General Report on Lands of the Wabag–Tari Area, Territory of Papua and New Guinea, 1960-61

Comprising papers by R. A. Perry, M. J. Bik,
E. A. Fitzpatrick, H. A. Haantjens, J. R. McAlpine, R. Pullen,
R. G. Robbins, G. K. Rutherford, and J. C. Saunders

Land Research Series No. 15

Commonwealth Scientific and Industrial
Research Organization, Australia
Melbourne 1965

Printed by CSIRO, Melbourne

CONTENTS

Maps

PART I. INTRODUCTION

By J. R. McAlpine*

I. Survey Area

The land surveyed has been named the "Wabag–Tari area" and covers approximately 6200 sq miles. It lies between lat. 5°15′S. and 6°30′S. and long. 142°40′E. and 144°E.

The area includes the Wabag and Laiagam subdistricts of the Western Highlands district of the Territory of New Guinea and the Mendi, Lake Kutubu, and Tari subdistricts of the Southern Highlands district of the Territory of Papua. Both Territories are governed as an administrative union.

II. Survey Procedure

The object of the survey by a team of scientists working in collaboration was to map and describe the lands of the area at reconnaissance level. As on previous surveys carried out by the Division of Land Research and Regional Survey, the basic descriptive unit is the land system, which is an area or group of areas with a recurring pattern of land forms, soils, and vegetation. The land system, forest, and land use maps and descriptions provide a basis for an assessment of the potentialities of the area and for recommendations for further research.

The method of survey is based on the concept that each type of country or land system is expressed on aerial photographs by a distinctive pattern, so that a map of the land systems can be produced from air photographs. The method requires complete aerial photographic cover of the area.

For this survey traverse routes were selected by pre-survey photo analysis to provide the best compromise between accessibility and the need to inspect all types of country. Most of the traverses were carried out on foot, some 1500 miles being covered in this manner. Vehicles were used on existing roads near Wabag, Mendi, and Tari and advantage was also taken of aircraft and the extensive system of air strips present in the area (Fig. 1).

Field work was carried out during two periods: the northern and New Guinea half of the area between June and October 1960; the southern and Papuan half between June and October 1961.

Members of the main survey team were: Dr. G. K. Rutherford and Mr. H. A. Haantjens, pedologists; Dr. M. J. Bik, geomorphologist; Dr. R. G. Robbins and Mr. R. Pullen, plant ecologists; and Mr. J. R. McAlpine, transport officer.

In addition, field botanical collections were made by Dr. R. D. Hoogland and Mr. R. Schodde and a forest resources survey of the area was carried out by Mr. J. Saunders. Mr. J. Jennings, of the Australian National University, accompanied the

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

survey team for our months in the major limestone regions of the area. Mrs. R. Schodde of the Division of Wildlife Research, CSIRO, made a bird collection in the Mt. Giluwe and Lake Kutubu areas of the Southern Highlands and Mr. E. A. Fitzpatrick studied available climatic data from the area.

A further short field trip was made to the area in August 1963 by Mr. R. A. Perry, who compiled and collated the final report.

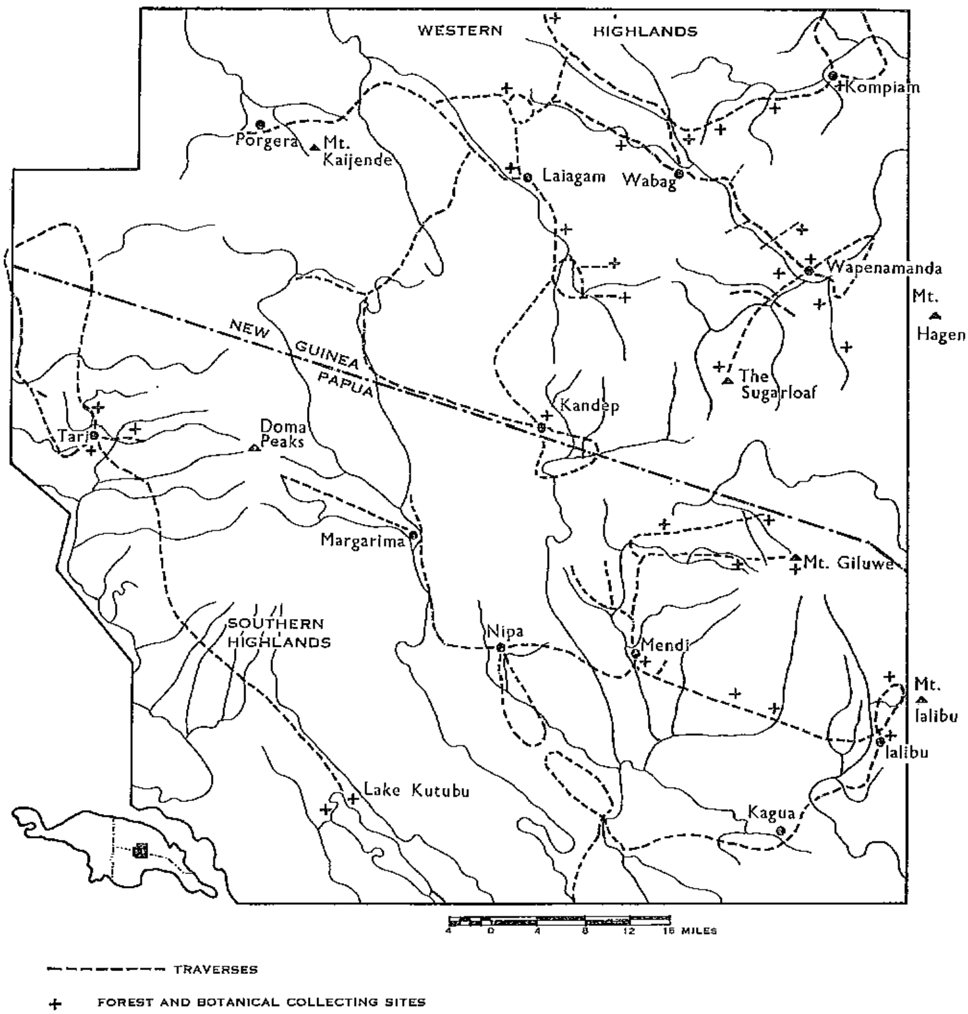


Fig. 1.—Traverses and forest and botanical collecting sites.

III. Air Photography and Maps

The area surveyed was covered by air photographs taken at a scale of 1 : 50,000 (at sea level) by Adastra Airways between 1959 and 1961.

The base map of the area at a scale of 1 : 250,000 was prepared by the Division of National Mapping, Department of National Development, from preliminary detail plots at 1 : 50,000. These were compiled from aerial photographs which had been adjusted to available control using the H. G. Jerie block adjustment method. (Jerie 1958, 1960).

As no large-scale map of the area has yet been produced, nomenclature data obtained in the field will be published on preliminary detail plots at 1 : 50,000 by the Division of National Mapping.

IV. Communications

Owing to the general inaccessibility of the area, consolidation of administrative influence (i.e. the spread of *Pax Britannica*) has taken place only since 1945, following the introduction of aircraft and the construction of numerous air strips.

Initial penetration of the northern part was made by Taylor and Black in 1937 and the northern administrative centre, Wabag, was established in 1946. The southern part was first penetrated by Hides and O'Malley in 1935 and later by Champion and Adamson in 1936. The southern administrative centres of Mendi and Tari were established in 1953 and 1954 respectively.

Access to the area from outside is restricted to aircraft. There are 16 air strips in the area, of which only three, Wabag, Tari, and Wapenamanda, are capable of handling DC3 aircraft. All air strips are commonly closed after rain or during bad weather.

Communication within the area is restricted to walking tracks, aircraft, and three separate road networks. To the south, roads surround Mendi and Tari. In the north, Wabag, Wapenamanda, Kompiam, and Laiagam are connected by road. Since the survey a road connecting Wapenamanda with the main highlands road system at Mt. Hagen has been completed (late 1961). However, the whole region still remains dependent on aircraft for its outside supplies.

V. Acknowledgments

The survey was financed by the Administration of the Territory of Papua and New Guinea through the Department of Territories, Canberra. Their cooperation in all phases of the survey is gratefully acknowledged.

Thanks are given to the Administration staff in the Western and Southern Highlands districts, under District Commissioners T. Ellis and R. White respectively, for the essential assistance always given promptly to the survey team. Particular thanks are given for the hospitality shown to the survey team at the out-stations of these districts.

The help given by Territory Airlines and Ansett–MAL of Mt. Hagen is also greatly appreciated.

VI. References

Jerie, H. G. (1958).—Block adjustment by means of analogue computer. *Photogrammetria* **14**: 161–76.

Jerie, H. G. (1960).—Block adjustment with analogue computers applying "composed sections". Evaluation of the accuracy to be expected. Intern. Training Centre Publ. A/2.

