siviai).

Secondary forest and garden regrowth are not included in Table 7. In extreme cases they are dominant and only minor elements of other vegetation types remain (Kovio).

## VII. Man and Vegetation

The induced nature of savannahs and grasslands has been dealt with earlier. Secondary forest is probably much more widely spread and farther from population centres than one would deduce from the air photographs or would notice at first sight in the field. Near villages the rotation period is short and regrowth is not given the opportunity to reach anything near the original vegetation. However, clearings are also made high up in the hills far away from villages. As the indigenes seldom return to the same area here, it follows that considerable areas of forest have been cultivated at one time or another.

Trees often planted near villages are betel-nut palm, *Terminalia kaernbachii*, *Erythrina*, and *Araucaria*. After villages have been deserted these trees remain as proof of past occupation and lead one to expect a former disturbance of the surrounding vegetation.

Where bamboo is common in the natural forest it tends to be abundant in secondary stages.

The occasional individual of *Albizia falcata* occurs in the natural hill forest mostly along edges of small streams and, rarely, gregariously on land-slides; where it is otherwise found gregariously it is a sure sign of the secondary nature of the forest.

In the undisturbed alluvium forest of the coastal plain no one tree species was found to be dominant. Where a combination of *Canarium acutifolium* and *Alstonia spectabilis* was dominant the forest was invariably secondary. Neither species was found to grow to a great height. In later stages they are topped by various other species but will remain dominant in the sense of number of individuals.

One of the characteristics of secondary forest, abundance of rattan and lianes, is a typical feature also of the natural types of poor alluvium forest on slightly lower-lying sites; the two are not always easily distinguished.

## VIII. Notes on Special Features and Some Individual Tree Species

### (a) *Buttresses and Stilt Roots*

There is a definite though not quite clear correlation between habitat and the formation of buttresses: they are best developed, highest, and most frequent on level or gently sloping ground, i.e. in alluvium and fan forests. Provided the ground is fairly level they are also common at higher altitudes, e.g. forested plateaux in the Managalase. They are less conspicuous on hill slopes though low to moderate buttresses may be quite common here.

A second positive correlation exists between tree girth and height of buttresses. Large buttresses are always found on emergent and canopy trees, i.e. large trees with a big girth. This is another reason why large buttresses are scarce on hill slopes as large trees are here commonly absent or nearly so.

Stilt roots are normally present in all forest types though usually inconspicuously so and rarely very common. An exception is the abundance of stilt roots in the *Rhizophora* type of mangrove forest.

Stilt roots do not normally originate high above the ground (exceptions: *Pandanus* spp., *Ficus* sp.), they are usually rather small and thin and occur on small to medium-sized trees. They tend to become more common on swampy sites as well as on steep hill slopes at higher altitude, roughly above 3000 ft, where slope wash is a normal feature. Generally they would appear to be a means of improving anchorage. It should be noted that it is not always possible to distinguish between true stilt roots, normal roots exposed by slope wash, and small plank buttresses with a space between the lower margin and the ground.

### (*b*) *Epiphytes*

The reconnaissance nature of the survey did not permit the separate recording of data on different types of epiphytes: orchids, ferns, Araceae, etc.

The main factor governing the occurrence of epiphytes appears to be humidity of the air. This is particularly evident with mossy epiphytes. Thus epiphytes increase with increasing altitude. Mossy epiphytes especially are abundant in lower montane forest. Eastward through the fan forests south of Ubo there is a marked increase in mossy epiphytes, which become abundant north-east of Mafu towards the Wowo Gap and in the fan forests south of Mafu. The joint effect of increasing altitude and rainfall may be the cause.

On several occasions epiphytes were found to be common in mixed deciduous forest, and even abundant in the crowns of old trees. It appears that they are able to withstand a drought period. Higher up in the hills south of the Musa valley where deciduous trees were found common up to 2600 ft, mossy epiphytes are often also common.

The abundance of epiphytes often changes over a short distance: they can be inconspicuous on the upper and middle part of the slope and very common a little further down in a ravine and/or near a creek.

The abundance of low epiphytes may depend on light intensity (Richards 1952), though again they are more common where more humid conditions prevail.

*Casuarina* is usually free of epiphytes. Also *Araucaria* and eucalypts were found to carry few epiphytes, except at higher altitudes where *Usnea* sp. is common. Here ferns and *Dischidia* sp. are locally also common on eucalypts.

### (*c*) *Bamboo*

Bamboo was not found restricted to a particular habitat or a particular type of forest. It is very common in the hill and fan forests with many deciduous trees surrounding the Musa valley and in the western part of the Sibium Range. It seems to favour poor open-canopy forest, though it was occasionally found in fairly dense forest with a well-closed canopy. It often grows in patches and can at short range vary in frequency from present to abundant. Where it occurs it is always most abundant on ridges and steep slopes; it tends to become abundant in secondary forest. Locally it dominates the shrub and lower tree layers and forms the only undergrowth.

There are twining, scrambling, and erect forms, belonging to different species. The twining bamboos are usually thin and often grow up to the canopy; the scrambling type is thicker, does not grow as high, and does not grow in stools; the erect bamboo is usually thick and commonly grows in stools.

### (*d*) *Some Individual Tree Species*

Difficulties associated with taxonomic classification have prevented a floristic typing of vegetation communities in the rain forest during the survey. Although many of the common species are not restricted to a particular site they do show site preferences and varying abundance. Thus study of the relative abundance of the various species might be helpful in distinguishing types. Accidental establishment also plays a part. Some genera such as *Dillenia* seem to have a very restricted distribution, other species such as *Pometia pinnata*, *Alstonia scholaris*, and *Intsia bijuga* have a very wide one. Dominance of one species is rare in the natural forest; examples are *Anisoptera kostermansiana* and to a lesser degree *Pometia pinnata*.

Insufficient knowledge of species in very common genera such as *Ficus*, *Syzygium*, *Elaeocarpus*, and *Canarium* also hampers any attempt at floristic classification.

(i) *Anisoptera kostermansiana* (= *A. polyandra*?).—The species was found from little above sea level up to 2600 ft. It is very common in the mixed deciduous forests around the Musa valley and here at higher altitudes often mixed with *Castanopsis*. It is abundant on the southern and north-eastern slopes of the Sibium Range, here often mixed with *Intsia*, and in the forests east of Silimidi. It can completely dominate the canopy and lower layers. It occurs on level ground as well as on very steep slopes, and even here usually forms long straight boles and grows fairly large. Although reported to reach a height of 200 ft and a diameter of over 4 ft elsewhere (McAdam 1952), in the survey area it does not grow to a very large tree. It would appear to be a rapid grower and commonly occurs in secondary forest. It favours well-drained soils. Noteworthy is its absence or near-absence on the southern slopes of the Hydrographers Range, in the volcanic area, in the fan forest south of Ubo, and near Wowo Gap.

(ii) *Octomeles sumatrana*.—This species occurs throughout the area in river flood-plains and fans, on levees and scrolls, and also in lowland hill forest, as scattered individuals, in small groups of two or three or in usually small, dense, even-aged stands, the latter where river-bank gardens have been abandoned or the vegetation has been destroyed by a river's change of course. Seed production is abundant but the species does not regenerate in the shade and stands become undergrown by other species as they develop. Heights of over 165 ft, girths above buttress of 19 ft, and crowns to 130 ft wide were measured. The very large trees have a rather strongly tapering bole and thick buttresses up to 10 ft high spreading to 13 ft from the boles.

(iii) *Maniltoa ?schefferi*.—The species is common in flood-plains, fans, lower terraces, and lower hill slopes in and around the Musa valley, associated with deciduous trees. It favours moist sites at lower altitudes and is often found on deep clay soil in good-quality forest.

(iv) *Terminalia canaliculata*.—This species would appear to favour swampy sites in coastal areas, particularly where fans run out into poorly drained portions of the alluvial plain—north of Kakasa, north-west of Pongani, along the Bariji River between Gombara and Songada. In the field (mid July) it was conspicuous from afar by its foliage, which had then turned bright red just before shedding. In the air photos taken in August it is conspicuous by its bright white crown (it has then flushed new leaves). The period of deciduousness would thus appear to be short.

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# PART VII. FOREST RESOURCES OF THE SAFIA–PONGANI AREA

By J. C. SAUNDERS*

## I. INTRODUCTION

The aim of this Part and its associated map is to describe the forest resources of the area, indicating the location and extent of forests and assigning estimated stocking rates to each forest type. The land has also been classified into "terrain categories" giving an index of accessibility.

Forest covers 70% of the area, occurring in a wide range of environments from sea level to approximately 10,000 ft and from high-rainfall areas to zones of lower, more irregular rainfall resulting in occasional periods of moisture stress. Generally, the higher-yield† forests occur on well-drained alluvium, fans, and foothills in higher-rainfall areas, such as the coastal plain and in the Ubo–Mafor region. However, the presence of scattered *Araucaria* in some other areas considerably increases the yield of otherwise relatively low-yield forest types. A brief note on the forest potential of each land system is included under assessment of land use capability in Part II, Section III.

More than half of the forested area is found on rugged terrain (slopes exceeding 30°) rendering exploitation difficult to impossible. Forests on less rugged terrain are found mainly on the coastal plain, on foothills and fans surrounding the Musa basin, and in the Managalase.

No milling operations have taken place in the area.

## II. SURVEY METHODS

A preliminary air-photo interpretation was carried out in close association with other team members, particularly the plant ecologist. The land was mapped into seven broad habitat categories. The forests within each of these categories were then subdivided into types exhibiting distinct photo patterns. Traverses (based on track and road information gleaned from the Department of Native Affairs patrol reports) were then selected to visit each photo pattern as often as possible.

Field plots (mostly 20 chains × 1 chain, reduced) were located in photo patterns. Data recorded for all emergent and canopy trees whose girth exceeded 5 ft included girth at breast height (outside bark), merchantable length, total height, botanical name, and local name.‡ This information was augmented by visual observation when passing through forested areas and by the observations of the plant ecologist. From the quantitative information collected in each plot, combined with a visual photo appraisal of each plot's representative value, estimated stocking rates were

* Division of Land Research, CSIRO, Canberra, A.C.T.

† For the purposes of this paper, yield is equivalent to estimated stocking rate.

‡ Each tree was also classed on form and external symptoms of defect, as suitable or unsuitable for milling.

assigned to each forest type. These figures give a very approximate indication of timber volume and must be used with caution as the total area of sample plots was only 170 acres. Volumes quoted were based on a form factor of 0·5 and no allowance for internal defect was made.

Identifications of unknown species were based on the comparison of wood samples with wood specimens supported by herbarium material.

## III. Mapping

The final mapping of forest types was integrated with the general vegetation mapping on the accompanying map at a scale of 1 : 250,000. This integration and the similarity of nomenclature used in Parts VI and VII allow access to more detailed information on land forms, soils, etc., contained in the land system descriptions. However, the descriptions of the forest types in this Part vary from those in Part VI, as the former are restricted to trees above 5 ft in girth.

Yield of timber is indicated in three grades (high, >8000 super ft per acre; moderate, 5000–8000 super ft per acre; and low, 3500–5000 super ft per acre). Non-forested areas and forests with a stocking rate of less than 3000 super ft per acre are also indicated.

## IV. Terrain Categories

The area has been divided into three major categories on the basis of slope angle, 0–10°, 10–30°, and >30°. The first two categories have each been further divided into two, giving five categories in all.

Category Is includes all land with slopes less than 10° either permanently inundated or seasonally flooded for long periods. It includes both freshwater and tidal swamps and covers 10% of the area, mainly along the north, east, and west sides of the coastal plain.

Category I includes all land with slopes less than 10° that is either well drained or seasonally inundated for short to moderate periods. This includes all of the alluvium and most fans and covers 20% of the area. It occurs mainly on the coastal plain and in the Musa basin.

Category II includes land with slopes of 10–30°. It is found mainly in the foothills surrounding the Musa basin and in the Managalase, and covers 15% of the area.

Category IIa is more rugged than category II, and although the slopes are predominantly of 10–30°, up to 25% may exceed 30°. It covers 5% of the hilly country in the area and occurs mainly in the Managalase and on the foothills of the Owen Stanley and Hydrographers Ranges.

Category III includes all land with slope angles greater than 30° and covers 50% of the area. It is found on all the mountain ranges.

The terrain categories were mapped using the geomorphic units as a basis. Where subdivision of these units was necessary, slope angles were checked using a Leitz (Hackman) stereo slope comparator. A generalized map of terrain categories is shown in Figure 15, and Table 8 includes areas of forest types within each terrain category.

Terrain categories give an indication of accessibility both to and within forest types. In categories Is and III, access is difficult to impossible because of swampy conditions in the former and steep slopes and rugged terrain in the latter. Category I is readily accessible except in the irregular tall alluvium forest during the wet season. Category II may present moderate difficulty and this is generally also true for category IIa, except in its steeper parts.

Access to and within the survey area as a whole is discussed at length in Part VIII.

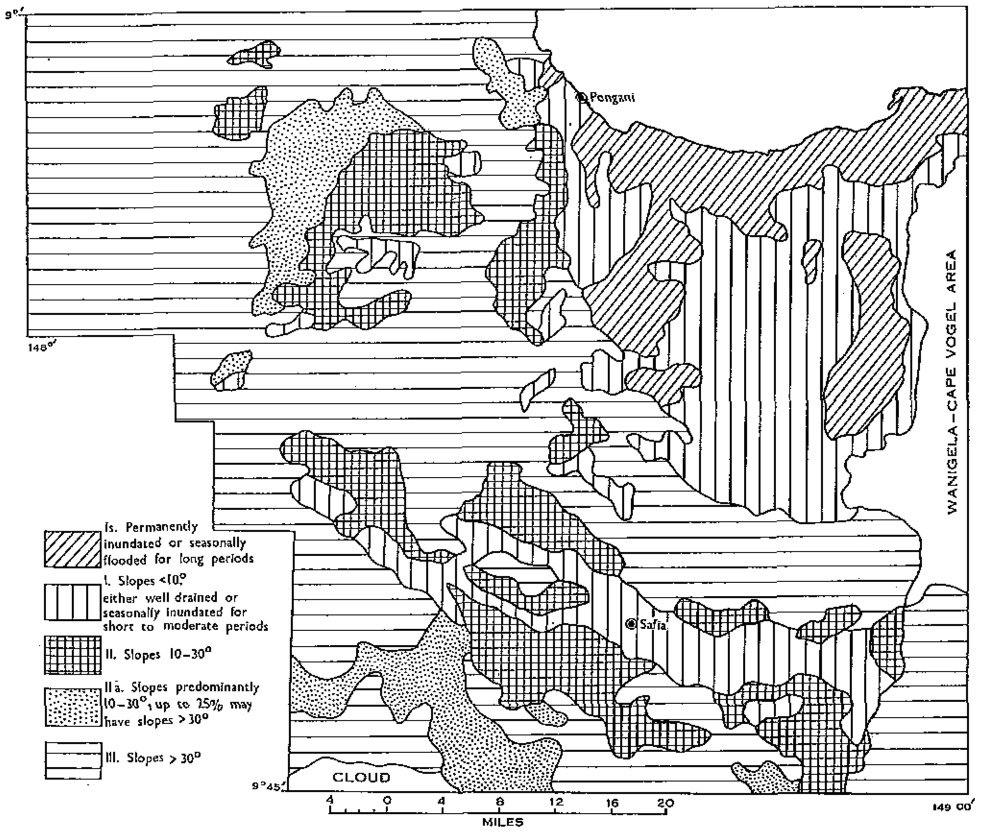


Fig. 15.—Generalized terrain categories.

## V. Classification and Description of Forest Types

The area has been subdivided into "forest" and "other areas". For the purposes of this report, a forest is defined as containing at least 3000 super ft of standing timber per acre from trees over 5 ft in girth at breast height (or above buttresses). Stands of timber excluded by this definition have thus been included in "other areas". The only exceptions to the above definition are mangrove, because of its possible value in the cutch industry; sago, as a potential source of starch; and montane forest, invaluable as a watershed protection forest.