PART II. SUMMARY DESCRIPTION OF THE WABAG–TARI AREA

By R. A. PERRY*

I. GENERAL

The area forms part of the New Guinea Highlands, which stretch for 1500 miles throughout the length of the island. The greater part of the area consists of rugged mountainous terrain (Plate 1, Fig. 1) between 5000 and 10,000 ft above sea level, but very small areas occur below 2000 ft and above 13,000 ft.

The main New Guinea divide runs through the north-eastern part of the area and separates waters of the Sepik River system from those of the Fly, Kikori, and Purari systems.

II. CLIMATE

At the lower elevations the climate is wet tropical, but with the lower temperatures at higher altitudes it is more akin to the moist, maritime temperate or "mesothermal" climates of higher latitudes.

A lack of seasonal contrast is characteristic of all climatic elements over the whole area. Rainfall is high, the lowest mean annual amount being 85 in. (Laiagam) and the highest 177 in. (Lake Kutubu). Rainfall is fairly evenly distributed throughout the year and in no part of the area is there a dry season. At elevations below 7000 ft, at least, the annual range of mean temperature is only 4°F and the diurnal range only about 20°F. Generally areas below 5000 ft above sea level are frost-free but above 8000 ft frosts are common. Snow occasionally falls on the summit of Mt. Giluwe.

III. GEOLOGY AND GEOMORPHOLOGY

During later Mesozoic times and again in the early to mid-Tertiary period the area was part of the Papuan Geosyncline and great thicknesses of marine sediments were laid down. Most of the present-day land surface is formed on Miocene sediments which change in facies from almost wholly limestones in the south-west, to mixed limestone–mudstone in a belt across the centre trending north-west–south-east, to coarse clastics in the north-east.

During Pliocene times the sediments were strongly folded along axes trending north-west–south-east, and major uplift occurred. Following uplift, vigorous erosion produced a strike range topography with relief attaining present dimensions.

In the Pleistocene period, great thicknesses of volcanic materials poured over the rugged landscape in the east (Mt. Giluwe, Mt. Hagen, Mt. Ialibu) and west (Doma Peaks) of the area and most of the area was blanketed by showers of ash. Later the summits of Mt. Giluwe and Mt. Hagen were glaciated.

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

IV. Soils

The dominating factor in soil formation appears to be the wet tropical climate, as similar soils have formed on diverse parent materials over large areas. Soil development is rapid and even steep slopes have deep soils. In general, the soils are strongly to slightly acid, low in available phosphate, and have a high but unsaturated exchange capacity. The most common soils on gentle to steep slopes between 3000 and 10,000 ft above sea level are humic brown clays.

Of the other soil groups the reddish clay soils typically occur at low altitudes, the peaty soils at high altitudes or under swampy conditions at any altitude, the shallow dark clay soils on steep slopes on limestone, the deep dark clay soils on doline floors and slumps, the humic olive ash soils at moderate altitudes on old alluvia or higher up on volcanic slopes, and the gleyed plastic heavy clay soils on gentler slopes on shales and siltstones.

V. Vegetation

Over most of the area the natural vegetation was originally rain forest varying from three-layered (lowland rain forest) below 4000 ft, through two-layered (lower montane rain forest) between 3000 and 10,000 ft, to one-layered (montane rain forest) above 10,000 ft and below the tree line at about 12,500 ft. Natural grasslands occur above about 12,000 ft and in frost pockets down to about 8000 ft. Various swamp and bog communities occur on wet sites.

Except for the steepest slopes and wet sites, and some areas with low population density, most of the vegetation between about 4000 and 8000 ft above sea level has been modified by man and is maintained as either grasslands or gardens and regrowth.

VI. Land Systems

The lands of the area have been mapped and described as 39 land systems, each of which is characterized by a pattern of rocks, topography, soils, and vegetation. The land systems are described in tabular form in Part III and their main characteristics are listed in Table 1.

The most important definite features of the land systems are rock type and topography.

(a) Land Systems Mainly on Limestone

These are most common in the south-western half of the area, where they comprise most of the land. Two land systems (Kaijende in the highlands, Duma in the Kutubu lowlands) consist of mountains and precipices (Plate 1, Fig. 2) and four of karst lands (Plate 2, Fig. 1). The karst lands include Pinnacle land system, consisting of rugged tower karst, Nembi and Digumu land systems, consisting of doline and tower karst in the highlands and Kutubu lowlands respectively, and Suma land system, consisting of hills and dolines.

(b) Land Systems Mainly on Unresistant, Non-calcareous Sedimentary Rocks

In contrast to the limestone land systems these are dominant in the north-eastern half of the area. Two subgroups, mountains (Plate 2, Fig. 2) and hills and benchlands (Plate 3, Fig. 1), have been defined. Of the mountainous land systems, Nop consists of summit areas, Ambum is formed on mainly greywacke and siltstone, and Tou on sandstone. Eight land systems comprise the hills and benchlands—Yalis consists of saucer-shaped plateaux and cliffs; Wongum of low rounded hills and ridges; Andabare of the lower slopes of upland valleys; Tsang of hills and mountains on sandstone; Laiagam of rolling country on mudstone; Tibinini of long gentle slopes in the highlands; Hariu of long gentle slopes and low hills in the Kutubu lowlands; and Kagua of plains and terraces.

(*c*) *Land Systems Mainly on Basic Intrusive Rocks*

This group occupies only small areas in the north-eastern part of the area. Nose land system is mountainous, and Silim land system consists of rounded hills and ridges (Plate 3, Fig. 2).

(*d*) *Land Systems on Volcanic Materials*

Two main areas of volcanic materials occur in the area, one associated with Mt. Giluwe, Mt. Hagen, and Mt. Ialibu in the east and one with Doma Peaks in the west. Within them seven subgroups of land systems have been recognized.

In the mountain subgroup (Plate 4, Fig. 1), Giluwe land system comprises the rugged glaciated summit areas of Mt. Giluwe and Mt. Hagen; Ialibu land system comprises rugged non-glaciated summit areas; and Doma land system is less rugged.

In the plateaux and upland basin subgroup (Plate 4, Fig. 2), Sugarloaf land system consists of the undulating to hilly volcanic plateaux of The Sugarloaf; Lava land system consists of plateaux at 9500–11,500 ft on the sides of Mt. Giluwe; and Dibibi land system consists of upland basins in the Doma Peaks area.

The long gentle piedmont slopes form Nemarep land system (Plate 5, Fig. 1).

The plains subgroup contains only Tari land system, which consists of undulating to rolling plains (Plate 5, Fig. 2).

In the low hill ridges subgroup, Tage land system consists of ridges and long gentle slopes in the Kutubu lowlands and Kwandi land system consists of ridges formed by the dissection of a volcanic plain near Tari.

Younger volcanic features comprise ash and scoria cones (Birap land system) and valley flows (Poroma land system).

Only one land system (Lai) comprises the gorge subgroup. It consists of steep-sided, deep gorges (Plate 6, Fig. 1).

(*e*) *Land Systems on Alluvium*

In only a small proportion of the area is the land surface formed of alluvium. Of the land systems on terraces and fans, Tambul is mainly undissected valley floors; Wabag is similar but deeply and fairly densely dissected (Plate 6, Fig. 2); Winjaka is dissected into low hilly country; and Ko consists of undissected piedmont fans. Of the lake and river plains, Kandep land system (Plate 7, Fig. 1) consists of high-altitude swampy plains; Kaugel land system consists of narrow flood-plains and river terraces along major rivers; and Kutubu land system consists of flood-plains near Lake Kutubu.

VII. Forestry

For forestry purposes, the area can be considered in four altitudinal zones: lowland, below 4000 ft; lower montane, between 4000 and 10,000 ft; montane, between 10,000 and 12,500 ft; and alpine, above 12,500 ft. Forested land, covering 60% of the area, occurs in the lower three zones. Forty per cent of the area is not forested, because of cold (alpine zone and upland basins) or wet (swamps and bogs) sites or clearing by man. The lowland and montane forests are little disturbed, owing to the low population in the former and an unsatisfactory environment for agriculture in the latter. The lower montane forest has been extensively cleared for indigenous agriculture.

The forests are classified into 14 types, three in the lowland zone, 10 in the lower montane zone, and one in the montane zone. Each is described and approximate stocking rates, estimated from plots 2–10 ac in extent covering about 0·005% of the forested area, are given.

Timber is an important resource (Plate 7, Fig. 2), particularly in the lower montane forests, but lack of access restricts present utilization to local requirements.

VIII. Population and Land Use

A map of land use in the area has been prepared from an analysis of cultivation patterns on the air photographs in conjunction with limited field observations. This map shows that 1760 sq miles (29% of the total area) is used for cultivation. Of this, 3% is cultivated intensely (>50% of the land normally used), 11% moderately (10 to 50% of the land normally used), and 86% at a low intensity (<10% of the land normally used). Sweet potato is the main crop on almost all the cultivated land.

A comparison of the land use map with the land system map shows that in 16 land systems no land is used, in five land systems only small areas are used, in seven land systems between 30% and 50%, in five land systems about 80%, and in five land systems all of the land is used.

IX. Land Use Capability

The agricultural potentiality of each unit of the land systems has been assessed in terms of eight land capability classes (numbered I to VIII). With the exception of class I, subclasses indicating the nature of the limiting factors are denoted by letter symbols, e.g. "e" for erodability, "st" for stony, "a" for altitude. Land classes I–IV are suitable for cultivation but in decreasing order, classes V–VIII are not suitable for cultivation but classes V–VII are suited to grazing and forestry.

On a regional basis, only four land systems (Tibinini, Poroma, Tambul, and Wabag) with a total area of 240 sq miles have a high proportion of class I–III land and can be considered to have high to moderately high potentialities for agriculture. At the other end of the scale, 11 land systems (Kandep, Kutubu, Kaijende, Duma, Pinnacle, Tou, Tsang, Giluwe, Ialibu, Doma, and Lai) totalling 1450 sq miles are comprised principally of class VII–VIII land and must be considered to have little or no value for agriculture, grazing, or forestry.

TABLE 1

MAJOR CHARACTERISTICS OF THE LAND SYSTEMS

Land System	Area (sq miles)	Altitude (ft)	Topography	Soil Family	Vegetation
			Land Systems Mainly on Limestone		
Kaijende	720	3500–11,500	Massifs and precipices	Vakari, outcrop	Sword grass, lower montane rain forest
Duma	30	2000–3500	Massifs and precipices	Kaijende, outcrop	Lowland hill forest
Pinnacle	7	8000–11,500	Rugged tower karst	Outcrop, Nenja, Kaijende	Bare rock and lower montane rain forest
Nembi	310	3500–7500	Doline and tower karst	Nenja, Kaijende	Lower montane rain forest, sword grass
Digumu	190	2500–3500	Doline and tower karst	Nenja, Kaijende	Lowland hill forest
Suma	300	4000–10,000	Hills and dolines	Kaijende, Nenja, Vakari	Sword grass
			Land Systems Mainly on Unresistant, Non-calcareous Sedimentary Rocks		
Nop	80	8000–10,500	Mountain summit areas	Vakari	Montane rain forest, lower montane beech rain forest
Ambum	1550	4000–11,000	Mountains	Vakari, Wapenamanda, Nenja	Sword grass, lower montane rain forest
Tou	10	7000–10,000	Mountains	Skeletal	Lower montane rain forest
Yalis	25	6000–9000	Benches, slopes, and cliffs	Vakari, Wapenamanda	Sword grass, lower montane rain forest
Wongum	330	4000–8000	Hills and ridges	Nenja, Wapenamanda	Sword grass
Andabare	100	8000–9000	Lower slopes of upland valleys	Laiagam	Lower montane grassland
Tsang	35	7000–8500	Hills and mountains	Vakari	Lower montane rain forest
Laiagam	95	4000–9000	Hummocky hills and slopes	Tibiri	Sword grass
Tibinini	130	4000–8000	Long gentle slopes	Nenja	Sword grass, lower montane rain forest
Hariu	65	2500–3500	Long gentle slopes and low hills	Lombo, Tumundan	Lowland hill forest
Kagua	25	4500–5500	Plains and terraces	Lombo, Tirriraga, Vakari	Sword grass
			Land Systems Mainly on Basic Intrusive Rocks		
Nose	100	5000–9000	Mountains	Vakari	Lower montane rain forest
Silim	50	6500–8500	Hills and ridges	Wapenamanda, Vakari, Meriunda, Klareg	Sword grass, lower montane rain forest

Land Systems on Volcanic Materials

Giluwe	65	10,000–13,660	Mountain summit	Outcrop, Giluwe	Alpine grassland
Ialibu	100	4000–10,000	Rugged mountains	Vakari	Lower montane rain forest
Doma	330	3500–8000	Mountains	Vakari, Wapenamanda	Lower montane rain forest
Sugarloaf	95	9000–13,000	Plateaux	Mango, Wapu, Nenja	Lower montane and alpine grassland, lower montane beech rain forest
Dibibi	25	7500–9500	Upland basins	Meriunda	Lower montane grassland, sword grass
Lava	10	9500–11,500	Gentle slopes	*Dibibi*	Lower montane and alpine grasslands
Nemarep	650	5000–10,000	Long gentle slopes	Wapenamanda, Meriunda, Tabunaka, Vakari	Lower montane rain forest, sword grass
Tari	210	5000–7500	Plains	Wapenamanda, Klareg, Tabunaka, Meriunda	Sword grass
Tage	40	2500–3500	Hills and slopes	Kutubu, Herep	Lowland hill forest
Kwandi	75	5500–7500	Low ridges and valleys	Wapenamanda	Sword grass
Birap	30	5500–10,000	Cones	Wapenamanda, Tabunaka	Sword grass, lower montane rain forest
Poroma	30	3500–5500	Plains	Tabunaka	Sword grass
Lai	15	4000–7500	Gorges	Outcrop, Vakari	Sword grass

Land Systems on Alluvium

Tambul	20	6800–7300	Plains	Meriunda, Klareg	Sword grass
Winjaka	4	7200–7800	Low hills	Meriunda, Klareg	Sword grass
Wabag	60	5000–9500	Terraces and fans	Wapenamanda	Sword grass
Ko	60	5000–7500	Fans	Meriunda, Klareg, Tirriraga, Muriraga	Sword grass
Kandep	100	6500–9000	Swampy plains	Kiakau, Tirriraga, old alluvial clay soils	Sedge and grass–sedge bog, sword grass
Kaugel	7	4000–8000	Flood-plains	Alluvial soils	*Leersia* and *Phragmites* swamp
Kutubu	35	<2800	Swampy flood-plains	Recent alluvial soils	*Campnosperma*–sago palm forest, *Campnosperma coriacea* and *Casuarina* swamp woodlands, lowland *Pandanus* swamp

PART III. LAND SYSTEMS OF THE WABAG–TARI AREA

By R. A. PERRY,* M. J. Bik,† H. A. HAANTJENS,* J. R. MCALPINE,* R. PULLEN,* R. G. ROBBINS,‡ and G. K. RUTHERFORD §

The lands of the Wabag–Tari area have been mapped in 39 land systems, which are tracts of country (landscapes) with recurring patterns of topography, rocks, soils, and vegetation.

The land systems and their component units are described in tabular form and illustrated with block diagrams. They are arranged in five lithological groups (in decreasing age—limestones, mainly non-calcareous sediments, basic intrusives, volcanics, and alluvium), within which subgroups have been defined according to relief. The groups and subgroups are described in Part V and the main characteristics of the land systems are given in Table 1. On the land system map the groups and subgroups are indicated by colours, the individual land systems by symbols only.

For brevity, much of the description of each land system is in terms of names of units (e.g. soil families) described in succeeding relevant chapters. Descriptions of individual land systems, soils, vegetation communities, and forest types can be located by reference to the index. The land capability classes, indicated for each unit on the land system descriptions, are defined and described in Part VIII.

The extent of land systems was determined with a dot grid (40 dots/sq in) over a 1 : 250,000 map. Relative areas of the constituent units were estimated visually from the aerial photographs and from field experience.

The size of individual areas of land systems that can be shown on the map is limited by the mapping scale. At the scale chosen (1 : 250,000) only areas more than ½ mile wide can be shown, which means that narrower occurrences are included within the boundaries of other land systems. The main unmappable inclusions are noted at the bottom of each land system description.

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

† Formerly Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T. Present address: Department of Mines, Ontario, Canada.

‡ Formerly Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T. Present address: Geography Department, Australian National University, Canberra, A.C.T.

§ Formerly Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T. Present Address: Geography Department, Queen's University, Kingston, Ontario, Canada.

(1) Kaijende Land System* (720 sq miles)

Mountains and escarpments on limestone.

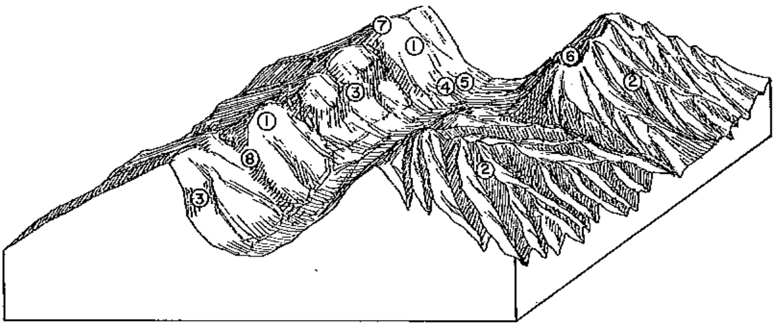
Geology.—Subhorizontal to steeply dipping Tertiary, minor Mesozoic limestone; locally Pleistocene ash.