As stated in Section II, the forests of the area fall into seven broad types of habitat — coastal, swamp, alluvium, fan, lowland hill, lower montane, and montane. Within each type of habitat the forest has been classified into forest types based on

TABLE 8

ESTIMATED STOCKING RATE AND SLOPE CATEGORIES OF THE FOREST TYPES

| Forest Type | Estimated Stocking Rate (super ft/ac) | Area (sq miles/slope category) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Is | I | II | IIa | III | Total |
| Coastal | | | | | | | |
| Mangrove | — | 60 | | | | | 60 |
| Swamp | | | | | | | |
| Sago | — | 40 | | | | | 40 |
| Alluvium | | | | | | | |
| Irregular tall alluvium forest | 5000 | | 110 | | | | 110 |
| Tall alluvium forest | 8500 | | 150 | | | | 150 |
| Total alluvium | | | 260 | | | | 260 |
| Fan | | | | | | | |
| *Casuarina* fan forest | (Moderate) | | <10 | | | | <10 |
| Mixed *Casuarina* fan forest | 8500 | | 10 | | | | 10 |
| Tall evergreen fan forest | 9000 | | 30 | <10 | | <10 | 30 |
| Mid-height fan forest | 6000 | | 10 | 10 | | | 20 |
| Low fan forest | 3500 | | 30 | | | | 30 |
| Tall mixed deciduous fan forest | 9000 | | 40 | | | | 40 |
| Total fan | | | 120 | 10 | | <10 | 130 |
| Lowland hill | | | | | | | |
| Foothill and mid-slope hill forest | 7500 | | | 30 | 10 | 520 | 560 |
| Plateau forest | 8500 | | 10 | 70 | 10 | | 90 |
| Small-crowned hill forest | 3500 | | | 20 | | 180 | 200 |
| Mixed deciduous hill forest | 6000 | | | 80 | 40 | 20 | 140 |
| Mixed *Araucaria* hill forest | (High) | | | 10 | <10 | 20 | 30 |
| *Castanopsis* hill forest | 6000 | | | 30 | <10 | 10 | 40 |
| Total lowland hill | | | 10 | 240 | 60 | 750 | 1060 |
| Lower montane | | | | | | | |
| Mixed *Castanopsis* lower montane forest | (Moderate) | | | <10 | 10 | 280 | 290 |
| Stunted lower montane forest | (Low) | | | | | 40 | 40 |
| Total lower montane | | | | <10 | 10 | 320 | 330 |
| Montane | | | | | | | |
| Montane forest | — | | | | | 10 | 10 |
| Total forested area | | 100 | 390 | 250 | 70 | 1080 | 1890 |
| Other areas | | 110 | 180 | 160 | 100 | 260 | 810 |
| Total area | | 210 | 570 | 410 | 170 | 1340 | 2700 |

characteristics observed on aerial photographs, such as density, height, and recognizable species in the canopy or emergent layers.

TABLE 9

TREES RECORDED AND THEIR FREQUENCY OF OCCURRENCE

Occurrence of trees is listed as A (abundant), VF (very frequent), F (frequent), VC (very common), C (common), or O (occasional)

| Botanical Name | Irregular Tall Alluvium Forest | Tall Alluvium Forest | Tall Evergreen Fan Forest | | Mid-height Fan Forest | Low Fan Forest | Tall Mixed Deciduous Fan Forest | Foothill and Mid-slope Hill Forest | | | Plateau Forest | Small-crowned Hill Forest | Mixed Deciduous Hill Forest | *Castanopsis* Hill Forest |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low Alt. | High Alt. | | | | Low Alt. | Med. Alt. | High Alt. | | | | |
| *Aglaia* sp. | | | C | | | | | | O | O | | | | |
| *Ailanthus integrifolia* | O | | O | | O | O | | | O | | | | | |
| *Albizia falcata* | | O | O | | | | | O | O | O | O | O | O | |
| *Aleurites moluccana* | | | | | | | | | | O | O | O | | |
| *Alstonia scholaris* | F | F | O | O | O | | C | O | O | O | C | O | C | |
| *Alstonia spectabilis* | O | | O | | | | O | | | | | | | |
| *Amoora* sp. | O | | | O | | | | | | | | | | |
| *Anisoptera kostermansiana* | | VC | C | O | C | | C | C | O | O | O | O | C | O |
| *Anthocephalus cadamba* | O | C | O | | O | O | O | | | | | | | |
| *Araucaria hunsteinii* | | | | | | | | | O | O | | O | O | O |
| *Artocarpus* spp. | | O | O | O | O | | O | O | | | O | O | | |
| *Astronia* sp. | | | | | | | | | | | O | | | |
| *Bischofia javanica* | C | O | | | | | | | | | | | | |
| *Buchanania* sp. | O | | O | | O | | O | O | | | | | | |
| *Calophyllum* spp. | | | | O | | O | | | | | | | | O |
| *Cananga odorata* | | O | | | | | O | | | | | | | |
| *Canarium* spp. | C | O | C | O | O | | O | O | C | C | | C | O | C |
| *Castanopsis acuminatissima* | | | | | | | | | C | C | O | F | | A |
| *Cedrela toona* | | O | O | | | | | O | | O | | O | O | |
| *Celtis* spp. | O | C | C | O | O | | C | O | O | O | | O | C | |
| *Cerbera floribunda* | | | | | | | | | | | | O | | |
| *Chisocheton* sp. | | | | O | | | | O | O | O | O | | | |
| *Chrysophyllum* sp. | O | | O | | | | | O | | | | | | |
| *Cinnamomum* sp. | | | O | O | | | O | O | | | O | | | |
| *Cordia dichotoma* | | O | | O | | | O | | | | | | O | |
| *Cryptocarya* spp. | O | O | C | F | O | | C | | C | C | C | O | O | C |
| *Diospyros* sp. | | | | | | O | | | | | | | | |
| *Dracontomelum* spp. | O | C | O | O | C | | O | O | | | | O | O | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ?*Drypetes* sp. | O | O | O | O | O | | | | | | | | | |
| *Dysoxylum* spp. | C | O | C | C | O | O | O | O | C | C | C | O | | O |
| *Elaeocarpus* spp. | C | C | | O | | | O | | O | O | O | O | C | O |
| *Endospermum* sp. | C | O | O | O | O | | O | | O | O | O | O | | O |
| *Erythrina* sp. | | | | | | | | | | | | | O | |
| *Eucalyptopsis papuana* | | | | | | | | | | | | O | | |
| *Euodia* spp. | | | | O | | | | | O | | | | | |
| *Ficus* spp. | F | F | O | O | O | O | C | O | | C | C | O | O | |
| *Ficus* spp. (strangler) | C | F | C | C | C | C | C | C | C | | O | O | O | |
| *Firmiana papuana* | | O | | | | O | | | | O | | O | | |
| *Flindersia* sp. | O | O | O | | | | | | O | | | | | O |
| *Galbulimima belgraveana* | | | | | | | | | | | O | | | |
| *Ganophyllum falcatum* | | | | | | | O | | | | O | | | |
| *Garcinia* sp. | | | O | | | | | | O | | | O | | |
| *Garuga floribunda* | | O | | | | | | | | | | | | |
| *Gonystylus macrophyllus* | | | | | | | | | | | O | O | | O |
| *Grevillea* sp. | | | | | | | | | | O | | | | |
| *Heritiera* sp. | | | | | | | O | O | | | | | | |
| *Hibiscus carrii* | | O | | C | | | O | | | O | O | | | |
| *Hopea* sp. | | | | | | | | | O | | | | | |
| *Horsfieldia* sp. | | | O | O | O | | O | O | | O | | O | | |
| *Inocarpus edulis* | | O | | | | | | | | | | | | |
| *Intsia bijuga* | | VC | C | | C | C | O | C | | | | O | C | |
| *Kibara* sp. | | | | | | | | | | | O | | | |
| *Lagerstroemia* sp. | | | | | O | | O | | | | O | | | O |
| *Laportea* sp. | O | | O | | O | O | O | | | | | | | |
| *Lithocarpus* spp. | | | | | | | | | | O | O | O | | VC |
| *Litsea* spp. | | | | O | | | O | | | O | | O | | O |
| *Macaranga* spp. | | | | | | | | | | O | O | O | | |
| *Mangifera* sp. | | | | | O | C | | | | | | | | |
| *Maniltoa* sp. | | O | O | | C | O | O | O | | | | O | | |
| *Microcos* sp. | | | | | | | O | | | O | | | | |
| *Myristica* sp. | | O | | | | | | | | | | | | |
| *Nauclea* sp. | | | | | O | | | | | | | | | |
| *Neonauclea* spp. | O | O | | C | O | O | O | O | | | O | O | | O |
| *Octomeles sumatrana* | F | F | C | | O | | O | | | | O | | O | |

TABLE 9 (*Continued*)

| Botanical Name | Irregular Tall Alluvium Forest | Tall Alluvium Forest | Tall Evergreen Fan Forest | | Mid-height Fan Forest | Low Fan Forest | Tall Mixed Deciduous Fan Forest | Foothill and Mid-slope Hill Forest | | | Plateau Forest | Small-crowned Hill Forest | Mixed Deciduous Hill Forest | *Castanopsis* Hill Forest |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low Alt. | High Alt. | | | | Low Alt. | Med. Alt. | High Alt. | | | | |
| *Opocunonia nymanii* | | | | | | | | | | | | O | | |
| *Palaquium* sp. | C | VC | O | O | O | C | O | O | | O | O | O | | O |
| *Pangium edule* | | | O | | | | | | | | | | | |
| *Parartocarpus venenosus* | O | O | | | | | O | O | | O | O | O | | |
| *Parinari corymbosa* | | | O | | O | | | O | | | | | | |
| *Pimeleodendron amboinicum* | | | | O | | | O | O | | | | | | |
| *Pisonia* sp. | | O | | | | | | | | | | | | |
| *Planchonella* spp. | | | O | O | | | C | O | C | O | O | | | |
| *Planchonia timorensis* | C | VC | O | | O | O | O | | | | | | O | |
| ?*Platea* sp. | | | | | | | | | | O | O | | | |
| *Podocarpus blumei* | | | | | | | | | | O | | O | | |
| *Podocarpus* sp. (amarus type) | | | | | | | | | | O | | O | | C |
| *Podocarpus* sp. (imbricatus type) | | | | O | | | | | O | O | | O | | C |
| *Pometia pinnata* | F | VF | C | | O | | | C | C | O | C | O | C | O |
| *Pometia tomentosa* | | O | | C | | | C | C | C | C | C | C | C | O |
| *Pterocarpus indicus* | O | C | O | | O | O | O | O | | | | O | | |
| *Pterocymbium* sp. | | O | | | | | C | O | O | O | | O | C | |
| *Schizomeria* sp. | | | | | | | | | | O | | O | | C |
| *Sloanea* spp. | | O | O | C | O | | C | O | C | C | C | C | O | VC |
| *Spondias dulcis* | | O | O | O | | | O | | | | | | O | |
| *Sterculia* spp. | O | O | O | | O | O | C | O | C | O | O | C | C | |
| *Syzygium* spp. | | O | C | O | O | | O | | O | O | O | O | | C |
| *Terminalia* spp. | F | F | O | O | O | C | C | O | O | O | O | O | C | O |
| *Tetrameles nudiflora* | O | O | | O | | | C | | O | | | O | | |
| *Trichadenia* sp. | | | | | | | O | | | | | | | |
| *Tristiropsis* sp. | | | O | | | | | O | | | | | | |
| *Vitex cofassus* | O | C | O | | | | O | O | O | | | O | C | |
| *Wrightia* sp. | | | | | | | | O | | | | | | |
| *Xanthophyllum* sp. | | | | | | | | O | | O | | | | O |
| ?*Xanthostemon* sp. | | | | | | | | | | | | O | | |

Table 8 lists the forest types with their estimated stocking rates and areas within each terrain category. Table 9 contains lists of trees recorded in alluvium, fan, and hill forest types.

### (*a*) *Coastal*

Mangrove occurs on category Is land and is the only forest type that has been recognized in the coastal zone.

(i) *Mangrove* (60 sq miles).—This occurs in a strip 2–3 miles wide along the coast from the Bariji River to the eastern boundary of the area, with isolated small patches along the remaining coastline. No attempt has been made to map the individual communities. Generally there is a tall community of *Bruguiera–Rhizophora*, up to 80 ft high in a narrow band bordering the dendritic pattern of stream channels. Away from the stream channels the height of the mangrove tapers rapidly to a low, often open, scrub. The best development of mangrove occurs in the Musa River delta; even here, however, the trees rarely exceed 3 ft in girth. Associated genera are *Aegiceras*, *Avicennia*, *Lumnitzera*, *Xylocarpus*, and *Nypa* palms.

### (*b*) *Swamp*

The swamp zone covers approximately 150 sq miles of category Is land, mainly on the east and west sides of the coastal plain and to the north of the plain bordering the landward edge of the coastal zone. Swamp communities include a wide range of types from floating aquatic vegetation to seasonally inundated sago communities. Only one forest type has been recognized.

(i) *Sago* (40 sq miles).—This forest type is found on land that is subject to seasonal inundation only and occurs in patches on the coastal plain mainly along the foot of the mountains and along the landward edge of the coastal zone. It consists of dense stands of tall sago palms 20–40 ft high, with scattered trees 50–60 ft high. The associated trees are generally *Nauclea* sp., *Mitragyne speciosa*, and *Ficus* spp. The lower, less dense stands of sago on wetter sites are not included.

### (*c*) *Alluvium*

The alluvium forests are virtually confined to the central part of the coastal plain and a band following the course of the Musa River. Two forest types, both occurring on category I land, have been recognized based on drainage.

(i) *Irregular Tall Alluvium Forest* (110 sq miles).—This forest is found on poorly drained areas which may be subject to seasonal flooding for moderate periods. It occurs in patches on the coastal plain and as a band along the Musa River covering the back slopes from the levees. Some scattered emergents, 125–150 ft high, occur over a rather open canopy 100 ft high. Rattan is common to abundant. Species composition is evergreen broad-leaf and mainly mixed except in some areas, such as on old flood-outs where *Octomeles sumatrana* dominates the community. The most frequently occurring species are *Pometia pinnata*, *Ficus* spp., *Terminalia* spp., *Octomeles sumatrana*, and *Alstonia scholaris*. The white crowns of *Terminalia canaliculata* are particularly noticeable along old stream channels.

Girths usually range from 5 to 7 ft except in *Octomeles* where girths of 15 ft are not uncommon. The estimated stocking rate for the type is 5000 super ft per acre from 9 trees per acre. However, in the stands of *Octomeles* the figures are much higher.

Because of the unsatisfactory moisture regime, the poorly drained alluvium forest is rarely cleared for agriculture.

(ii) *Tall Alluvium Forest* (150 sq miles).—This type is found on alluvium which is not flooded, or flooded to a slight depth for short periods. It occurs mainly in the central higher part of the coastal plain, with some patches on higher ground behind the coastal zone and on the higher Musa River levees. It has a closed uneven canopy 115–130 ft high with emergents rising to 150 ft. Rattan is present. The species composition is mixed evergreen and broad-leaf in content, the most frequently occurring species being similar to those of the irregular tall alluvium forest, but in different proportions.

Girths range from 5 to 11 ft and the estimated stocking rate is 8500 super ft per acre from 9 trees per acre.

The tall alluvium forest is cleared for agriculture but areas so affected are relatively small because of the low population in the locality.

### (*d*) *Fan*

Fan forests cover 130 sq miles on mainly category I land and are scattered throughout the area, but the largest occurrence is in the Ubo–Ibinambo fan region. Six forest types have been recognized based on structure and floristic composition.

(i) Casuarina *Fan Forest* ($<10$ sq miles).—This type occurs only on the Ubo fan. The fan is bouldery in nature and poorly drained. The forest consists of an almost pure pioneer stand of *Casuarina cunninghamiana* in various stages of development. As the fan becomes more stable and drainage conditions improve, broad-leaf species enter the forest, forming a lower layer and preventing the regeneration of *Casuarina*. The *Casuarina* attains a height of 200 ft.

Girths of the tallest trees generally range from 3 to 5 ft and in this girth class 24 trees per acre were recorded. Although no volume figure was estimated, the stocking rate is classed as moderate.

(ii) *Mixed* Casuarina *Fan Forest* (10 sq miles).—This forest is also restricted to the Ibinambo and Ubo fans and is a later stage in development than the *Casuarina* fan forest. In this type, the remaining pioneer *Casuarina* forms an open upper layer 200 ft high above a broad-leaf forest 115–130 ft high. The species composition and structure of the broad-leaf element are similar to that of the tall evergreen fan forest described later.