Landscape Description.—Parallel mountain ridges and escarpments, mainly sharp-crested, locally slightly bevelled. Undercut valley walls.

Landscape Dynamics.—Apparently subject to rapid solution and minor rock slides. Rapid slumping of ash cover.

Altitude.—3500–11,500 ft. Internal relief up to 3000 ft.

Population and Land Use.—1800 people concentrated on 76 sq miles of land used for cultivation (mainly parts of units 4 and 5, but very small parts of most units are gardened in heavily populated parts of the area).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Normal steep slopes, rectilinear, 35–45°, and up to 200 yd long, partly with debris cover or outcropping rock	Much outcrop with humic brown clay soils of Vakari family, minor shallow dark clay soils of Kaijende family	Lower montane rain forest (beech, oak, and mixed). Gardens and garden regrowth. Sword grass and shrub regrowth. Minor montane rain forest	VIII
2	Large	Dip slopes and chevrons, rectilinear, 15–45°, and up to 2000 yd long, partly with debris cover, partly with outcropping rock	Humic brown clay soils of Vakari family with outcrop, minor shallow dark clay soils of Kaijende family on the steepest slopes		VIe–VIII
3	Medium	Precipitous slopes 40–90° and up to 500 yd long; bare rock surfaces on slopes of more than 70°	Much outcrop with shallow dark clay soils of Kaijende family and stony humic brown clay soils of Vakari family	Bare rock or sword grass and shrub regrowth. Lower montane oak and beech rain forest	VIII
4	Small	Slightly concave scree slopes 25–35° and up to 300 yd long; locally hummocky with boulder-covered surfaces	Bouldery humic brown clay soils of Vakari family with stony shallow dark clay soils of Kaijende family	Gardens and garden regrowth. Sword grass and shrub regrowth. Lower montane beech or oak rain forest	VIIe
5	Small	Colluvial aprons with slightly concave slopes 8–20°, up to 200 yd long	Humic brown clay soils of Vakari family, minor reddish clay soils of Herep family		IIIe and VIe
6	Small	Enclosed depressions up to 100 yd wide and 250 ft deep, mainly with very steep side slopes; solution shafts with near-vertical rock walls	Humic brown clay soils of Vakari family	Gardens and garden regrowth. Sword grass and shrub regrowth	VIe
7	Small	Ridge crests up to 50 yd wide attaining 30°, irregular, solution-derived microrelief	Outcrop and shallow dark clay soils of Kaijende family with humic brown clay soils of Vakari family	Lower montane beech or oak rain forest. Locally gardens and garden regrowth. Sword grass and shrub regrowth	VIII
8	Small	Dry gullies up to 200 yd wide, with steep side slopes 30–55°; floor slopes 10–45°	Humic brown clay soils of Vakari and Nenja families with shallow dark clay soils of Kaijende family and rock outcrop on steep slopes	Sword grass and shrub regrowth. Remnants lower montane beech or oak rain forest. Minor gardens and garden regrowth	VIII

*Comparable with Elimbari land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Nembi, Suma, Ambum, Andabare, and Kaugel land systems.

(2) Duma Land System* (30 sq miles)

Mountains and escarpments on limestone.

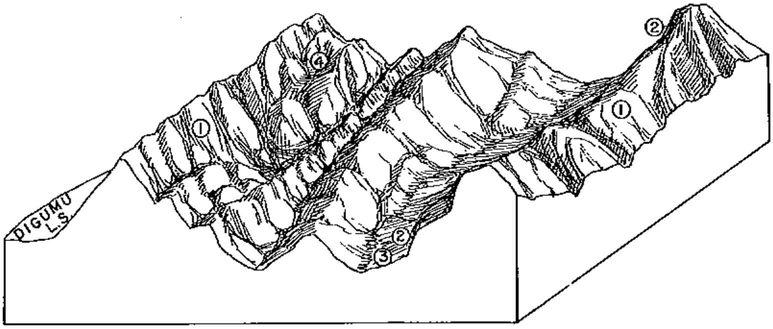
Geology.—Subhorizontal to steeply dipping Tertiary, minor Mesozoic, limestone.

Landscape Description.—Parallel mountain ridges and escarpments, mainly sharp-crested, locally slightly bevelled.

Landscape Dynamics.—Apparently subject to rapid solution and minor rock slides. No stream activity.

Altitude.—2000–3500 ft. Internal relief up to 1000 ft.

Population and Land Use.—Unpopulated. Very small area used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep slopes, rectilinear, 20–40°, partly with debris cover on outcropping rock	Mainly outcrop. No information but probably shallow dark clay soils of Kaijende family	Lowland hill forest	VIII
2	Medium	Precipitous slopes 40–90°			
3	Small	Scree slopes and colluvial aprons	Probably gleyed plastic heavy clay soils of Lombo family and shallow dark clay soils of Kaijende family		VIe.s3, VIe.st
4	Small	Enclosed depressions, up to 100 yd wide and 250 ft deep	Probably deep brown clay soils on floors		VIe

*Unmappable inclusions: Digumu, Hariu, and Kaugel land systems.

(3) Pinnacle Land System* (7 sq miles)

Rugged limestone towers.

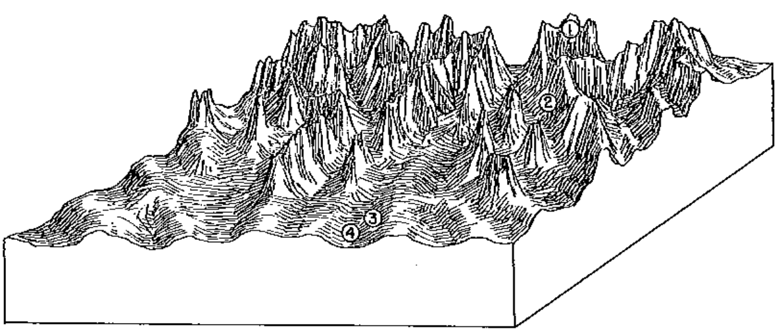
Geology.—Tertiary limestone.

Landscape Description.—Rugged karst. Steep-sided mainly pyramidal hills and spire-crowned towers with precipitous rocky slopes, interspersed with enclosed depressions. No surface drainage.

Landscape Dynamics.—Rapid solution on steeper slopes. Rock sliding.

Altitude.—8000–11,500 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Medium	Very steep tower spires and rocky cliffs	Mainly limestone outcrop, minor shallow dark clay soils of Kaijende family	Bare rock to stunted forest	VIII
2	Medium	Steep hill slopes	Mainly shallow dark clay soils of Kaijende family with outcrop, minor humic brown clay soils of Vakari family	Montane rain forest and lower montane mixed and beech rain forest	VIII
3	Medium	Slopes of enclosed depressions	Probably humic brown clay soils of Nenja family with deep surface soils		VIe.a
4	Small	Floors of enclosed depressions	Mainly moderately drained deep dark clay soils of Tupisanda family, minor humic brown clay soils of Vakari family	Lower montane mixed rain forest. Minor lower montane grassland	I and VId.a

*Unmappable inclusions: Nembi land system.

(4) Nembi Land System* (310 sq miles)

Limestone sink-hole country.

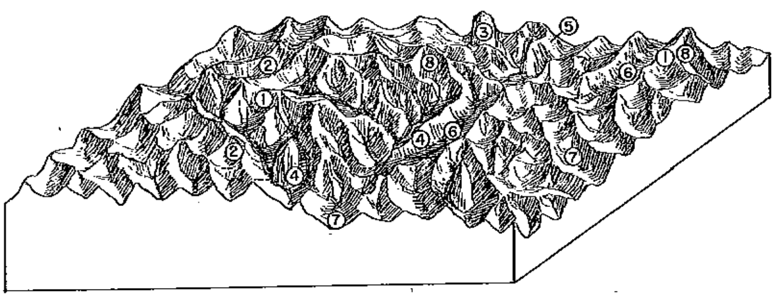
Geology.—Mainly subhorizontal, partly moderately dipping, Tertiary limestone, with occasional high-angle longitudinal faults.

Landscape Description.—Rugged karst with enclosed depressions, pyramids, and towers. Steep-sided mainly pyramidal hills, partly with dip-controlled chevron pattern, and spire-crowned towers with precipitous rocky lower slopes, interspersed with funnel-shaped depressions. Locally fault escarpments. Local surface drainage non-existent.

Landscape Dynamics.—Rapid solution on steeper slopes. Minor rock sliding.

Altitude.—3500–7500 ft. Internal relief up to 500 ft.

Population and Land Use.—10,300 people concentrated on 93 sq miles of land used for cultivation (mostly valley floors and doline floors in the lower and eastern part of the land system).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Medium	Steep hill slopes, commonly rectilinear, 35–45° and up to 100 yd long; up to 55° on dip slopes, partly with debris cover, partly with outcropping rock	Mainly shallow dark clay soils of Kaijende family with outcrop, some humic brown clay soils of Vakari family	Lower montane rain forest (oak, beech, and mixed). Sword grass and shrub regrowth. Minor gardens and garden regrowth	VIII
2	Large	Moderate slopes of enclosed depressions 15–35° and up to 100 yd long	Probably humic brown clay soils of Nenja family with deep surface soils		VIe–VIIe
3	Small	Very steep tower spires, 55–70°, partly covered by debris, partly rock outcrop	Mainly limestone outcrop, minor shallow dark clay soils of Kaijende family	Sword grass and shrub regrowth. Small bare areas. Stunted lower montane rain forest	VIII
4	Small	Rocky cliffs, mainly basal tower walls, 70–90°	Mainly limestone outcrop	Bare rocks or sword grass and shrub regrowth	VIII
5	Small	Fault-scarps, gullied, south-facing slopes, 30–50° and up to 300 yd long	Mainly shallow dark clay soils of Kaijende family with rock outcrop and some humic brown clay soils of Vakari family	Sword grass and shrub regrowth. Lower montane oak or beech rain forest	VIIe–VIII
6	Small	Valley floors	Probably humic brown clay soils of Vakari family	Sword grass and shrub regrowth. Gardens and garden regrowth	IIe–IIIe
7	Small	Floors of enclosed depressions, level surfaces up to 25 yd in extent, broken by small solution shafts	Mainly moderately drained deep dark clay soils of Tupisanda family, minor humic brown clay soils of Nenja family	Lower montane rain forest. Sword grass and shrub regrowth. Garden and garden regrowth	I–IId
8	Very small	Dry gullies, up to 150 yd wide, with steep side slopes 45–55°; floor slopes 40–45°	Mainly shallow dark clay soils of Kaijende family with rock outcrop, some humic brown clay soils of Vakari family	Sword grass and shrub regrowth	VII–VIII

*Unmappable inclusions: Kaijende, Pinnacle, Suma, Nemarep, and Kaugel land systems.

(5) Digumu Land System* (190 sq miles)

Limestone sink-hole country.

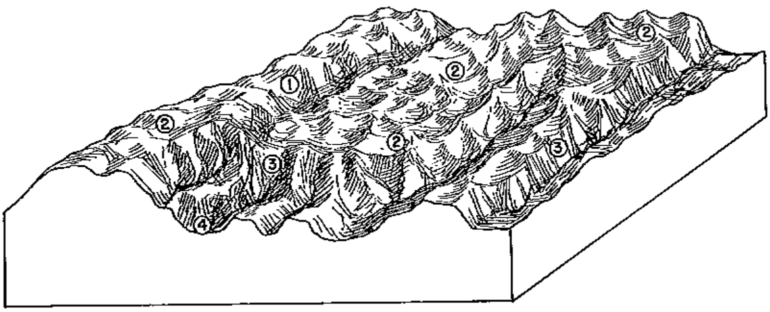
Geology.—Mainly subhorizontal Tertiary limestone.

Landscape Description.—Rugged karst with enclosed depressions, pyramids, and towers. Local surface drainage non-existent.

Landscape Dynamics.—Rapid solution on steeper slopes. Minor rock sliding.

Altitude.—2500–3500 ft. Internal relief up to 500 ft.

Population and Land Use.—Unpopulated. Practically no land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Small	Steep hill slopes, commonly rectilinear, 35–55°	Mainly shallow dark clay soils of Kaijende family with outcrop	Lowland hill forest. Lower montane beech rain forest	VIII
2	Large	Moderate slopes of enclosed depressions, 15–35°	Probably humic brown clay soils of Nenja family with shallow surface soils	Lowland hill forest. Gardens and garden regrowth	VIe
3	Very small	Rocky cliffs, 70–90°	Mainly limestone outcrop	Bare rocks or regrowth	VIII
4	Small	Floors of enclosed depressions, level surfaces broken by small solution shafts	Probably moderately drained deep dark clay soils of Tupisanda family, minor humic clay soils of Nenja family	Lowland hill forest	I–IId

*Unmappable inclusions: Duma, Hariu, Mubi, Tage, and Kaugel land systems.

(6) SUMA LAND SYSTEM* (300 SQ MILES)

Hilly sink-hole country.

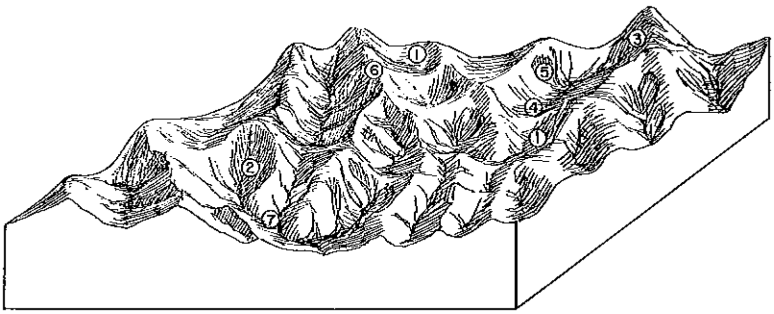
Geology.—Gently to moderately dipping Tertiary calcareous greywacke sandstone, siltstone, and shale, with thin intercalations of pure limestone; partly covered by Pleistocene ash, and very locally by Pleistocene andesitic lava. Recent colluvium, mainly of arenaceous rock, locally containing ash and lava-derived material. Recent fine-textured alluvium.

Landscape Description.—Hilly pattern of enclosed depressions, isolated or in fields, up to 500 ft deep and 2500 yd long, separated by mountains and spurs. Little surface drainage.

Landscape Dynamics.—Slopes subject to cyclic weathering and slumping; removal of soluble and insoluble weathering products through sink holes; insignificant stream erosion.

Altitude.—4000–10,000 ft. Internal relief up to 1000 ft.

Population and Land Use.—7300 people concentrated on 83 sq miles of land used for cultivation (lower-altitude parts, mostly in Nembi and lower Wage River valleys).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Normal side slopes of enclosed depressions, slightly concave, 15–30° and up to 300 yd long	Mainly humic brown clay soils of Vakari family, some humic brown clay soils of Nenja family	Sword grass and shrub regrowth. Gardens and garden regrowth. Remnants of lower montane oak rain forest	VIe–VIIe
2	Medium	Steeper side slopes, 30–45° and up to 100 yd long, covered by small doline-like depressions	Shallow dark clay soils of Kaijende family, some humic brown clay soils of Vakari family		VIIe–VIII
3	Small	Rocky side slopes, steep or precipitous, 45–90°	Mainly rock outcrop	Bare rock	VIII
4	Small	Lower slopes and floors, up to 200 yd wide, gently concave, rolling surfaces attaining 10°, broken by occasional solution shafts	Humic brown clay soils of Vakari family with deep surface soils	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* and *Ischaemum* grasslands. Remnants of lower montane oak and mixed rain forest. Minor lower montane grasslands	IIIe
5	Small	Slump scars, elongate floors, 10–20° and up to 300 yd long	Humic brown clay soils of Nenja family, some humic brown clay soils of Wapenamanda family and some rock outcrop	Sword grass and shrub regrowth	IIIe and VIe
6	Medium	Crests and slopes of mountains and spurs	Humic brown clay soils of Nenja family, some humic brown ash soils of Tabunaka family	Sword grass and shrub regrowth. *Imperata* and *Ischaemum* grasslands. Remnants lower montane oak and beech rain forest	IIIe, VIe; IVe.a, VIe.a
7	Very small	Channels up to 5 yd wide and 10 ft deep, locally calcreted boulder gravel cemented by travertine			

*Unmappable inclusions: Kaijende, Nembi, Ambum, Wongum, Andabare, Nemarep, Kandep, and Kaugel land systems.

(7) Nop Land System* (80 sq miles)

Rounded mountain summit areas.

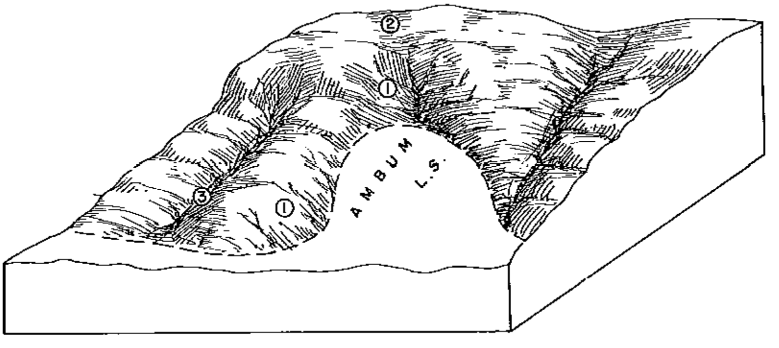
Geology.—Gently to moderately dipping greywacke sandstone, siltstone, and minor conglomerate, shale, and marl, partly Mesozoic, mainly of Tertiary age; partly covered with volcanic ash.