The estimated stocking rate for this type is 8500 super ft per acre from 11 trees per acre.

(iii) *Tall Evergreen Fan Forest* (30 sq miles).—The main occurrences of this type are on the Ibinambo and Bariji fans. Smaller areas are found in the upper Bariji and upper Musa valleys and in the Managalase. It resembles the tall alluvium forest in structure, except that the canopy is denser and emergents are taller. It is found in a wide altitudinal range of approximately 0–2500 ft and thus species composition varies markedly. At lower altitudes the most commonly occurring species are *Pometia pinnata*, *Ficus* spp., *Canarium* spp., *Octomeles sumatrana*, *Anisoptera kostermansiana*, and *Intsia bijuga*. At higher altitudes on the Ibinambo fan, the most commonly occurring species are *Cryptocarya* spp., *Pometia tomentosa*, *Ficus* spp., and *Neonauclea* sp. The canopy is dense and uneven, 115–130 ft high, with emergents often attaining 150–165 ft.

Girths range from 5 to 10 ft with occasional larger sizes and the estimated stocking rate is 9000 super ft per acre from 11 trees per acre.

(iv) *Mid-height Fan Forest* (20 sq miles).—This type occurs mainly on marginal fans to the west and south of the coastal plain and in some upland basins. There is one occurrence in the upper Musa basin. It differs from the tall evergreen fan forest in that the canopy is lower in height and crown size is smaller. Species composition is similar to that of the tall broad-leaf fan forest and girths are generally smaller, falling mainly into the 5–8-ft class.

The estimated stocking rate is 6000 super ft from 8 trees per acre.

(v) *Low Fan Forest* (30 sq miles).—This occurs on marginal fans to the west and south of the coastal plain and in upland basins. It is a more stunted version of the mid-height fan forest, with smaller crowns and lower height. Species commonly occurring are *Intsia bijuga*, *Terminalia* spp., *Ficus* spp., and *Mangifera* sp. Sites are often poorly drained.

Girths are generally small but fall into the 5–8-ft range. The estimated stocking rate is 3500 super ft per acre from 7 trees per acre.

(vi) *Tall Mixed Deciduous Fan Forest* (40 sq miles).—This occurs on the Ubo fan and on marginal fans on the south-west side of the Musa basin. Structurally it is similar to the tall evergreen fan forest, with a dense uneven canopy 115–130 ft high and emergents to 165 ft. The species composition, however, differs in the proportionately large number of deciduous trees present. The most commonly occurring species are *Pometia tomentosa*, *Ficus* spp., *Sterculia* spp., and *Terminalia* spp. *Anisoptera kostermansiana*, although common on fans at the western end of the Musa basin, is virtually absent from the Ubo fan. With *Tetrameles nudiflora*, the reverse is the case.

Girths are generally in the 5–10-ft range with occasional larger sizes occurring. The estimated stocking rate is 9000 super ft per acre from 11 trees per acre.

### (*e*) *Lowland Hill*

Lowland hill forests cover almost 40% of the area and are found below 3500 ft altitude predominantly on categories III and II land. They are subdivided partly on structure and partly on floristics.

(i) *Foothill and Mid-slope Hill Forest* (560 sq miles).—This is the largest single forest type and is found on all hill and mountain systems in the area, but the main concentration is in the north-west quarter of the area. It is predominantly an evergreen broad-leaf forest with a canopy at 100–115 ft and emergents to 130 ft. The canopy is uneven and closed to sometimes open. On foothills the species composition is very mixed, but in higher areas the ridges may be dominated by *Castanopsis* with the mixed forest relegated to side slopes and gullies. Scattered *Araucaria* emergents sometimes occur, at higher altitudes.

Because of the wide altitudinal range of this type, Table 9 shows three lists of trees recorded at low, medium, and high altitudes. At low altitudes the most commonly occurring species are *Pometia pinnata*, *P. tomentosa*, *Ficus* spp., and *Intsia bijuga*. At high altitudes, *Castanopsis acuminatissima*, *Cryptocarya* spp., *Pometia tomentosa*, and *Sloanea* spp. are the most commonly occurring species. There is no abrupt change in composition and some species occur over the whole range.

Girths are mainly in the 5–7-ft range with some larger sizes occurring. The estimated stocking rate for this type is 7500 super ft per acre from 10 trees per acre.

(ii) *Plateau Forest* (90 sq miles).—This type is confined to plateaux and gently sloping land particularly in the Managalase region, but some small areas occur near Sasaru and Silimidi. It is a tall evergreen broad-leaf forest with a dense uneven canopy at 120 ft. Emergents attain a height of 165 ft. Species composition is very mixed, the most commonly occurring trees being *Pometia tomentosa*, *Pometia pinnata*, *Ficus* spp., *Cryptocarya* spp., and *Sloanea* spp. *Anisoptera kostermansiana* is virtually absent in the Managalase.

Girths generally fall into the 5–8-ft range with some larger sizes occurring. The estimated stocking rate is 8500 super ft per acre from 10 trees per acre.

(iii) *Small-crowned Hill Forest* (200 sq miles).—This forest occurs mainly on the Sibium and Didana Ranges and in the Umwate Gap region. It is an evergreen forest with a low, often open canopy of small crowns at 70–80 ft with emergents up to 130 ft high. The emergent species are often *Araucaria hunsteinii* and *Podocarpus* spp. The canopy is composed of mixed broad-leaf species with *Castanopsis acuminatissima* often dominant on ridges. The most commonly occurring species are *Castanopsis acuminatissima*, *Pometia tomentosa*, and *Pometia pinnata*. *Eucalyptopsis papuana* was found as a locally dominant tree in a small area in the upper Musa valley.

Girths generally fall into the 5–8-ft range with some larger sizes occurring up to 10 ft. The estimated stocking rate is 3500 super ft per acre from 7 trees per acre. Where conifers occur, particularly *Araucaria*, the stocking rate rises sharply.

(iv) *Mixed Deciduous Hill Forest* (140 sq miles).—This forest is found on lower hills around the Musa basin, particularly on the southern side. Some land is completely covered but on other land it is found on side slopes and gullies with *Eucalyptus* savannah on the ridges. The canopy, 100–115 ft high, is generally open but may be dense locally and emergents rise to 130 ft. At higher altitudes *Araucaria* often occurs as an emergent. The canopy trees are broad-leaf species and deciduous trees are typically common.

Girths generally fall into the 5–6-ft range with some slightly larger. The estimated stocking rate is 6000 super ft per acre from 8 trees per acre. The presence of *Araucaria* considerably augments this figure.

(v) *Mixed* Araucaria *Hill Forest* (30 sq miles).—This type occurs in patches scattered throughout the Sibium–Didana and Owen Stanley Ranges. It is distinguished from other hill forest by the occurrence of a relatively dense emergent layer of *Araucaria* up to 180 ft high, over a broad-leaf canopy layer at 100–115 ft. The regeneration of *Araucaria* is particularly vigorous in a stand near the Ubo fan. *Araucaria hunsteinii* is the main species, with an occasional *A. cunninghamii* present; however, at high altitudes on the Goropu Mountains the hoop pine (*A. cunninghamii*) occurs in pure stands.

No plots were located in this forest type, thus the stocking rate, though probably very high, was not estimated.

(vi) Castanopsis *Hill Forest* (40 sq miles).—This type occurs mainly in the Silimidi fan–Wowo Gap region with a small occurrence in the Upper Musa. It is found above 2000 ft altitude and generally on areas with small internal relief and broad ridges. On this type of land the almost pure stands of ridge-dominating *Castanopsis* cover a high proportion of the land compared to the area occupied by mixed species in the gullies. The high proportion of *Castanopsis* distinguishes this type from other hill forests containing *Castanopsis*. Other very common species are *Lithocarpus* spp., *Sloanea* spp., and *Syzygium* spp.

The canopy at 100–115 ft is closed and is composed of small to medium-sized crowns. Emergents, often *Araucaria*, can attain a height of 130 ft.

Girths generally fall into the 5–7-ft range but some, mainly conifers, were recorded up to 14 ft. The estimated stocking rate is 6000 super ft per acre from 8 trees per acre. The presence of *Araucaria* considerably increases this figure and the plot recorded over 24,000 super ft per acre.

### (*f*) *Lower Montane*

Lower montane forests are found between 3500 ft and 9000 ft altitude, almost exclusively on category III land. Two types, of different canopy heights, have been distinguished.

(i) *Mixed* Castanopsis *Lower Montane Forest* (290 sq miles).—This occurs throughout the mountain ranges of the area between 3500 ft and 4800 ft altitude. The change from lowland hill forest is gradual and the mapping follows a slight darkening in the tone of the photo pattern. The canopy at 80–100 ft is mainly evergreen and broad-leaf in nature, with some conifers present. Emergents, mainly *Podocarpus* spp. and occasionally *Araucaria*, attain a height of 115 ft.

No plots were measured in this type but visual observations show that girths are mainly in the 5–6-ft range with some, particularly the conifers, larger. In the absence of plot data no estimate of the stocking rate was made, but by comparison with similar forest in other survey areas, the stocking rate may be classed as moderate.

*Castanopsis* is often dominant, particularly at lower altitudes in the range, and the following species are commonly present: *Araucaria hunsteinii*, *Calophyllum* sp., *Castanopsis acuminatissima*, *Cinnamomum* sp., *Cryptocarya* spp., *Elaeocarpus* sp., *Lithocarpus* sp., *Podocarpus* spp., *Rhodamnia* sp., *Schizomeria* sp., *Sloanea* sp., *Syzygium* spp., and Sapotaceae.

(ii) *Stunted Lower Montane Forest* (40 sq miles).—This occurs on all mountain ranges in the area between 4800 and 9000 ft altitude. It has an open canopy 65–80 ft high, similar in composition to the mixed *Castanopsis* lower montane forest but no *Castanopsis* is present. On air photos, patches of *Nothofagus* are noticeable on the Owen Stanley Range along the western edge of the area.

No plots were measured in this type and the forest is assumed to have a low stocking rate; however, over most of its range it is important as a watershed protection forest.

### (g) *Montane*

(i) *Montane Forest* (10 sq miles).—This type occurs on category III land between approximately 9000 and 10,000 ft altitude on Mt. Suckling. Although recognizable on the air photos, it was not visited and thus no description is given. It is non-commercial forest but its inclusion as a forest type in this report is due to its invaluable role as a protection forest. Above 10,000 ft the montane forest gives way to alpine grassland.

# PART VIII. AGRICULTURAL POTENTIAL OF THE SAFIA–PONGANI AREA

By H. A. HAANTJENS*

## I. LAND USE CAPABILITY CLASSIFICATION

The detailed land use capability classification as applied in Part II to the land units in each land system is essentially the same as that used by the United States Soil Conservation Service (Klingebiel and Montgomery 1961). It categorizes increasing *seriousness* of various hazards or limitations to land use in eight land classes (I to VIII), and subdivides these into subclasses shown by letter symbols, which indicate the *nature* of the hazard or limitation. The system is based on modern agricultural practices, not on shifting cultivation. Some modifications to suit the conditions of reconnaissance surveys in New Guinea have been discussed by Haantjens (1963).

The agricultural interpretation of the subclass symbols is presented in Appendix III. The assessment is tentative in that it had to be made in the total absence in the area of any agriculture based on modern practices. Flood hazards had to be deduced entirely from circumstantial evidence, whilst the exact significance of soil deficiencies and erosion hazards cannot be accurately gauged until some agricultural experience has accumulated.

The estimated approximate areas of land occupied by each land class and subclass, and their distribution over the land systems are presented in Table 10. Probably the most striking feature is the large area of class I land, which, moreover, commonly occurs in large contiguous units, and is particularly impressive when expressed as 5–6% of the total survey area. Its value is further enhanced by the considerable areas of class II and III land, although particularly subclass IIIe commonly occurs as small scattered areas associated with poorer land. There is remarkably little class IV and V land, but a large expanse of class VI land, much of which has a real potential for grazing or tree crops. In contrast to these considerable assets, there is also an unusually high proportion of unusable class VIII land, whilst the large areas of class VII land are generally not much better.

With regard to the subclass symbols, erosion hazards are clearly the most common limitation for agricultural development, followed by various soil limitations including moisture deficiency, slow permeability, stoniness, and alkalinity. Large areas are also affected by excessive wetness in the form of high water-tables and overflow.

Subclass symbol $s_1$, denoting unusually large deficiencies in the supply of plant nutrients from the soil, has been used only once in this report, in connection with the pure sands of recent beach ridges along the coast. There are, of course, considerable differences in chemical composition between the soils in this area (Table 5, Part V), but it seems likely that no other soils will prove to be so outstandingly infertile that they should be specially earmarked in the land use capability classification, whilst

* Division of Land Research, CSIRO, Canberra, A.C.T.

TABLE 10

ESTIMATED AREA AND DISTRIBUTION OF LAND USE CAPABILITY CLASSES AND SUBCLASSES

| Land Class | Subclass | Area (sq miles) | Areal Distribution over Land Systems |
|---|---|---|---|
| I | | 155 | Momoiogo (76), Safia (17), Liamu (17), Nembadi (15), Siviai (7·5), Ibinambo (5), Gobera (5), Boborobo (3·5), Silimidi (3·5), Aiare (2·5), Uoive (2·5), Tahama (0·3) |
| II | | 205 | |
| | e | 82 | Uoive (35), Tahama (17·5), Foasi (8), Ibinambo (5·5), Liamu (4·2), Aiare (3·5), Iwuji (3·5), Boborobo (2), Sibium (1·5), Siviai (1), Kovio (0·5), Wowo (0·3) |
| | e,$s_2$ | 3·5 | Iwuji |
| | $s_2$ | 11 | Safia (8), Iwuji (3·5) |
| | $s_3$ | 1·5 | Safia |
| | st | 18 | Nembadi (7·5), Korala (4·5), Ubo (2·5), Aiare (1·7), Boborobo (1), Tahama (0·4) |
| | d | 88 | Momoiogo (75), Nembadi (8), Safia (2), Aiare (1·3), Pawara (1), Wowo (0·4) |
| III | | 230 | |
| | e | 170 | Uoive (38·5), Aimare (16), Silimidi (15), Tahama (14), Owalama (13·5), Didana (10·5), Avikaro (10), Foasi (9·5), Arumbai (7·5), Wowo (5), Suwari (5), Iwuji (4), Amora (4), Guaya (4), Hydrographers (3), Kovio (2·5), Misima (2·5), Sibium (2), Fiobobo (1·5), Siviai (1), Liamu (0·7), Banderi (0·5) |
| | e,$s_3$ | 10 | Arumbai (9), Asaga (1) |
| | $s_2$ | 10 | Safia (7), Nembadi (1·5), Iwuji (1), Momoiogo (0·7) |
| | st | 7 | Ubo (2·5), Aiare (1·7), Boborobo (1·5), Siviai (1) |
| | d | 4 | Nembadi (3), Safia (1), Pawara (0·5) |
| | f | 23 | Momoiogo (22), Boborobo (1) |
| | d,f | 5 | Korala |
| IV | | 60 | |
| | e,$s_2$,$s_3$ | 10 | Fiobobo (8), Avikaro (2) |
| | $s_3$ | 3 | Aiare (1·3), Boborobo (1), Asaga (1) |
| | $s_2$,$s_3$ | 3 | Asaga |
| | a | 7 | Ubo |
| | f | 11 | Gobera (6), Aiare (2·5), Nembadi (1·5), Imo (0·5), Tahama (0·3) |
| | d,f | 1 | Imo |
| | d,a | 7 | Ubo |
| | f,a | 10 | Dove |
| | d,f,a | 9 | Dove |
| V | | 40 | |
| | st | 11 | Korala (4), Ubo (3), Siviai (1), Asaga (1), Sibium (0·7), Kovio (0·5), Safia (0·5), Aiare (0·3) |
| | st,a | 8 | Ubo (7·5), Ibinambo (1) |
| | d | 5 | Nembadi (3·5), Siviai (0·7), Pawara (0·7) |
| | d,f | 3 | Imo (2·5), Gorabuna (0·3) |
| | d,a | 10 | Ubo (8·5), Dove (1) |
| | d,$s_3$ | 3 | Gobera |

TABLE 10 (*Continued*)

| Land Class | Subclass | Area (sq miles) | Areal Distribution over Land Systems |
|---|---|---|---|
| VI | | 465 | |
| | e | 166 | Avikaro (30), Aimare (21·5), Guaya (16), Silimidi (15), Boborobo (11·5), Didana (10·5), Uoive (8), Misima (6·5), Wowo (6·5), Foasi (5·5), Suwari (5), Hydrographers (4·5), Amora (4·5), Siviai (4·5), Tahama (4·5), Sesaro (4), Banderi (3·5), Kovio (2), Gorabuna (2), Darumu (1) |
| | e,$s_2$ | 78 | Avikaro (25), Arumbai (12·5), Asaga (12), Darumu (9·5), Fiobobo (8), Korala (3·5), Banderi (3), Misima (2), Uoive (1·5), Nembadi (1) |
| | e,$s_3$ | 20 | Amora (19), Arumbai (0·7) |
| | e,$s_2$,$s_3$ | 36 | Asaga (31), Darumu (3·5), Aimare (1·5) |
| | e,st | 18 | Fiobobo (12), Didana (4·5), Sesaro (0·7), Sibium (0·7) |
| | $s_2$ | 13 | Gobera (6), Nembadi (2·5), Liamu (1·7), Safia (1·5), Momoiogo (0·7), Iwuji (0·4) |
| | $s_2$,$s_3$ | 13 | Korala (11), Boborobo (2) |
| | st | 4 | Uoive (3), Korala (1·4) |
| | st,a | 4 | Ubo (2·5), Ibinambo (1·5) |
| | d,f | 21 | Tortore (12), Imo (5), Gobera (2·5), Momoiogo (1) |
| | f,a | 3 | Dove |
| | d,f,a | 85 | Dove |
| | d,$s_3$ | 4 | Asaga (2·5), Avikaro (1) |
| | f,st | 4 | Aiare (2·5), Nembadi (1), Ubo (0·5), Gorabuna (0·4) |
| VII | | 685 | |
| | e | 227 | Guaya (38), Tahama (33), Amora (30), Owalama (20), Suwari (15), Avikaro (14), Aimare (13), Gorabuna (12·5), Suckling Complex (10), Uoive (8·5), Kovio (7), Hydrographers (5), Sibium (5), Siviai (5), Foasi (4·5), Misima (4), Silimidi (2·5), Wowo (0·5) |
| | e,$s_2$ | 302 | Fiobobo (83), Didana (65), Arumbai (45), Sesaro (36), Uoive (16), Avikaro (13), Aimare (13), Manna (12), Bariji (7), Asaga (6), Adau (3), Misima (1·5), Banderi (1), Iwuji (0·7) |
| | e,st | 3 | Sibium |
| | $s_2$ | 2 | Liamu (1·7), Iwuji (0·4) |
| | $s_1$,$s_2$ | 2 | Bendorodo (1), Pawara (0·5) |
| | st,a | 3 | Ubo (2·5), Ibinambo (1) |
| | d | 3 | Boborobo (1·5), Pawara (1) |
| | d,f | 81 | Tortore (80), Momoiogo (1) |
| | d,a | 11 | Tortore |
| | d,f,a | 47 | Tortore |
| VIII | | 805 | Misima (106), Fiobobo (86), Bendorodo (60), Owalama (55·5), Suckling Complex (50), Arumbai (47), Hydrographers (43), Foasi (42), Amora (37), Sesaro (33), Tahama (30), Guaya (26), Suwari (20·5), Bariji (17), Gorabuna (13·5), Aimare (13·5), Manna (12·5), Kovio (7·5), Adau (6·5), Siviai (5), Darumu (4), Silimidi (3), Sibium (2·5), Gobera (2·5), Safia (1·5), Uoive (1·5), Bandera (1), Dove (1), Nembadi (1), Tortore (1), Ibinambo (0·7), Ubo (0·7), Pawara (0·5), Wowo (0·5) |

on the other hand nearly all of them will require some measure of fertilizer application when brought into continuous use for crop production. Especially at this stage, when there is no experience at all with fertilizer responses, it is too hazardous to express a definite opinion on this matter.

## II. Regional Potential for Agricultural Development

The great variation in terrain and soil conditions in the Safia–Pongani area generally causes land use capability to vary over short distances. Nevertheless, distinct regional differences in pattern emerge. These are in the first instance related to the land systems, each of which has been individually assessed in Part II in terms of possibilities for the production of crops, livestock, and timber. A broader regional picture is obtained by the combination of land systems into the 12 land use capability groups shown on the map of regional potential for agricultural development. In considering this map it should be borne in mind that the areas shown in the same colour are generally not homogeneous, and that a land system may have been placed in a group either because it consists mostly of land of a corresponding level of land use capability, or because it comprises a mixture of better and poorer land.

*Land Use Capability Group 1.*—A large proportion of the land in this group is very good and should offer excellent prospects for a great variety of uses. Other parts appear to require slight drainage improvement, particularly for tree crops, in order to reach optimal productivity. Small areas have moisture-deficient and less fertile gravelly or sandy soils, or have overflow hazards. It should be noted that this group represents the largest area of very good land ever found in one survey area, and that its value is enhanced by its occurrence as large complexes, which should facilitate large-scale development. Land systems combined in this group are Momoiogo, Safia, Liamu, and Ibinambo. Lack of field data makes inclusion of Ibinambo land system in this group rather tentative, and its land use capability may not be as high as that of the others.

*Land Use Capability Group 2.*—Mainly due to steeper slopes and stronger dissection, the possibilities for agricultural development are more limited than in group 1. Large parts have a high potential for tree crops and grazing, but such land is commonly interspersed with ravines or steep hills that are best kept in forest. This feature will tend to make land subdivision and management more complicated. Whilst many narrow strips of reasonably level land are theoretically suitable for cultivation, arable crops are probably best restricted to a few more extensive complexes of undulating terrain. Some erosion-control measures appear to be required almost everywhere. Soil limitations include local stoniness and some moisture deficiencies in parts of Iwuji and Uoive land systems, and probably below-average soil fertility in Silimidi land system. As a whole the area encompassed by group 2 should, however, be capable of sustained high productivity.

*Land Use Capability Group 3.*—Although topographically eminently suitable for intensive development, cultivation will commonly be difficult or impossible because of stoniness of the land surface. The alkalinity of the soils would seem to be a limitation for many tree crops. Poor drainage will further restrict the possibilities for arable crops and tree crops in the western part of the land in this group, which includes only

Ubo land system. None of these factors is expected to limit pasture development, particularly if this includes a leguminous component well suited to the calcareous soils. This group is therefore judged to have a high potential for grazing. Any tree crops adapted to alkaline soils could also be successfully grown. Irrigated rice would be an alternative possibility to pastures on poorly drained land.

*Land Use Capability Group 4.*—This group includes land of a similar nature to that of group 2, but with a lower potential all round, because of a greater proportion of steep slopes. Only small areas, mainly in Boborobo and Siviai land systems, offer any practical possibilities for arable crops. Deep friable soils, particularly the ash soils in Tahama land system, appear to be eminently suitable for tree crops, although chemical soil fertility may in some cases be below average, particularly in Boborobo land system. Because of the difficult topography, most land in this group is only moderately suitable for tree crops or grazing, with the steepest slopes, particularly in Siviai, Wowo, and Tahama land systems, best left in forest. Careful management is required to avoid erosion and the possibilities for mechanization are strictly limited, except for aerial operations in establishment and maintenance of pastures.

*Land Use Capability Group 5.*—Although topographic conditions are favourable, the land in this group is generally moderately suitable only for improved pastures. Limiting factors are slowly permeable, poorly drained soils in Korala and Gobera land systems, very sandy soils with high water-tables in Pawara land system, flood hazards in Gobera land system, and gravelly and stony soils in Korala and Gobera land systems. Removal of these limitations would be very difficult and land use must be adapted to them. Establishment and maintenance of improved pastures may meet with some difficulties in parts of Korala land system, because of the very poor physical soil properties and microrelief. Small areas in this group are more suitable for tree crops and arable crops. Coconut palms are probably the only tree crop suitable in Pawara land system.

*Land Use Capability Group 6.*—Nearly all land in this group is too steep for cultivation and most soils are too shallow and deficient in moisture for tree crops. Low soil fertility appears to be a further limitation in Banderi land system, and instability of many slopes in Avikaro land system, whilst some areas in this land system have slowly permeable soils. None of these limitations seems to be particularly serious for grazing, for which this land is judged to have a moderate capability. Numerous small creeks could supply water for cattle, whilst there is also ample scope for the construction of dams. Cultivation of tree crops would be possible where there are deeper soils.

*Land Use Capability Group 7.*—Flood hazards and/or poor drainage render this land moderately suitable only for grazing. Although the topography is level and the soils fertile, most of the land is too wet to be used during the rainy season, whilst on the drier Musa River levees in Dove land system flooding* makes intensive management difficult. Here, as well as on the driest parts of Imo land system, quick-growing arable crops may offer possibilities. Land reclamation seems possible only

* There is a possibility that flood hazards along the lower Musa River have become much smaller since the major breakthrough at Garagarata has greatly reduced the flow in the main channel.

by major works, which include thorough improvement of the surface drainage by a network of small and large drainage channels. Flood protection may require local construction of levee banks and probably the diversion of the Musa River to the swamps east of the present levee belt. Most reclaimed land in Imo land system would be suitable for arable crops and to a lesser extent for tree crops. In Dove land system the high alkalinity of the soils may limit the possibilities for arable crops, and strongly restrict those for tree crops. Proper water control would render much land in this group very suitable for irrigated rice.

*Land Use Capability Group 8.*—Land use potential in this group is mainly limited by poor physical properties of the soils, which are also stony in places. Temporary waterlogging after heavy rain is common, whilst nearly all the soils are susceptible to drought, the more so as this group occurs in the low-rainfall zone of the Musa basin. In places, moreover, slopes are too steep for cultivation. Most of this land appears to be moderately suitable for grazing. Pasture improvement is needed to increase productivity, but this is likely to meet with some difficulties, particularly since the soils appear to be of low fertility. This group comprises Darumu and Asaga land systems.

*Land Use Capability Group 9.*—Much too steep for cultivation, but generally having deep friable soils, this rugged land has only a low potential for tree crops or grazing. Comprising important catchment areas, it is generally best left under protection forest, but pockets of land with less steep slopes, occurring in all component land systems, could be worth utilizing, particularly for tree crops, although pastures may be safer in Aimare land system because of risk of landslides and soil slips. Other land systems in this group are Sibium, Suwari, Kovio, and Guaya.

*Land Use Capability Group 10.*—Similar in steepness to group 9, this land is unsuitable for tree crops because the soils are shallow or physically poor. Extensive grazing forms the only possible form of agricultural development, particularly in Arumbai land system, on less steep crestal areas around Fiobobo in Fiobobo land system, and in parts of Amora land system with somewhat gentler slopes. Such development would not be unreasonable, as these areas are already largely covered with savannah, grassland, or regrowth. The greater part of the land in this group, however, is best left in protection forest, for it includes important catchment areas.

*Land Use Capability Group 11.*—This group comprises swamp land of Tortore land system unusable for agricultural purposes in its present condition. Reclamation would be difficult, but may be possible in major projects involving the construction of large drainage channels and, in the lowest areas near the coast, also empoldering. The large swamp west of the Musa River could only be drained after blocking of the Garagarata breakthrough and construction of a levee bank along the left bank of the river, or after diversion of the Musa River towards the east. As the swamps appear to be largely fed by rivers, efficient water control in the western part may be possible only in conjunction with flood control in the higher reaches of the Korala, Imo, and Bariji Rivers. The generally very plastic clay soils of the swamps make it doubtful if the reclaimed land would be suitable for uses other than pastures and irrigated rice. Particularly in the northern and eastern sectors, alkaline soils would further limit the suitability of this land for arable crops and particularly for tree crops. The possibility of converting parts of these swamps into fish ponds could be investigated. The merits of drainage or regulation of water levels in the swamps could only be assessed by a general hydrological survey of the coastal plain.

*Land Use Capability Group 12.*—This group comprises land with virtually no possibilities for agricultural development. It includes the mangrove swamps of Bendorodo land system, which are difficult to reclaim because of the small tidal range and sandy substrata — this could cause salt water seepage — and not worth reclaiming because of the very poor soils. The remainder of the group comprises the most rugged parts of the survey area — Bariji, Manna, Adau, Gorabuna, Owalama, Hydrographers, Sesara, Didana, Misima, and Suckling Complex land systems. These are mostly important catchment areas that should be left under protection forest. Certain areas in this group, particularly Adau and Suckling Complex land systems, are very scenic and could be of importance in the development of a tourist industry.

## III. Influence of Climatic Variations on Agricultural Potential

Limitations to land use imposed by climatic conditions are not directly accounted for in the land use capability classification used in this report. Regional differences in climate should always be considered in the practical implementation of the land use capability predictions. For instance, class I land may be cultivated throughout the year in areas with a well-distributed rainfall, but only during the wet season where there is a marked dry season. The suitability of such land for particular crops may also vary with differences in rainfall and cloud cover, and with variations in temperature at different altitudes.

It is impossible to go into any details of the effects of climate on land use capability in the Safia–Pongani area, because meteorological data are almost completely lacking. In most of the area, with a probable mean annual rainfall from 80 to 150 in., serious water stress in crops can be expected only in exceptional years. Even in the Musa basin, where the mean annual rainfall may locally be as low as 60 in., moisture deficiencies are not likely to be a major limitation to land use. These remarks apply to crops grown on deep soils with a good water-holding capacity. On shallow or coarse-textured, as well as on compact heavy clay soils, long dry spells will cause more damage, particularly in the lower-rainfall areas. This is borne out by soil and vegetation observations in the dry zone of the Musa basin, particularly in Darumu, Asaga, Avikaro, Adau, Arumbai, Fiobobo, and Avuru land systems, and along the western margin of the coastal plain in parts of Nembadi, Iwuji, and Banderi land systems. In all these areas, measures to reduce run-off (contour ridges and ditches, terrace benches) and to conserve water (mulching, compost, fallow, spacing) would be profitable but are commonly not practicable. Most of this land therefore has been judged suitable only for grazing or forestry.

From the few data available it would seem that the lower rainfall in the Musa basin is not so much due to the presence of a well-defined dry season as to great irregularity in rainfall. Falls varying from 1 to 13 in. can be expected in most months except July and October, which appear to be more consistently dry, and March and August, which appear to receive consistently more than 4 in. This irregularity would probably pose greater problems for arable farming than for pastures or tree crops, although it seems that deep-rooting arable crops could be grown without serious risks of drought damage on good soils in Safia and Liamu land systems in most years. Nevertheless, significant increases in yield and full protection against dry spells may result from the application of supplementary sprinkler irrigation on the flat land in the Musa valley. Adequate water supplies appear to be available from several large perennial streams, and probably also from ground-water resources of good quality.

Although there are indications that the rainfall in the coastal plain is not a great deal higher than in the Musa basin, the topographic situation is such that a more pronounced contrast can be expected between a long reliable wet season and a short moderately dry season during the winter months. Thus, crop rotations could be more confidently based on seasonal variations. As most soils have, moreover, a high water-holding capacity and crops locally can also draw on shallow water-tables, there seems to be little reason for supplementary irrigation in this area.

Notwithstanding the great variation in altitude within the survey area, agricultural development will be concerned almost completely with lowland crops because the high country is too rugged for exploitation. There are only a few exceptions to this. Broad upper crests above 3500 ft in Foasi land system would be suitable for highland crops, but these are so inaccessible that this is of little or no practical significance. Crops such as tea and possibly highland coffee could be grown in the highest eastern parts of Silimidi land system (up to 3500 ft), and the highest northern parts of Tahama land system (up to 3200 ft).

## IV. Population Distribution and Land Use Capability Groups

The map of regional potential for agricultural development shows the distribution and size of Papuan villages in the Safia–Pongani area. It can be expected *a priori* that the correlation between land use capability groups and population density will be far from perfect, because the groups are based on possibilities for permanent land use with modern agricultural practices, whilst the Papuan population is wholly dependent on shifting cultivation for its subsistence.