Landscape Description.—Rounded mountain summit areas. Coarse pattern of small subparallel streams.

Landscape Dynamics.—Fairly stable surface.

Altitude.—8000–10,000 ft. Internal relief up to 500 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Slopes 20–40° and up to 800 yd long with rounded salients and re-entrants, undulating or hummocky surfaces	Mainly humic brown clay soils of Vakari family. Humic brown clay soils of Wapenamanda family on ash remnants; gleyed plastic heavy clay soils of Tumundan family on shales. Humic brown clay soils of Nenja family	Lower montane beech rain forest, locally lower montane grassland on lower valley slopes	VIIe.a
2	Large	Rounded crests up to ½ mile wide with convex slopes	Mainly humic brown clay soils of Vakari family, some reddish clay soils of Herep family. Humic brown soils of Wapenamanda family on ash remnants	Montane rain forest and minor alpine grassland	VIe.a
3	Very small	Channels up to 15 ft deep, ungraded and graded beds with boulder gravel			

*Unmappable inclusions: Andabare land system.

(8) Ambum Land System* (1550 sq miles)

Mountains on soft, non-calcareous, sedimentary rocks.

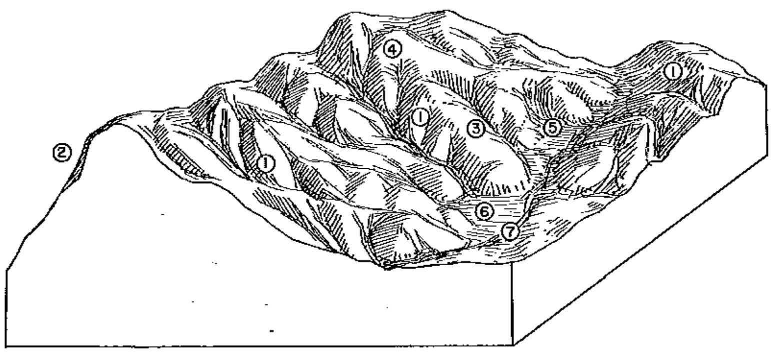
Geology.—Gently to moderately dipping greywacke sandstone, siltstone, and minor conglomerate, shale, marl, and limestone, partly of Mesozoic, mainly of Tertiary age; partly covered by Pleistocene ash.

Landscape Description.—Branching or parallel, steep-sided hill and mountain ridges, generally with narrow crests; locally with strong structural control, forming chevron ridges and minor cuestas. Strongly dissected by a rectangular or subdendritic pattern of narrow valleys with minor colluvial foot slopes.

Landscape Dynamics.—Steep slopes undergoing alternate weathering and slumping at moderate rates, with more rapid slipping in areas with ash cover. Active stream erosion. Slow build-up of colluvial aprons and embayment fills.

Altitude.—Mostly 4000–9000 ft. Some areas as low as 3000 and as high as 11,000 ft. Internal relief up to 2000 ft.

Population and Land Use.—Mostly unpopulated but 53,100 people are concentrated on 526 sq miles of land used for cultivation (lower, broader, and more gently sloping valleys).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Normal steep slopes 20–40° and up to 500 yd long with rounded salients and re-entrants, undulating or hummocky surfaces	Mainly humic brown clay soils of Vakari family. Humic brown clay soils of Wapenamanda family on ash, gleyed plastic heavy clay soils of Tumundan family on shales	Sword grass and shrub regrowth. Gardens and garden regrowth. Lower montane rain forest (oak, beech, and mixed) especially above about 8500 ft. *Casuarina* plantations. *Imperata* and *Ischaemum* grasslands and *Leersia* swamp. Minor lowland hill forest below about 4000 ft	VIe–VIIe, some VIIe.s3
2	Medium	Unusually steep slopes 40–60° and up to 250 yd long with sharper salients and re-entrants	Mainly humic brown clay soils of Nenja family	Lower montane oak or beech rain forest. Sword grass and shrub regrowth	VIII
3	Medium	Dip slopes, mainly smooth, structural surfaces, 5–35° and up to 3000 yd long	Shallow humic brown clay soils of Nenja family with sandstone outcrop, humic brown clay soils of Wapenamanda family on ash	As unit 1	VIe and VIe.st; IIIe on ash soils
4	Very small	Minor rounded crests, up to 50 yd wide, with convex slopes attaining 35°	Mainly humic brown clay soils of Vakari family, some reddish clay soils of Herep family. Humic brown clay soils of Wapenamanda family on ash remnants		VIe
5	Very small	Lower slope-embayments, concave slopes 3–15° and up to 250 yd long in colluvial embayments and alcove floors	Mainly humic brown clay soils of Vakari family, humic brown clay soils of Wapenamanda family on ash colluvium, some peaty soils of Mango family		IIe–IIIe with VId
6	Very small	Gently concave colluvial aprons and toes attaining 10° and up to 400 yd long, locally hummocky or rolling surfaces	Humic brown clay soils of Vakari and Nenja families, gleyed plastic heavy clay soils of Laiagam family. Humic brown clay soils of Wapenamanda family on ash colluvium	Gardens and garden regrowth. Sword grass and shrub regrowth. Lower montane rain forest. Minor lowland hill forest below about 4000 ft	IIIe and IVs3
7	Very small	Channels up to 10 yd wide and up to 15 ft deep, ungraded and graded beds with boulder gravel			

*Comparable with Kuta and Koge land systems of the Goroka–Mt. Hagen area. Unmappable inclusions: Kaijende, Suma, Nop, Wongum, Andabare, Tsang, Laiagam, Tibinini, Kandep, and Kaugel land systems.

(9) Tou Land System (10 sq miles)

Massive sandstone mountains.

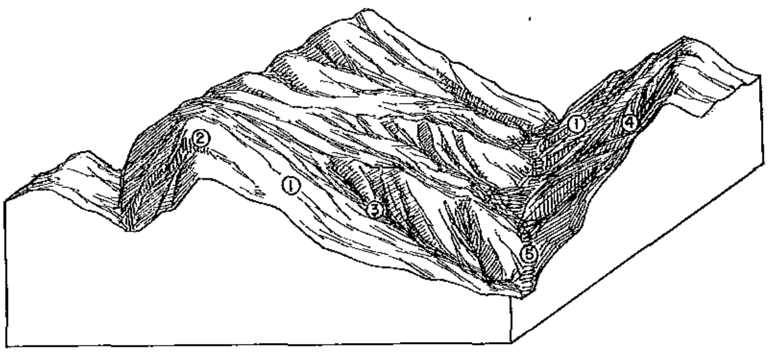
Geology.—Thick sandstone of probable Tertiary age.

Landscape Description.—Massive, steep-sided, sharp-crested mountain ridges. Strongly dissected by sub-parallel gullies consequent on the main slopes.

Landscape Dynamics.—Steep slopes undergoing alternate weathering and slumping at moderate rates. Active stream erosion.

Altitude.—7000–10,000 ft. Internal relief up to 2000 ft.

Population and Land Use.—Unpopulated. Small areas used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep slopes up to 1 mile long with rounded or sharp-crested salients	Fine- to medium-textured skeletal soils high in sandstone boulders, and shallow bouldery members of Vakari family	Lower montane mixed rain forest, cleared areas sword grass and shrub regrowth	VIII
2	Very small	Rounded crests up to 100 yd wide	Humic brown clay soils of Vakari family	Lower montane beech rain forest	IIIe
3	Very small	Gullies on steep slopes	Probably shallow bouldery humic brown clay soils of Vakari family	Lower montane mixed rain forest	VIII
4	Small	Landslip	Shallow bouldery humic brown clay soils of Vakari family becoming deeper on slip floor	Forest cover displaced by landslide	VIe.st–VIIe.st
5	Very small	Channels up to 100 yd wide			

(10) Yalis Land System (25 sq miles)

Benches, slopes, and cliffs.