The main concentrations of population are in the Managalase area in land use capability groups 2 and 4, in the Kumusi trough in group 9, in the Musa basin in groups 1, 5, 6, and 9, and near the coast in groups 1 and 5. These areas are separated by almost uninhabited mountain ranges in groups 9, 10, and 12. Whilst Papuan settlement in the hilly areas of groups 2, 4, 6, and 9 is to be expected, because this land can generally be considered as very suitable for shifting cultivation, it is interesting to note that it remains so localized. In group 2, Uoive land system is densely settled, but Iwuji and Silimidi land systems are unpopulated. In group 4 many villages occur in Tahama land system, very few in Boborobo and Siviai land systems, and none in Wowo land system. All areas of group 6 appear to be under-settled in relation to their potential for shifting cultivation. This is in contrast to many other areas in New Guinea* where this type of terrain has tended to become over-populated.

* For example the Maprik area, Sepik District; Bagasin and Bogia areas, Madang District; Cape Vogel area, Milne Bay District; eastern Wahgi valley and Bena Bena areas, Eastern Highlands District.

In group 9 only Kovio land system is densely populated and sparse settlement occurs in Aimare land system, whilst Sibium, Suwari, Guaya, and Foasi land systems are nearly or completely empty. This is understandable for the last two land systems, which include large areas in the cold, wet, cloudy lower montane zone, but not for the others.

In general, the physical differences between land systems in the same land use capability group are not great enough to explain these large differences in population density. Historical and social factors are likely to be mostly responsible, but it is probably not pure coincidence that the areas with the densest population are all young volcanic areas or largely covered with volcanic ash. It is interesting to note the almost complete lack of villages in the eastern part of the Musa basin, although conditions for shifting cultivation in groups 1, 2, and 4 in this area appear to be good. A similar situation occurs on the plains north of Mt. Suckling (Wanigela–Cape Vogel area). It is possible that taboos connected with this imposing mountain are mainly responsible; they may have a realistic foundation in the danger of catastrophic landslides.

Notwithstanding the concentration of the population in well-defined areas, settlement is by no means static. Large areas of secondary grassland suggest the possibility of formerly denser population in Iwuji, Nembadi, Safia, and parts of Momoiogo land systems (groups 1 and 2). There are also indications of a larger population in a more recent past in the isolated small basins of Boborobo land system (group 4), where emigration to the coastal plain and the Musa basin has reached its last stages. Conversely, in the Musa basin, villages in the peripheral area are gradually moving towards the centre of the basin.

The very sparse settlement in the mountains of groups 9, 10, and 12 has already been mentioned. In group 10 this is probably due to the predominance of poor shallow soils, which, together with a commonly rather low rainfall and in many places a eucalypt savannah vegetation, makes this land as unfavourable for shifting cultivation as it is for arable crops or tree crops. Unfavourable soil, vegetation, and climate conditions are almost exclusively responsible for the lack of Papuan settlement on group 8. Finally, Papuan settlement is absent or very sparse in the mangrove swamps of group 12 and the freshwater swamps and poorly drained plains of groups 11 and 7, although a number of villages occur along the lower Musa River on the best-drained land in group 7.

The best land in the area — in group 1 — is mostly only sparsely settled, but it is a feature of this group that villages are widely distributed throughout its area. Nembadi land system is the most densely populated land system in this group, but this is as much due to its position along the coast as to its fertile soils. The distribution of settlement in group 1 clearly illustrates a point that also holds good in most other parts of the area: villages are commonly situated along the margins of the land use capability groups, near the boundary between two contrasting types of terrain. The low population density in group 1 follows a pattern that is common throughout New Guinea. Although crop yields are high, land clearing is more difficult because of the very tall forest and level topography. But the main reasons for the smaller population on most alluvial plains are probably a higher incidence of malaria, greater difficulties in the past to defend villages against raiders, and less pleasant living conditions than in the mountains.

## V. Communications

In the absence of any road network in the area, problems of accessibility of areas offering scope for agricultural development are of the greatest importance. The position is summarized in Table 11, in which a distinction is made between the difficulties that can be expected in constructing roads *within* a land system, and the problems involved in bringing roads *to* a land system.

### (*a*) *Road Construction within Land Systems*

Obstacles to road construction occur in nearly all land systems. They appear to be slight only in Liamu, Ubo, Ibinambo, and Iwuji land systems. The kinds of obstacles encountered vary greatly in different parts of the area and include rugged terrain, unstable slopes, scarcity of road building materials, drainage deficiencies, and river crossings.

(i) *Ruggedness*.—In this area with its high proportion of rugged terrain, difficult topographic conditions are the principal reason for great or very great problems in road construction in 25* out of the 45 land systems described. Factors determining the seriousness of the problem are not only slope steepness, but also the magnitude of the relief, the density of dissection, and the arrangement of the slope elements. Given the same slope and relief conditions, road construction will be easier where there exists a pattern of interconnecting or parallel ridges or valleys than where the country is very irregularly broken. These somewhat more favourable conditions exist in Tahama land system with its long north–south ridges, in Silimidi land system, and in the central part of Fiobobo land system, where a road from the coastal plain to the Musa basin would have to negotiate very steep marginal ascents but could follow fairly low gradients along most of the way across.

(ii) *Slope Stability*.—Within a given range of slope steepness, road construction and particularly road maintenance will be less costly on stable than on unstable slopes. Serious risks of landslides or soil slips are likely to add greatly to the problem of road building in Avikaro, Aimare, Misima, and Suckling Complex land systems, and to a lesser degree in Kovio, Gorabuna, Foasi, and Amora land systems. No particular stability problems are to be expected on steep slopes in Bariji, Manna, Adau, Arumbai, Fiobobo, Avuru, Sesaro, and Didana land systems, where rock weathering is shallow. The position is more unpredictable in Sibium, Siviai, Silimidi, Wowo, Suwari, Tahama, Owalama, Guaya, and Hydrographers land systems, where deep weathering is common, but the latosolic soils appear to form fairly stable slopes.

(iii) *Road-building Materials*.—Generally this will not be a problem in the area. The abundance of basalt, hornfelsed basalt, and basic–ultrabasic rocks will provide an adequate supply of road metal in most areas. Even where these rocks are deeply weathered, suitable quarry sites may generally be found near incised streams. In

* These land systems are Sibium, Siviai, Silimidi, Wowo, Suwari, Avikaro, Aimare, Bariji, Manna, Adau, Arumbai, Fiobobo, Avuru, Tahama, Kovio, Gorabuna, Owalama, Guaya, Foasi, Hydrographers, Amora, Sesaro, Didana, Misima, and Suckling Complex.

TABLE 11

ACCESSIBILITY OF LAND SYSTEMS IN THE SAFIA–PONGANI AREA

(Explanatory notes in the text)

| Land System | Problems of Road Construction in Land System | Problems of Access to Land System |
|---|---|---|
| Pawara | Moderate | Slight |
| Bendorodo | Great | Slight |
| Tortore | Very great | Slight |
| Imo | Great | Slight |
| Dove | Great | Slight |
| Momoiogo | Moderate | Moderate |
| Gobera | Great | Moderate |
| Aiare | Great | Very great |
| Nembadi | Moderate | Slight |
| Safia | Moderate | Moderate |
| Liamu | Slight | Moderate |
| Ubo | Slight | Moderate |
| Korala | Moderate | Moderate |
| Boborobo | Moderate | Great |
| Sibium | Very great | Very great |
| Ibinambo | Slight | Moderate |
| Siviai | Great | Great |
| Silimidi | Great | Moderate |
| Wowo | Very great | Moderate |
| Suwari | Very great | Very great |
| Darumu | Moderate | Great |
| Iwuji | Slight | Slight |
| Uoive | Moderate | Great |
| Asaga | Moderate | Moderate to great |
| Banderi | Moderate | Slight |
| Avikaro | Very great | Moderate to great |
| Aimare | Very great | Very great |
| Bariji | Very great | Great |
| Manna | Very great | Moderate |
| Adau | Very great | Moderate |
| Arumbai | Great | Moderate to great |
| Fiobobo | Very great | Moderate |
| Avuru | Very great | Very great |
| Tahama | Great | Great |
| Kovio | Very great | Moderate |
| Gorabuna | Very great | Very great |
| Owalama | Very great | Very great |
| Guaya | Very great | Great |
| Foasi | Very great | Very great |
| Hydrographers | Very great | Slight |
| Amora | Very great | Great |
| Sesaro | Very great | Moderate |
| Didana | Very great | Very great |
| Misima | Very great | Great |
| Suckling Complex | Very great | Moderate |

addition to this, river gravel deposits of varying size occur throughout a large part of the area. It would appear that suitable subgrade is available in many places in the form of poorly sorted colluvial deposits and weathered rock. Partly weathered volcanic ash may also be suitable for this purpose. Excavated material removed from road cuttings is probably mostly usable as fill. Because of their montmorillonite content, shallow clayey soils are generally less suitable for fill than the deep kaolinitic red and brown soils, which may, however, require stabilization to prevent erosion.

In sharp contrast to this generally favourable situation is the almost complete absence of road-building material in the coastal plain. There is virtually no gravel and only a limited supply of mainly fine sand, whilst the silty and clayey surface soils appear to have little bearing strength. Both subgrade and metal will have to be brought in from basalt areas, fans, and river terraces to the west. Because of this, road-building difficulties have been assessed as moderate in Momoiogo land system. Lack of road-building material similarly adds to the problems in Imo, Dove, and Tortore land systems, but to a lesser degree in Pawara and Bendorodo land systems, where at least large quantities of sand are available. Good-quality road metal also appears to be scarce in Tahama land system, but here large supplies are closer at hand in the surrounding land systems.

(iv) *Drainage Conditions*.—High water-tables and/or periodic inundations pose problems to road building, particularly in Bendorodo, Tortore, Imo, and Dove land systems, but also in Pawara and locally in Gobera, Ubo, and Boborobo land systems. Unless extensive reclamation projects are carried out, roads in these areas will have to be built up above normal flood level and provided with numerous culverts and drainage ditches. Under the present conditions road construction in Bendorodo and Tortore land systems should be limited to unavoidable short stretches necessary to establish vital connections. Similarly, roads should avoid Imo and Dove land systems wherever possible.

Drainage problems caused by slowly permeable heavy clay soils can be expected in large parts of Korala, Darumu, and Asaga land systems and locally in Boborobo land system. Good surface drainage as well as thick subgrades and probably removal of clay horizons may be necessary to avoid damage to road surfaces after wet periods.

(v) *River Crossings*.—The dense stream pattern in the area renders a large number of bridges or causeways a necessary part of the road-building programme in most parts. Any road in the hilly and mountainous land systems is likely to require a large number of culverts and small bridges. Fewer but larger bridges are needed in the plains, particularly in Gobera and Aiare land systems but also in Nembadi and Safia land systems. On the other hand, bridging of rivers will be a minor problem in such level to rolling land systems as Momoiogo, Liamu, Ubo, Korala, Boborobo, Ibinambo, Iwuji, and Asaga. Bridging of some of the larger braided rivers in plains, such as the Pongani River and the Musa River and its tributaries in the Musa basin, will be complicated by the great increase in width of river beds during floods and by a tendency of some of these rivers to shift their main channel.

### (*b*) *Regional Communications**

As the whole of the area is at present inaccessible to motor traffic, the terms used

* See also Figure 1.

to define access to land systems in Table 11 obviously do not refer to the present situation, but indicate possibilities for future road access based on certain assumptions about the opening up of the area.

(1) Road links with the areas of highest agricultural and forestry potential will be required most urgently. These areas are the coastal plain, the Managalase, and the Musa basin.

(2) Access to the coastal plain and the Managalase is best provided from the north, either by a coastal road from Oro Bay (north of the survey area), or by a road across the lower Musa River from Porlock Harbour (east of the area), or by establishing port facilities at Songada or Foru. In view of the imminent improvement of Oro Bay as a harbour, the first of these appears to be the most probable, the more so because it would provide the shortest link with the Managalase area. The construction of a trunk road along the sharply indented hilly coastline of the Hydrographers Range would be a major project, even though the aerial distance between Oro Bay and Pongani is only 13 miles, and landslide risks appear to be small. As far as the Managalase is concerned, a connection with Oro Bay would be simpler than a route to Popondetta through rugged country between Mt. Lamington and the Hydrographers Range. In Table 11 all land systems that can be easily connected to an Oro Bay road-head in the vicinity of Pongani have been defined as easily accessible, whilst those that are further away or separated from the coast by topographic barriers such as mountains or swamps have been classified as progressively less accessible.

(3) Access to the Musa basin is practicable only along two routes. The simplest is from Collingwood Bay — with harbour facilities probably at Sinapa (east of the survey area) — via the Goropu coastal plain (Wanigela–Cape Vogel area) through Wowo Gap. The second route is from the Musa coastal plain via the hills of Fiobobo land system south of Ovessa, and crossing the Musa River somewhere in Gobera land system. Which of these routes will be chosen depends largely on the relative rate of development in the Goropu and Musa coastal plains. Because of the greater problems involved in bringing access roads to the Musa basin than to the coastal plain, land systems that can be easily connected to road heads either in Wowo Gap or at a bridge on the Musa River have been classed as only moderately accessible, and those that are not, as having great or very great access problems.

(4) Any road link of the western part of the area with the Popondetta–Kokoda road (north-east of the survey area) would be very difficult, except from the north-western edge of Kovio land system. Such a road would, moreover, mostly traverse land without possibilities for agricultural development. On the other hand, widespread development in Tahama land system could create the incentive for road construction to the south, to Sibium land system, the Aiare basin, and the south-eastern part of Kovio land system.

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## APPENDIX 1

### Use of the 7th Approximation in the Soil Classification in the Safia–Pongani Area

By H. A. Haantjens*

Generally the 7th Approximation provided a convenient and meaningful framework for the classification of the wide range of soils found in this complex area. However, it was impossible in some cases to place the soil families with certainty into the categories of the 7th Approximation, either because of lack of data or because of difficulties encountered with the system itself.

Tentative new higher category names using the 7th Approximation's nomenclature system were given to several soil groups that are either represented only by number in the 7th Approximation (Ochrudox) or not represented at all (Lithic Hapludolls, Ochrustox, Orthic Ochrandepts, Spodic Ochrandepts, Orthic, Aquic, and Argillic Ochrustox, Lithic, Orthic, Ustic, and Argillic Ochrudox). Such tentative names are given in brackets in Table 4.

#### (*a*) *Problems Caused by Lack of Data*

It was necessary to complete the classification of the soils before analytical data were available. Such data as became available later did not cover all the soil families, nor did they always include all the information required for the differentiae used in the 7th Approximation. Moreover, the observations on soil samples obtained from auger holes, made necessary by the rapid survey methods and absence of soil exposures, precluded obtaining reliable information on such morphological soil characteristics as the nature of horizon boundaries, structure, and presence of cutans. All these restrictions made it necessary to modify some of the differentiae prescribed in the 7th Approximation.

pH was substituted for base saturation in distinguishing between mollic and umbric epipedon, Alfisols and Ultisols, Ustox and Udox, Eutric and Orthic Dystrochrepts. Profiles with a minimum pH of 6 were considered to be more than 50% saturated, profiles with pH 5–6 as having more than 25% saturation, and profiles with a maximum pH of 5·5 as having less than 25% saturation. With few exceptions these assumptions were confirmed by later chemical data (Table 5). The exceptions concern the Mioki and Silimidi families of the Orthic Ochrustox, which combine weakly acid to neutral reaction with low base saturation. As the classification has been set up on the basis of pH rather than base saturation, these families have to remain in the Ochrustox great group.

Even when base saturation data became available it was not possible to distinguish with certainty between Alfisols and Ultisols. In the first place, no samples had been collected of the latter, which are not widespread in the area. In the second place,

* Division of Land Research, CSIRO, Canberra, A.C.T.

saturation percentages in this report are based on direct determination of the C.E.C. and not on its determination by summation of bases and hydrogen as prescribed in the 7th Approximation for the distinction between Alfisols and Ultisols.

The presence of a mollic or umbric epipedon was assessed solely on colour and structure. In all cases, however, this was confirmed by organic carbon figures becoming available later, even though these were sometimes lower than those reported for ochric epipedons. The C/N ratio limit of 17 in distinguishing between mollic and umbric epipedon proved useless: all samples except one (a Dystrochrept) have ratios well below 17.

Mineralogical differentiae as used in the 7th Approximation to distinguish between Dystrochrepts and Oxisols were not available in time and are very meagre even at this stage. Instead of from such data, the weathering status of the soils in question was assessed from their texture — clay to heavy clay in Oxisols,* silty clay or coarser texture in Dystrochrepts — and from the presence or absence of significant amounts of little-weathered rock fragments, which seems to be related to site stability. The clay mineralogy, which is important in the definition of the Oxisols, could be assessed initially only from colour, structure, and consistency in relation to texture.

Mineralogical uncertainties also affect the distinction between Ochrandepts and Dystrochrepts. Where colluvial soils appear to be derived from a mixture of volcanic ash and other material, they have been placed in the latter group.

Limitations in field work and lack of laboratory data commonly prevented establishing beyond doubt the presence of an argillic horizon, which is the main differentia between Argudolls and Hapludolls, Argaquolls and Haplaquolls, Udalfs or Ochrults and Ochrepts, Argillic Ochrudox/Ochrustox and Orthic Ochrudox/ Ochrustox. The exact nature of the boundary between coarser- and finer-textured horizons and the presence or absence of illuviation cutans could often not be ascertained, whilst the absence of mineralogical data commonly made it impossible to be sure whether texture contrasts were due to pedogenesis or to depositional phenomena (ash admixture, colluviation, sheet wash). For these reasons an argillic horizon has been assumed to be present in all soils with a significantly finer-textured subsoil (at least one textural class) except where there are obvious discontinuities in the soil materials.

### (*b*) *Problems Concerning 7th Approximation Differentiae*

Complete adherence to some of the precisely defined differentiae was impracticable. In some cases soil profiles were combined into a family on the basis of their general similarity, and because of their dissimilarity from related other families, even though they would strictly have to be separated at a higher categorical level because of slight overlaps in the arbitrary limits set to one or other important differentia, such as the mollic epipedon, or depth and nature of gley features. Complete adherence to these limits would have made it necessary to establish several more families and subgroups without any apparent significance to soil genesis, soil geography, or land use capability. Examples of this procedure are the Fiobobo family, which includes

* This seems justified, because no parent materials in the area contain sufficient amounts of resistant minerals to produce coarser textures after maximal weathering.

profiles that theoretically belong to two subgroups, the Orthic and the Mollic Typudalfs, and the Awala family, with profiles theoretically belonging to the Orthic, Udollic, and Albollic Argaquolls. In such cases the suborder name refers to the most common and typical profiles in the family.

Two small alterations were made in criteria set in the 7th Approximation. In addition to the minimum depth of the mollic epipedon in Mollisols set at 4 in. when overlying hard rock and at one-third of the solum in shallow soils, the writer introduced an arbitrary limit of 6 in. in recent alluvial soils. The term "lithic" as applied to several subgroups in the 7th Approximation refers to any shallow, unbroken, hard rock contact. In the classification in this report the term is understood to mean a shallow contact with C horizon material that is more similar to the parent rock than to the solum, and that is either hard (massive or fragmented) or firm to very firm (massive and dense) in more weathered rock or less consolidated sedimentary rock.

As would be expected, the greatest difficulties in classification are experienced with the poorly established order of the Oxisols and in their delineation from the Dystrochrepts and from the Ultisols. Mineralogical data now available for several families of the Oxisols indicate that none of these ought to have been classified in this order on the basis of the criteria set out in the 7th Approximation. The Boro family comes very close, but contains still more than 1% weatherable minerals. The other families have even more weatherable minerals and in addition the percentage of 2 : 1 clay minerals is too high. In some Oxisol profiles weatherable minerals were found that could not have been derived from the parent rock, but represented admixture of foreign material. Such minerals should not be taken into account in assessing the weathering status of the soil, unless they are very common. The routine X-ray clay mineral data do not record gibbsite, goethite, or similar hydrated Al and Fe oxides in any sample. The percentage of such minerals is an important differentia in distinguishing Oxisols in the 7th Approximation. Their total absence seems unlikely. Thus the apparent lack of data on this point adds further uncertainty to the classification. The evidence pro and contra classification as Oxisol is sometimes conflicting, e.g. the Togofu family fits the Oxisols well in soil morphology, chemical properties, and clay mineralogy, but poorly with regard to soil depth and sand mineralogy.

In the absence of analytical data and in view of the allowed presence of an argillic horizon in Oxisols in the 7th Approximation, it was difficult to distinguish between Oxisols and Ultisols. It was decided to classify acid weathered soils as Ultisols and not as Oxisols if they have a marked and sudden texture contrast between the A and B horizons (in some cases accompanied by slight bleaching of the lower A horizon) and a plastic consistency of the B horizon, which appears to be associated with higher bulk density and more pronounced blocky structure and cutans. In addition the Samage family of the Ultisols also appears to be less weathered than any of the Oxisols. If, however, the mineralogical evidence would prevent the B horizon of the Oxisols from being called an oxic horizon, many of the Oxisol families should have been classified as Ultisols on the basis of textural differentiation.

The difficulty in distinguishing between Oxisols and Dystrochrepts was discussed above. On the strength of the mineralogical evidence several Oxisol families should be classified as Dystrochrepts. The vagueness between these groups is emphasized by the presence in the 7th Approximation of a subgroup of Oxic Dystrochrepts. For the soils in this area, however, it seems to be almost impossible to differentiate between Orthic and Oxic Dystrochrepts on the basis of the differentiae prescribed.

Summarizing the above discussion, it can be said that if the differentiae of the 7th Approximation are closely adhered to, no Oxisols can be distinguished in the area. Of the Ustox suborder, Mioki and Silimidi families should have been classified as Eutric or Oxic Dystrochrepts, Jare as Dystric Eutrochrept, Busi as Aquic Eutrochrept, and Arumbai as Ochrultic Typudalf. Of the Udox suborder Sirorata, Boro, and Korua families should be Oxic Dystrochrepts, whilst Wowo family is difficult to classify in any system. This family may even be considered as a Mollisol. Aimare, Siviai, and Moni families should all have been called Typochrults, Togofu family a Rhodochrult. The author considers, however, that the families grouped in the Oxisols in this report have important features in common that clearly set them apart from other groups of soils in the area. These features are strong weathering, reddish and bright brown colours, high clay content combined with relatively great friability and low C.E.C., and lack of strong or sudden texture contrast within the profile. These properties should be given more weight in the comprehensive classification system, whilst the mineralogical criteria should be relaxed.

## APPENDIX II

### Structural Descriptions of Certain Forest Types

(i) *Irregular Tall Alluvium Forest.*—Uppermost layer formed by scattered emergents 125–150 ft high. Canopy at 100 ft, irregular to very irregular, open. Lower storeys irregular to very irregular, generally open, often moderately dense. Shrub layer very dense, rarely moderately dense. Herb layer sparse to nearly absent, rarely moderately dense. Palms common to abundant; a fan palm, *Licuala* sp., present to abundant. *Pandanus* usually present, often very common to abundant. Locally sago. Rattan common to abundant. Thick and thin climbers very common to abundant. Low to high buttresses very common to abundant. Visibility poor to very poor. High epiphytes common, low epiphytes present. Average girth at breast height of trees 20 in. and over, 58 in. (average of 35 trees measured).

(ii) *Tall Alluvium Forest.*—Scattered emergents 130–150 ft high, rarely up to 165 ft. Canopy at 115–130 ft, irregular, rather open to fairly dense. Lower storeys irregular, generally fairly dense, locally rather open. Shrub layer irregular, rather open to fairly dense. Herb layer sparse to very sparse, sometimes almost absent. Palms generally very common, often common or also abundant. Fan palm (*Licuala* sp.) present to common. *Pandanus* present to fairly common. Rattan present to fairly common, sometimes common. Thick and thin climbers generally common, often fairly common. Low to high buttresses common to very common. Visibility generally moderate, often rather poor or also fairly good. Epiphytes generally fairly common to common, often present to rare. Average girth at breast height of trees 20 in. and over, 45 in. (average of 173 trees measured).

(iii) *Foothill Forest.*—Canopy very irregular, generally open, occasionally dense, 100–115 ft high, with large gaps. Emergents to 130 ft. Girths low to moderate; trees with large girths scattered. Lower storeys moderately dense to dense. Shrub layer moderately dense. Visibility variable, depending on nature of shrub layer. Herb layer very sparse. Thin climbers fairly common to common, thick climbers present to common. High epiphytes fairly common, low epiphytes rare. Rattan rare to fairly common. Palms fairly common to common. Low and moderate buttresses common, high buttresses present to common.

(iv) *Mid-slope Forest.*—Emergents to 130 ft high, occasionally higher. Canopy at 115 ft, irregular, with gaps, often locally dense. Emergents and canopy trees with long, straight, clear boles. Girths small to moderate, large girths rare. Lower storeys fairly dense; poles very common to abundant. Shrub layer rather open, mainly consisting of long thin, slender saplings. Visibility fairly good to good. Herb layer very sparse, occasionally moderately dense. Thin climbers fairly common, thick climbers present to fairly common. Stilt roots present, sometimes fairly common. High epiphytes common, low epiphytes present; mossy epiphytes often common.

Rattan rare to present. Bamboo locally present to fairly common. Small palms fairly common to common. Low and medium buttresses common, often fairly common; high buttresses present.

(v) *Plateau Forest.*—A fairly dense forest if undisturbed. Trees high and straight with long, clear boles. Emergents reach 165 ft. Girths low to moderate, with scattered trees of large girth present but not as many or as large as in the tall alluvium forest. Shrub layer moderately dense, visibility fairly good. Herb layer sparse to moderately dense. Climbers common.

(vi) Castanopsis *Forest.*—Canopy well closed, 70–80 %, 100–115 ft high. Crowns small to moderate, 20–40 ft. Emergents up to 130 ft. Girths small to moderate, few large, the moderate and large ones often belonging to *Castanopsis.* In the lower tree storeys, trees in pole stage often very common. Shrub layer consists of a great number of high slender saplings with rather few horizontal side branches and relatively few, small, entire leaves. Despite the great number of individuals the shrub layer looks rather open, the visibility is fairly good to good, except where many small palms and/or bamboo occur. Herb layer sparse, ferns and surface-root mosses common. Thin climbers variable, present to common, usually rather common; thick climbers present to rather common. High epiphytes common, especially in old trees; low epiphytes generally present, often rather common to common. Rattan rare. Stilt roots fairly common. Tree ferns usually present. Bamboo often present, sometimes common. Palms, usually of small size (low shrub and herb layer), present to fairly common. Low and medium buttresses common; high buttresses rare to present.

## APPENDIX III

### Explanation of Land Use Capability Class and Subclass Symbols

By H. A. Haantjens*

Land in classes I–IV is suitable for cultivation, but in decreasing order, class IV land being marginal for this form of land use. Land in classes V–VIII is *not* suitable for cultivation.

Class I land is very good land that 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, but irrigated rice-growing would generally involve special water supply measures.

Class II land is good land, not subject to flooding but requiring simple special practices to maintain or reach optimal productivity when cultivated. It can be used without special limitations for improved pastures or tree crops, except for the latter where drainage is imperfect. One subclass is suitable for irrigated rice.

IIe.—This land requires simple erosion control measures when cultivated, such as contour ploughing and strip cropping.

IIe,$s_2$.—This land requires a combination of the measures recommended for subclasses IIe and II$s_2$.

II$s_2$.—Shallow or coarse-textured soils require simple measures to conserve soil moisture, by an increase of organic matter content (green manuring, composting, or mulching).

II$s_3$.—Fine-textured soils pose difficulties in land preparation for arable crops. Measures are required to maintain a high organic matter level.

IIst.—This land is sufficiently stony to interfere with the cultivation of row crops, but stones can be removed without undue effort.

IId.—Minor drainage improvement by means of ditches is required for arable crops, but particularly for tree crops. This land is suitable for irrigated rice.

Class III is moderately good land requiring intensive special measures to improve and maintain productivity when cultivated. It can be used without or with minor limitations for pastures and in several cases also for tree crops, but is less suitable for the latter where drainage conditions are poor. Two subclasses are suitable for irrigated rice.

IIIe.—This land requires intensive erosion control measures when cultivated, such as bench terraces and cover crops.

IIIe,$s_3$.—On this land erosion hazards for cultivation are combined with slowly permeable fine-textured soils. This land is least suitable for tree crops, most suitable for pastures.

* Division of Land Research, CSIRO, Canberra, A.C.T.

IIIs$_2$.—Shallow or coarse-textured soils require intensive measures to conserve soil moisture, including grass rotations and fallow in cultivation, or clean weeding and mulching for tree crops.

IIIst.—This land is too stony for row crops and the removal of stones requires a major effort.

IIId.—This land requires much drainage improvement for arable crops by means of ditches and probably tiles. Less intensive measures are needed for pastures, but this land may be only marginally suitable for tree crops. It is suitable for irrigated rice.

IIIf.—Simple flood control measures are required such as straightening and deepening of natural drainage channels.

IIId,f.—This land combines the limitations of subclasses IId or IIId and IIIf.

Class IV land is of moderate quality. It can be cultivated occasionally or for a limited number of crops. It is suitable for improved pastures but commonly little suited or not suitable for tree crops. The land use capability of some of this land can be increased by major reclamation schemes.

IVe,s$_2$,s$_3$.—Physically poor and easily erodable soils render this land marginal for cultivation and unsuitable for tree crops. It appears to be suitable for improved pastures, but probably with some establishment problems.

IVs$_3$.—Poorly drained, slowly permeable, fine-textured soils restrict the number of suitable arable crops and particularly tree crops. This land is suitable for pastures although trampling may pose a problem.

IVs$_2$,s$_3$.—This land is similar to subclass IVe,s$_2$,s$_3$, but has no erosion hazards.

IVs$_2$.—Very shallow or coarse-textured soils would allow only occasional use of this land for cultivation and render it rather unsuitable for tree crops. It appears suitable for improved pastures.

IVa.—Alkaline soils would limit the number of suitable arable crops and particularly tree crops. This land is suitable for improved pastures.

IVf.—Flood hazards that cannot be eliminated or involve major flood-control schemes limit cultivation to quick-growing crops during the dry season and probably also restrict the possibilities for tree crops. This land is best suited for improved pastures.

IVd,f.—Flood hazards and poor drainage render this land suitable only for quick-growing arable crops in the dry season and for improved pasture. Reclamation, possible only by major schemes, would result in great increase in land use capability.

IVd,a.—Limited possibilities of improving poor drainage conditions, and alkaline soils render this land marginal for cultivation and unsuitable for tree crops. It is moderately suitable for improved pastures and very suitable for irrigated rice.

IVf,a.—Flood hazards and alkaline soils allow cultivation of only a small number of quick-growing arable crops during the dry season and render this land little suitable for tree crops. It is moderately suitable for improved pastures. Flood control, only possible by major works, would increase suitability for cultivation, but not much for tree crops.

IVd,f,a.—This land is similar to subclass IVd,f but the added limitation of alkaline soils would further restrict its suitability for tree crops, even after reclamation.

Class V land is nearly level, is not subject to erosion, and has productive soils but it is unsuitable for cultivation for other reasons. It would be productive pasture land and is in some cases suitable for tree crops and commonly for irrigated rice.

Vst.—This land is too stony for cultivation and removal of stones is not feasible. It is suitable for improved pastures or tree crops.

Vst,a.—This land is similar to subclass Vst, but alkaline soils strongly limit its suitability for tree crops.

Vd.—Limited possibilities for improvement of poor drainage conditions render this land suitable for improved pastures but unsuitable for cultivation or tree crops. It is very suitable for irrigated rice.

Vd,f.—Poor drainage and flood hazards render this land moderately suitable only for improved pastures. Reclamation, possible only by major works, would greatly increase the land use capability of this land.

Vd,a.—Limited possibilities for improvement of poor drainage, and alkaline soils make this land suitable only for improved pastures and irrigated rice.

Vd,$s_3$.—Limited possibilities for improvement of poor drainage of slowly permeable soils restrict the land use capability to improved pastures (with possible trampling problems) and irrigated rice.

Class VI land is unsuited for cultivation, but subject to only moderate limitations for pastures. Some of this land can be used for tree crops and most of it is suitable for forestry purposes.

VIe.—This land is too steep for cultivation but is suitable for tree crops with simple measures to control erosion and for improved pastures with careful management.