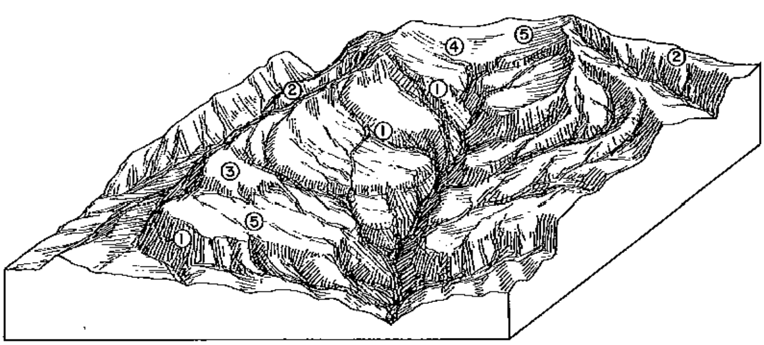
Geology.—Synclinal structure of greywacke sandstone, conglomerate, siltstone, and marl.

Landscape Description.—Escarpments and tilted strike benches, plateau surfaces, cuestas, and very long dip slopes drained by the Angapu and Timina Rivers.

Landscape Dynamics.—Steep slopes undergoing alternate weathering and slumping at moderate rates. Gentle slopes subject to slow slumping, rotational slipping, and creep.

Altitude.—6000–9000 ft. Internal relief up to 1000 ft.

Population and Land Use.—1200 people on 11 sq miles of land used for cultivation (mostly those parts of units 4 and 5 below about 8500 ft above sea level).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Small	Cliffs, steep valley slopes, and crests of strike benches	Mainly outcrop with stony skeletal soils	Stunted lower montane rain forest and *Casuarina* woodland. Sword grass and shrub regrowth	VIII
2	Medium	Ridges and spurs	Shallow humic brown clay soils of Vakari family, with Wapenamanda family on ash remnants	Sword grass and shrub regrowth. *Themeda* and *Imperata* grasslands. Gardens and garden regrowth. Lower montane rain forest	IIIe, VIe.s2–VIIe.s2
3	Small	Tilted strike benches	Humic brown clay soils of Vakari family commonly stony and mottled; minor peaty soils of Mango family in depressions	Gardens and garden regrowth. Sword grass and shrub regrowth	IIIe and VIe.st–minor VId
4	Medium	Saucer-shaped structural plateaux	Mainly humic brown clay soils of Vakari family, with Wapenamanda family on ash remnants; minor peaty soils of Mango family	Gardens and garden regrowth. Sword grass and shrub regrowth. Lower montane beech rain forest on higher sites. Minor *Leersia* swamp	IIe–IIIe, IVe.a, locally VId
5	Large	Long slopes	Mainly shallow humic brown clay soils of Vakari family, reddish clay soils of Herep family	Gardens and garden regrowth. Sword grass and shrub regrowth. Lower montane rain forest	VIIe

(11) Wongum Land System* (330 sq miles)

Hilly country on soft, sedimentary rocks.

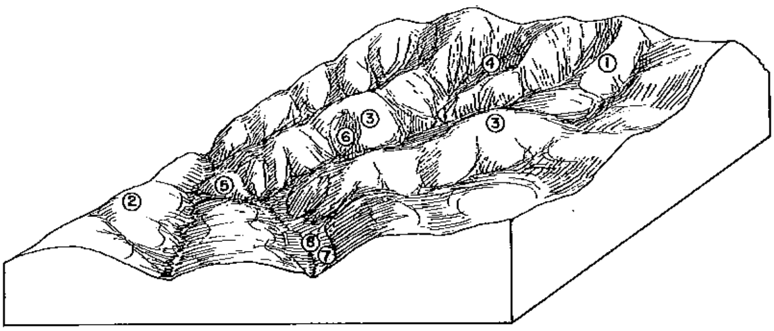
Geology.—Moderately dipping Tertiary, minor Mesozoic greywacke sandstone, siltstone, shale, and marl; locally limestone, partly covered by Pleistocene ash, and locally by Pleistocene andesitic lava.

Landscape Description.—Low hills, spurs, and branching hill ridges with rounded crests, steep sides, and smooth gentle foot slopes marginal to and including remnants of an upland surface; gentle slopes below limestone escarpments. Dendritic drainage incised up to 250 ft.

Landscape Dynamics.—Slow slumping, rotational slipping, and creep on all slopes. Steeper slopes subject to rapid slumping of ash cover and weathering profile. Little vertical stream erosion.

Altitude.—4000–8000 ft. Internal relief up to 250 ft.

Population and Land Use.—32,700 people on 266 sq miles of land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Medium	Undulating upland ash slopes with concave slopes attaining 15° and up to 1000 yd long	Humic brown clay soil of Wapenamanda and Tabunaka families, humic olive ash soils of Meriunda family	Sword grass and shrub regrowth. Gardens and garden regrowth. Minor *Imperata*, *Themeda*, and *Ischaemum* grasslands. Remnants of lower montane oak rain forest. Minor sedge and *Leersia* swamp	IIe–IIIe, IIId in depressions
2	Small	Ridge crests, convex slopes up to 15° and up to 200 yd long	Mainly humic brown clay soil of Vakari family, reddish clay soils of Herep family		IIIe
3	Very large	Hill and valley side slopes 15–40° and up to 400 yd long	Humic brown clay soils of Nenja family, humic brown clay soils of Wapenamanda family on ash remnants, minor humic brown clay soils of Ivivar family		VIe–VIIe
4	Small	Hill slope re-entrants with concave slopes 3–15° and up to 200 yd long	Mainly humic brown clay soils of Vakari family, some humic brown clay soils of Wapenamanda family on ash remnants		IIIe
5	Small	Colluvial aprons and toes attaining 10° and up to 500 yd long	Mainly humic brown clay soils of Vakari family, gleyed plastic heavy clay soils of Lombo family in depressions. Ash remnants, humic brown clay soils of Wapenamanda family, humic olive ash soils of Meriunda family in depressions		IIIe and IVs3
6	Very small	Slump alcoves with steep bounding slopes up to 70° and up to 300 yd long, locally with bare weathered rock surfaces; stepped floors with concave slopes 5–20° and up to 200 yd long	Mainly humic brown clay soils of Tabunaka family, deep dark clay soils of Tupisanda and Muriraga families	Sword grass and shrub regrowth, locally bare. Gardens and garden regrowth. *Leersia* swamp	Walls VIII, floors IIIe and VIe, minor VId
7	Very small	Flood-plains up to 75 yd wide with concave margins backing colluvial toes	Medium-textured recent alluvial soils with old alluvial clay soils on margins	*Leersia* and *Phragmites* swamp	VId,f
8	Very small	Channels up to 5 yd wide and 15 ft deep			

*Comparable with Kumun land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Kaijende, Suma, Andabare, Laiagam, Tibinini, Ko, Kandep, and Kaugel land systems.

(12) ANDABARE LAND SYSTEM* (100 SQ MILES)

Upland valleys with natural grassland.

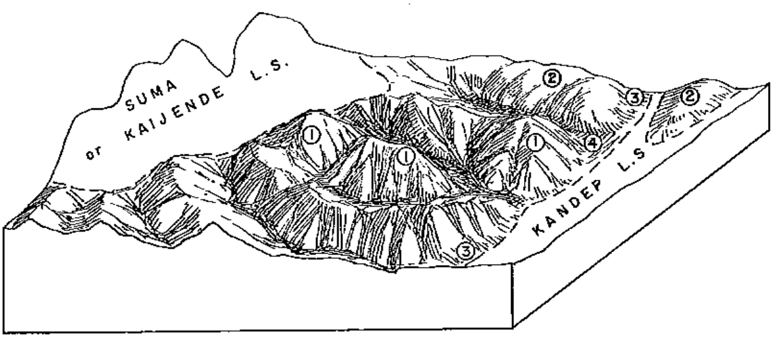
Geology.—Gently to moderately dipping greywacke sandstone, siltstone, and minor conglomerate, shale, and marl, partly Mesozoic, mainly of Tertiary age; colluvium derived therefrom; locally covered by volcanic ash.

Landscape Description.—Dissected slopes and fans found mainly below escarpments. Drainage subparallel.

Landscape Dynamics.—Rapid slumping, rotational slipping, and creep on all slopes. Strong colluviation.

Altitude.—8000–9000 ft. Internal relief up to 500 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Moderate to steep slopes of sharp-crested, subparallel ridges up to 500 yd long	Gleyed plastic heavy clay soils of Laiagam family	Lower montane grassland	VIe.s3.a
2	Very small	Rounded crests up to 200 yd wide with convex slopes	Gleyed plastic heavy clay soils of Pumakos family; minor humic brown clay soils of Vakari family		VIs3.a
3	Very small	Lower gentle slopes 5–10° and up to 500 yd long	Gleyed plastic heavy clay soils of Laiagam family		VIs3.a
4	Very small	Plains	Fine-textured alluvial soils. Depressions with gleyed plastic heavy clay soils of Pumakos family and peaty soils of Tirriraga family	Sedge bog. Lower montane grassland	VIId.a, IVa, and VIs3.a on terraces

*Unmappable inclusions: Kaijende, Suma, Ambum, and Kandep land systems.