VIe,$s_2$.—Too steep for cultivation, this land is probably also unsuitable for tree crops because of shallow soils. It is suitable for grazing and forestry.

VIe,$s_3$.—Too steep for cultivation, this land is only marginal for tree crops because of slowly permeable soils. It is suitable for improved pastures with careful management to avoid erosion.

VIe,$s_2$,$s_3$.—This land has physically poor and easily erodable soils that render it unsuitable for cultivation or tree crops and poor for forestry. It is suitable for grazing with limited possibilities for pasture improvement.

VIe,st.—A combination of erosion hazards and stoniness makes this land unsuitable for cultivation, and only marginal for tree crops. It is suitable for improved pastures with careful management to avoid erosion.

VI$s_2$.—Very gravelly soils render this land unsuitable for cultivation, marginal for tree crops, but suitable for grazing with limited possibilities for pasture improvement.

VI$s_2$,$s_3$.—Very poor physical soil conditions render this land unsuitable for cultivation and tree crops and poor for forestry. It is suitable for grazing, but pasture improvement may pose problems.

VIst.—Too stony for cultivation, this land is only marginal for tree crops but suitable for grazing and forestry.

VIst,a.—Too stony for cultivation, this land is also unsuitable for tree crops because of alkaline soils. It is moderately suitable for improved pastures and suitable for forestry.

VId,f.—Very poor drainage and flood hazards make this land suitable only for dry-season grazing, or cultivation of sago or swamp rice. Land reclamation by major schemes would greatly increase the land use capability for irrigated rice, improved pastures, and arable crops; it would increase it less for tree crops.

VIf,a.—Flood hazards render this land unsuitable for cultivation, and together with alkaline soils also for most tree crops. It is suitable for grazing during the dry season.

VId,f,a.—This land is similar to subclass VId,f, but because of alkaline soils it would be suitable for a smaller number of arable crops and unsuitable for most tree crops after reclamation.

VId,$s_3$.—Poor drainage and slowly permeable fine-textured soils render this land suitable only for grazing with limited possibilities for pasture improvement and for ponded rice-growing.

VIf,st.—Flood hazards and stoniness make this land marginal for tree crops but suitable for grazing and forestry.

Class VII land is subject to severe limitations for pastures and forestry, or totally unsuited for land use in its present condition, but reclaimable in major schemes. Except for a few subclasses it is unsuitable for tree crops.

VIIe.—This land requires intensive erosion control measures such as terracing for tree crops and very careful management for grazing. It is difficult land to manage, even for forestry.

VIIe,$s_2$.—Very shallow soils on steep slopes make this land unsuitable for tree crops and only marginal for grazing or forestry with very careful management.

VIIe,st.—This steep stony land is only marginally suitable for tree crops, grazing, and forestry with careful management.

VII$s_2$.—Very gravelly soils render this land suitable only for extensive grazing and forestry.

VII$s_1$,$s_2$.—Infertile loose and locally shifting sands prevent the use of this land, except for *Casuarina* forest and locally for coconut palms.

VIIst,a.—Stoniness and alkaline soils render this land suitable only for extensive grazing and forestry.

VIId.—This swampy land is virtually unusable in its present condition, except for small sago resources and possibly for swamp rice-growing. Land reclamation by major schemes would render this land suitable for irrigated rice and improved pastures, but less suitable for cultivation and most tree crops because of very clayey soils.

VIId,f.—Unusable in its present condition, this swampy land would also be difficult to reclaim, even in major schemes, because of its added flood hazards. Reclaimed land would be primarily suitable for irrigated rice and improved pastures, but less suitable for cultivation and most tree crops because of very clayey soils.

VIId,a.—Unusable in its present condition, this swampy land would, if reclaimed in major schemes, be suited for irrigated rice, improved pastures, and a limited number of arable crops, but would be unsuitable for most tree crops.

VIId,f,a.—This land is similar to subclass VIId,f, but would, after reclamation, be unsuitable for tree crops and many arable crops because of its alkaline soils.

Class VIII land has such unfavourable characteristics as to be unsuited for any form of agricultural production. Reclamation is not feasible. In many cases this land is important for watershed protection. Some of this land is covered by tall forest, but its exploitation would be very difficult.

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Fig. 1.—A fringing coastal beach bears the usual strand vegetation backed by pioneering *Casuarina* and *Avicennia* (Pawara land system).

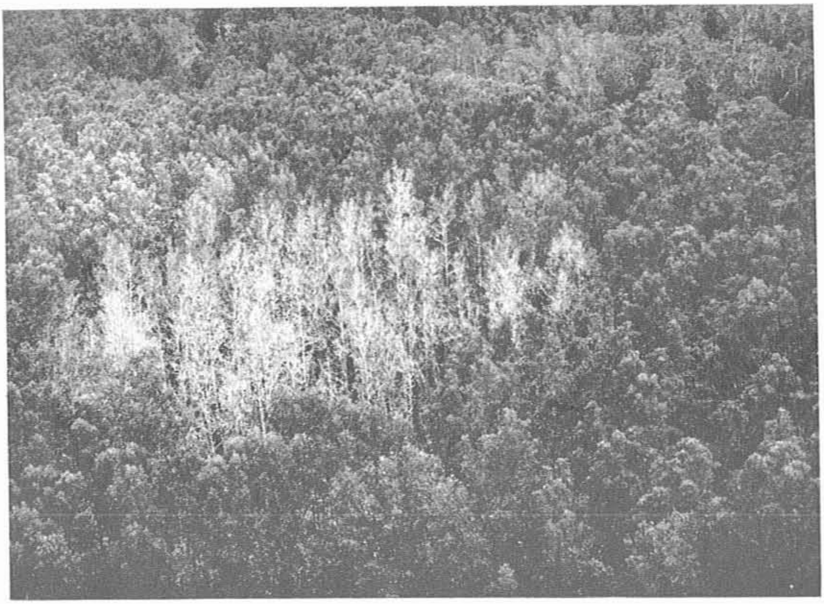

Fig. 2.—A belt of mangrove swamps (Bendorodo land system) borders the coast behind or between the beach ridges. Small circular patches of dead trees are a common and unexplained feature.

Fig. 1.—In 1943 the Musa River broke the banks of its present flood-plain lobe at Garagarata and a splay-like pattern of distributary courses now carries a considerable portion of its flow into the eastern marginal swamp. Large numbers of trees were killed by the increased swampiness consequent on this diversion.

Fig. 2.—A belt of *Pandanus* and dead or dying trees smothered with climbers fringes the deeper parts of the eastern swamps with open water and low herbaceous vegetation (Tortore land system).

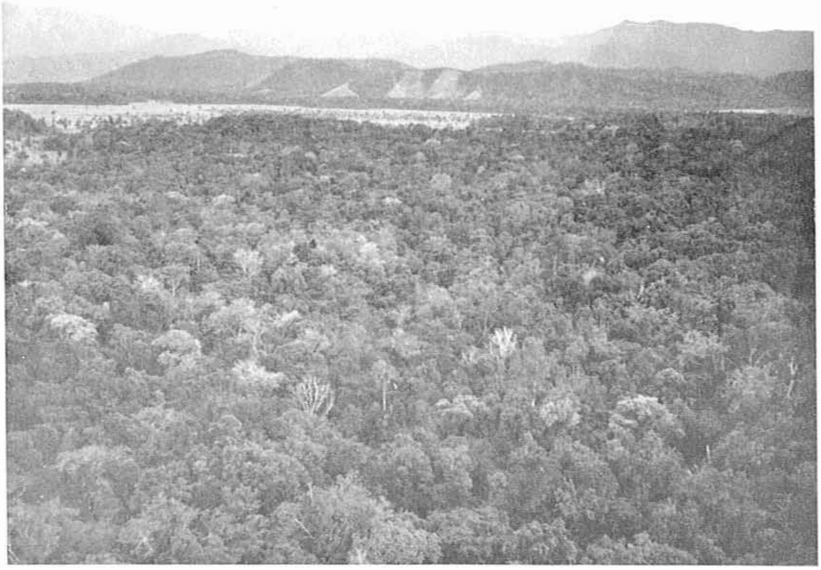

Fig. 1.—The stable, higher, well-drained central parts of the Musa coastal plain (Momoiogo land system) rise to 210 ft above sea level near Embessa. The original vegetation is a tall rain forest with a rather open irregular canopy but cleared extensive tracts of grassland are maintained by regular burning.

Fig. 2.—Nearer the coast Momoiogo land system is clothed with tall rain forest characterized by an abundance of palms, climbers, and buttressed trees.

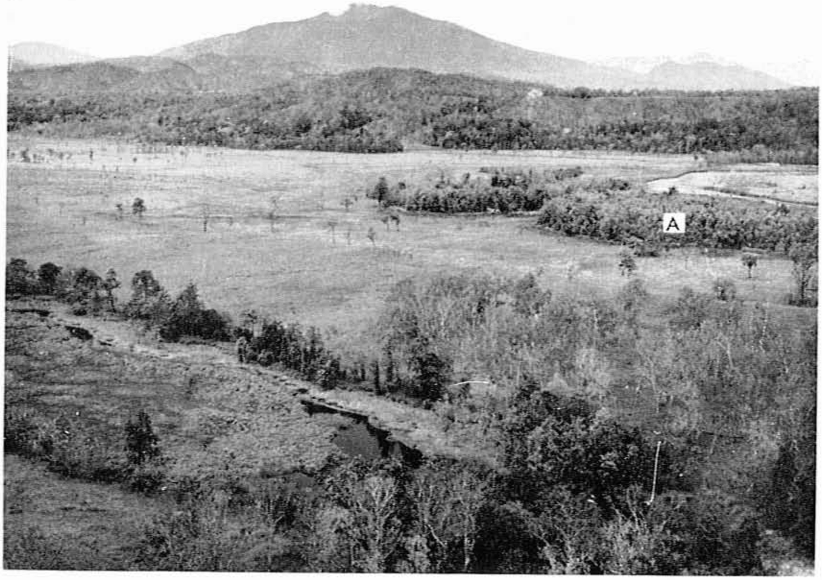


Fig. 1.—The forest on the fans in the Musa basin has been replaced by man-made grassland over large areas (Safia land system). In the lower parts of the fans scattered patches of poor, often swampy, alluvium forest (*A*) occur near rivers.

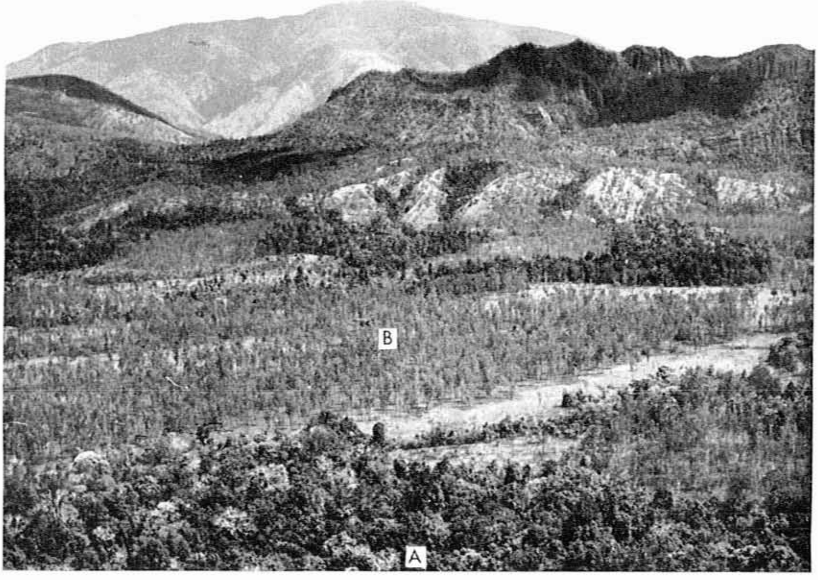


Fig. 2.—A view of the eastern Musa basin with forested fan slopes (*A*) with calcareous soils (Ubo land system) adjacent to low cuestas (*B*), with savannah vegetation and poor texture-contrast soils (Asaga land system) in the mid-ground.

Fig. 1.—Most, if not all, of the eucalypt savannah is a fire disclimax type of vegetation. Although mature trees are to a large extent fire-resistant, their regeneration is usually badly damaged by the recurrent grass fires.

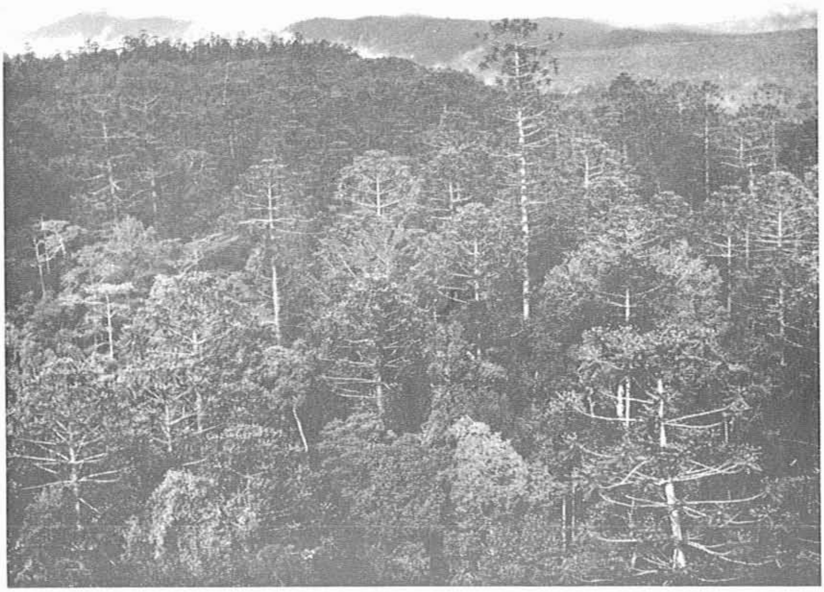

Fig. 2.—Klinki pine is found scattered in the hills around the Musa basin and occasionally forms a fairly dense upper storey over a canopy of broad-leaved trees. Unusually dense stands occur on shallow texture-contrast soils in Darumu land system north-east of Ubo and are reasonably accessible.

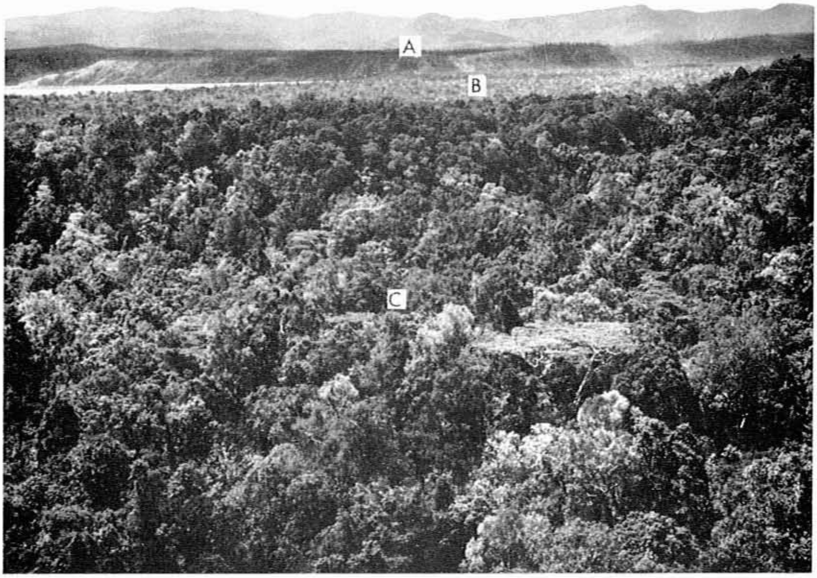


Fig. 1.—The dissected high terrace of Darumu land system (*A*) is separated by recent calcareous fans of Ubo land system (*B*) from the forested undulating surface of Silimidi land system (*C*), which is a deeply weathered mudflow fan with weakly acid, friable, reddish clay soils. Secondary forest with *Albizia falcata* occurs east of Silimidi.

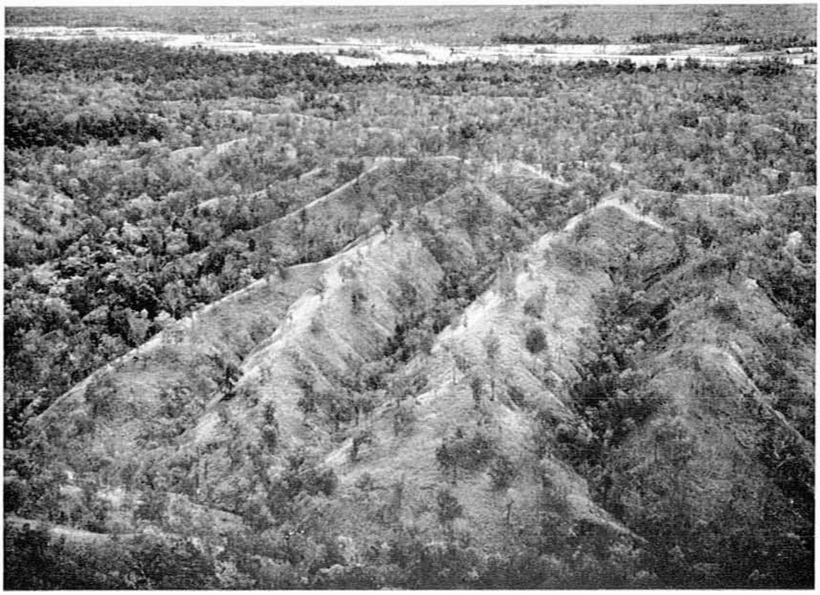

Fig. 2.—Benches raised up by late Pleistocene and Recent faulting were rapidly dissected into erosionally graded ridge and ravine landscapes made up of very steep straight slopes with very shallow soils and an intricate pattern of eucalypt savannah and mixed deciduous hill forest in valleys (Arumbai land system).


Fig. 1.—Very strong earth flow on deeply weathered parts of the raised benches has caused irregular hummocky slopes with colluvial soils, largely covered with mixed deciduous hill forest and locally patches of eucalypt savannah (*A*) mainly on ridge crests (Avikaro land system).

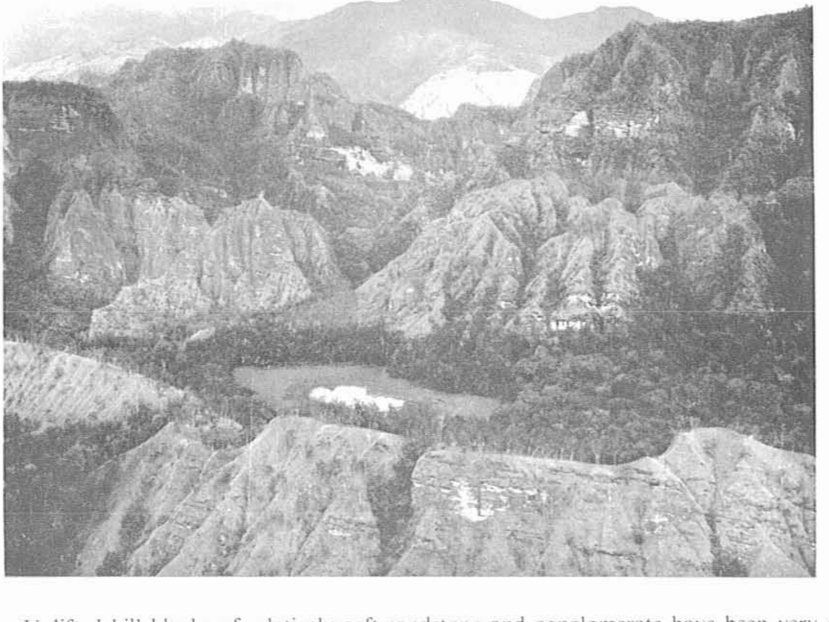

Fig. 2.—Uplifted hill blocks of relatively soft sandstone and conglomerate have been very deeply dissected into cliffs with scree slopes and precipitous slopes (Adau land system). The vegetation consists of short grassland, scrub, and open eucalypt savannah, with mixed deciduous hill forest on the better sites.

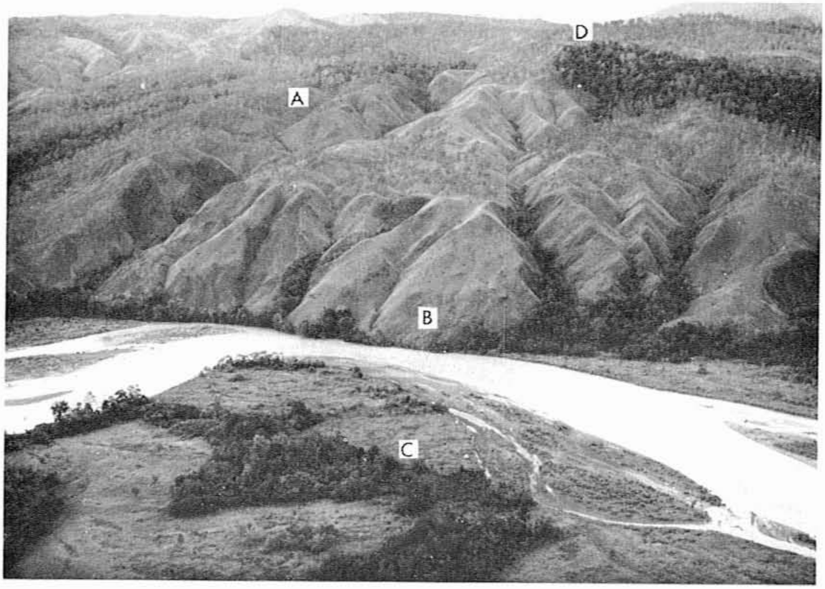


Fig. 1.—Recent fault scarps are well developed around the Musa basin and often lead up to raised benches and accordant ridge crests with relic weathering profiles (*A*). Such a fault scarp (*B*) separates the unstable flood-plain (*C*) of the Musa River (Gobera land system) from the hill ridges of Fiobobo land system (*D*), which are clothed with low hill forest, *Themeda australis* grassland, and eucalypt savannah.

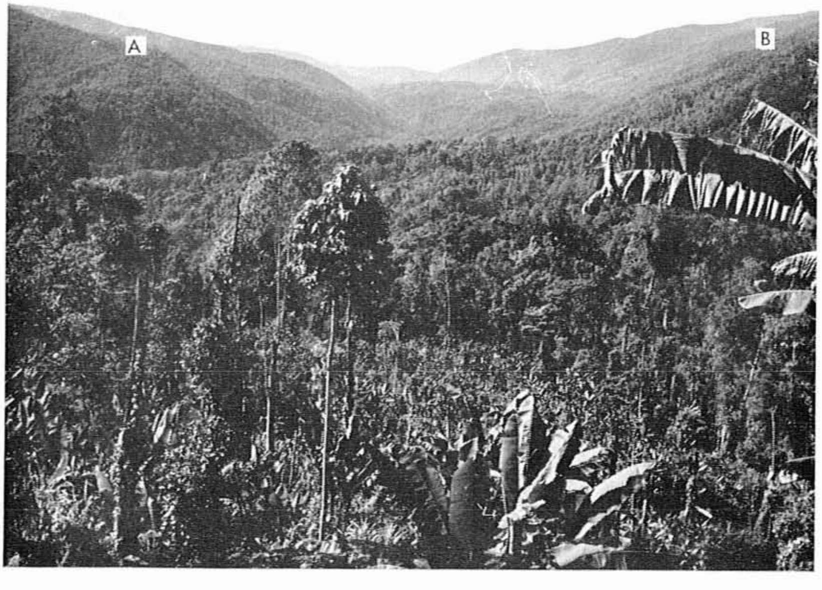


Fig. 2.—The ash-mantled mountains of Guaya land system (*A*) are separated from the rugged Owen Stanley Range (Misima land system, *B*) by the Kumusi fault trough. Sediments in this fault trough have been dissected into hill ridges (Kovio land system) mantled with andesitic ash from Mt. Lamington.

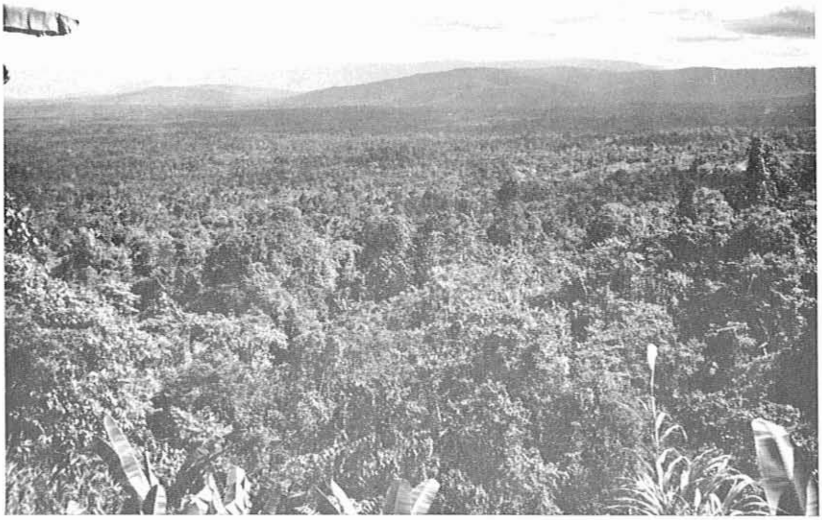

Fig. 1.—The southern foot slopes of a former andesitic strato-volcano now form a high plateau at 2000–3000 ft in the west-central Managalase. This plateau (Tahama land system) is now dissected into closely spaced parallel low hill ridges mantled with late Pleistocene and Recent andesitic ash layers from Mt. Lamington. This area is densely populated and heavily gardened, and large areas of the original tall plateau forest have been converted to secondary forest and garden regrowth.

Fig. 2.—In the east-central Managalase a complex volcanic plateau is made up of basalt lava flows, scoria mounds, and cinder cones with a characteristic range of dark brown clay soils (Uoive land system).

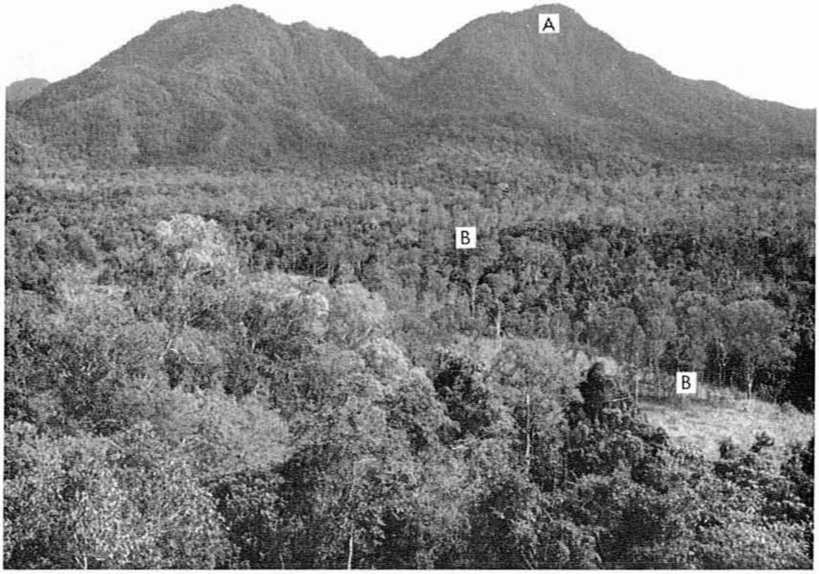


Fig. 1.—A line of partly dissected rhyodacite cones (Manna land system) occurs on the margin of the Managalase plateau. One of them rises to 3700 ft at Mt. Manna (*A*). The steep slopes of the cones, covered with rather poor open hill forest, are flanked by fan slopes and basalt lava flows (Iwuji land system), which carry mainly mid-height fan forest alternating with strips of eucalypt savannah (*B*).


Fig. 2.—Rapidly eroding very steep ridges make up most of the denudational mountain ranges. Small-crowned, irregular, and open hill forest covers the very steep slopes of a dissected Pleistocene strato-volcano (Hydrographers land system). In the background (*A*) the even slopes represent the initial surface of the volcano (Banderi land system).

Fig. 1.—At higher altitudes to the south of the Musa basin, hill forests rich in *Casuarina papuana* with scattered *Araucaria* topping the canopy (Avuru land system) occur adjacent to eucalypt savannah (not shown).

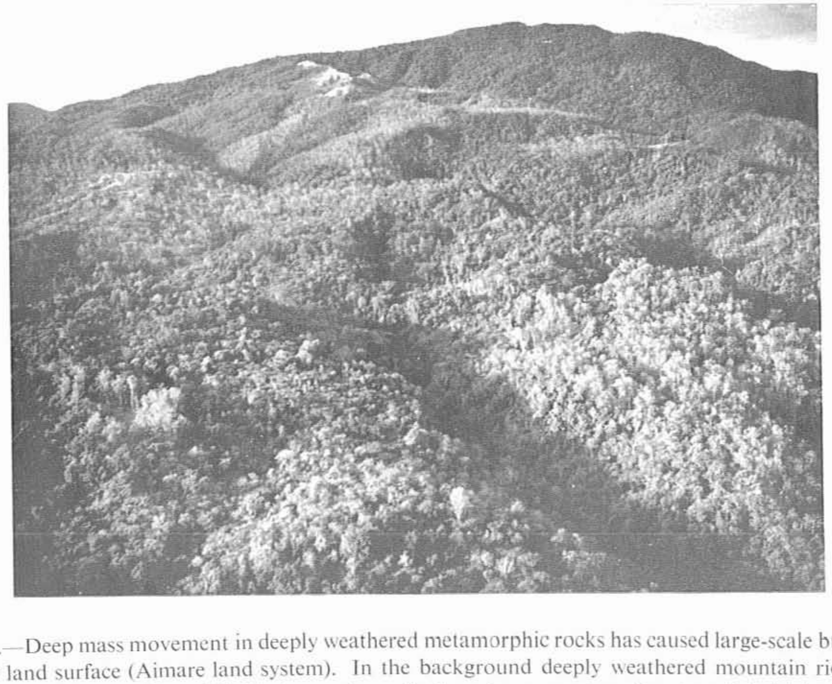

Fig. 2.—Deep mass movement in deeply weathered metamorphic rocks has caused large-scale buckling of the land surface (Aimare land system). In the background deeply weathered mountain ridges of Foasi land system, with red friable heavy clay soils, have lower montane forest on their higher slopes.

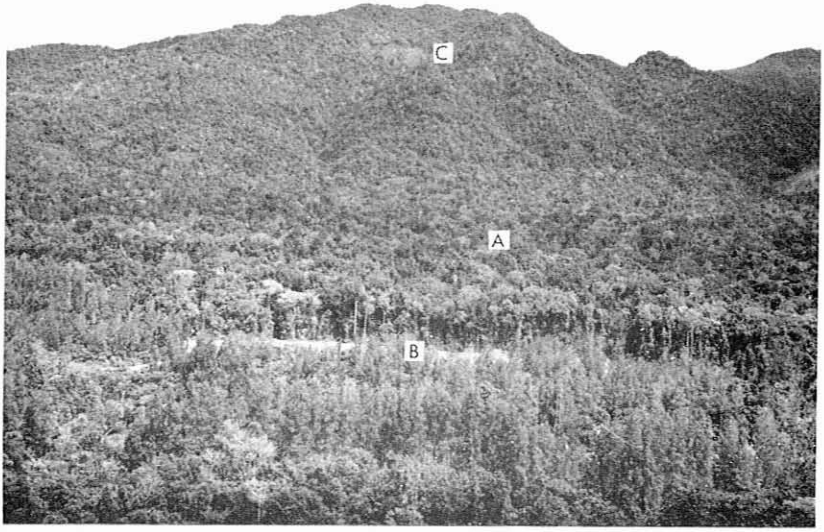


Fig. 1.—The Owen Stanley foothills are sharply separated from the Musa basin by a fault scarp. Forested fan slopes (*A*) (Liamu land system) separate an alluvial tract, with pioneering *Casuarina* lining the pebbly borders of present streams (*B*) (Gobera land system), from very steep forested mountain ridges with strong earth flow (*C*) (Amora land system).

Fig. 2.—Rapid recent uplift of the Owen Stanley Ranges has led to a very high rate of denudation in the form of major slumping in the Goropu Mountains, where montane forest and alpine scrub and grassland clothe the highest peaks (Suckling Complex land system).