(13) Tsang Land System* (35 sq miles)

Densely dissected mountains.

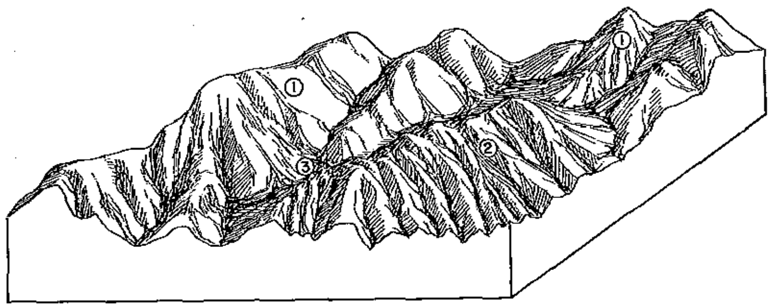
Geology.—Tuffaceous sandstone and sandstone and mudstone of Tertiary age; local ash cover.

Landscape Description.—Mountains and hills of densely dissected ridges locally with strong structural control.

Landscape Dynamics.—Steep slopes undergoing alternate weathering and slumping at moderate rates, with more rapid slipping in areas of ash cover. Active stream erosion.

Altitude.—*7000–8500 ft. Internal relief 200–800 ft.*

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Ridges with irregular crests and very steep slopes	*Mainly humic brown clay soils of* Vakari family becoming shallower on ridge crests and top slopes. Humic brown clay soils of Wapenamanda family on ash remnants—mainly lower slopes	Lower montane mixed and beech rain forest	VIIe–VIII
2	Medium	Chevron ridges			VIIe–VIII
3	Small	Colluvial slopes	Probably humic brown clay soils of Vakari family diffusely mottled		IIIe

*Unmappable inclusions: Ambum land system.

(14) Laiagam Land System* (95 sq miles)

Unstable slopes on mudstone.

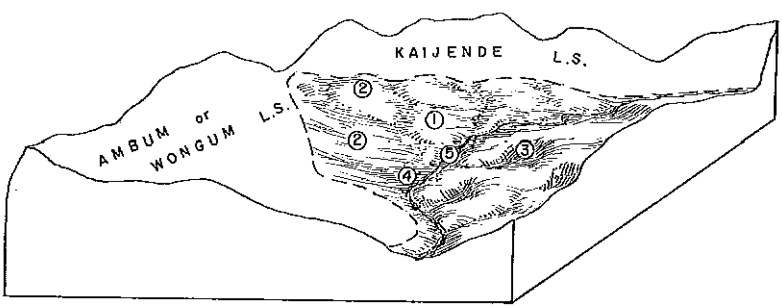
Geology.—Gently dipping Tertiary, minor Mesozoic, mudstone and shale, commonly with a surficial debris cover of andesitic lava, limestone, or sandstone, and locally with colluviated ash of Recent age.

Landscape Description.—Foot slopes of moderate gradient, mainly below escarpments, forming elongate, relatively low-lying tracts up to 3 miles wide. Partly hummocky, partly smooth in profile.

Landscape Dynamics.—Partly subject to rapid modification by continuous slumping and sliding. Very unstable slopes.

Altitude.—4000–9000 ft. Internal relief up to 50 ft.

Population and Land Use.—6000 people on 45 sq miles of land used for cultivation (that part below about 8500 ft above sea level).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Unstable hummocky slopes 2–15° and up to 1500 yd long	Mainly shallow gleyed plastic heavy clay soils of Tibiri family, minor humic brown clay soils of Vakari family	Sword grass and shrub regrowth. Gardens and garden regrowth. *Casuarina* plantations. Small areas *Imperata* grassland. Highland *Pandanus* swamp. *Leersia* swamp in hollows. Remnants of lower montane rain forest (oak, beech, and bog)	VIe.s3, VIId in hollows
2	Medium	Stable smooth slopes 2–10° and up to 500 yd long	Humic brown clay soils of Vakari and Nenja families, some gleyed plastic heavy clay soils of Lombo family		IIIe, IVs3
3	Small	Slump alcoves with bounding slopes 15–40° and up to 100 yd long; floors sloping 3–10°, very unstable	Shallow stony humic brown clay soils of Vakari family, some shallow gleyed plastic heavy clay soils of Tibiri family	Sword grass and shrub regrowth. Lower montane oak rain forest with some beech	VIe.s3 on floors, VIe.st–VIIe.st on walls
4	Very small	Discontinuous flood-plains up to 100 yd wide	Fine-textured recent alluvial soils, peaty soils of Tirriraga and Mango families	*Phragmites* swamp. *Casuarina* plantations	VIId.f
5	Very small	Channels up to 20 yd wide and up to 30 ft deep, ungraded floors, sloping 2–15°			

*Comparable with Womei land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Wongum, Suma, and Kaugel land systems.

(15) Tibinini Land System* (130 sq miles)

Long gentle slopes.

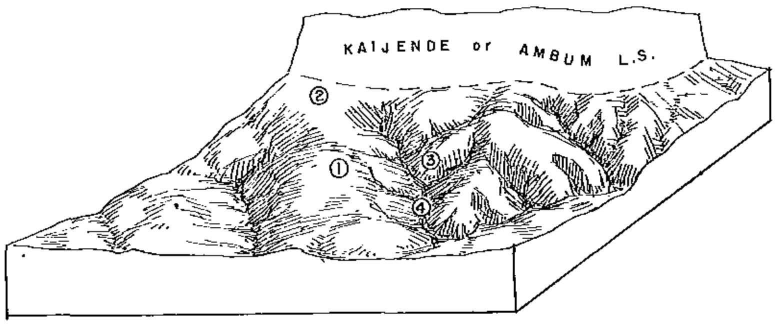
Geology.—Sandstone and siltstone of Tertiary age and Pleistocene and Recent colluvium derived therefrom; locally covered by Pleistocene ash.

Landscape Description.—Partly dissected colluvial foot slopes, and fans of combined alluvial and colluvial origin, found mainly below escarpments; locally dissected into flattish-crested ridges by subparallel drainage incised up to 100 ft.

Landscape Dynamics.—Gentle slopes relatively stable; moderate slumping on steep slopes.

Altitude.—4000–8000 ft. Internal relief up to 100 ft.

Population and Land Use.—2900 people concentrated on 33 sq miles of land used for cultivation (mostly those parts below about 8500 ft above sea level but in the west the headwaters of the Pai-era River are unpopulated).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Undulating gentle concave slopes 5–10° and up to about 2000 yd long	Mainly humic brown clay soils of Nenja family. Gleyed plastic heavy clay soils of Tumundan family, humic brown clay soils of Tabunaka and Wapenamanda families	Sword grass and shrub regrowth. Locally gardens and garden regrowth. *Imperata*, *Ischaemum*, and some *Themeda* and *Capillepedium* grasslands. *Leersia* swamp. Lower montane rain forest	IIe–IIIe
2	Small	Short steep upper slopes	Moderately drained deep dark clay soils of Tupisanda family, some humic brown clay soils of Nenja family	Lower montane oak rain forest. Sword grass and shrub regrowth. *Ischaemum* grassland	VIe
3	Small	Steep valley sides, irregularly broken, 20–25° and up to 100 yd long	Stony humic brown clay soils of Nenja and Yakari families, reddish clay soils of Herep family	Sword grass and shrub regrowth. Locally gardens and garden regrowth. Lower montane rain forest. Minor *Themeda* grassland	VIe.st
4	Very small	Channels			

*Unmappable inclusions: Ambum land system.

(16) Hariu Land System* (65 sq miles)

Long gentle slopes and low hills on soft sedimentary rocks.

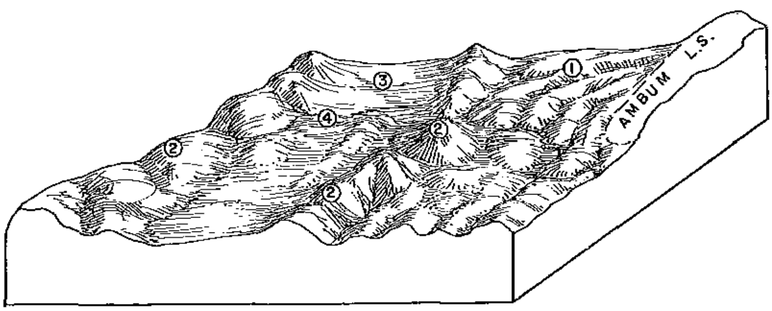
Geology.—Siltstone and mudstone of Tertiary age and colluvium therefrom.

Landscape Description.—*Partly* dissected colluvial foot slopes and fans of combined alluvial and colluvial origin, found mainly below escarpments. Some low hills and ridges. Sparse subparallel drainage.

Landscape Dynamics.—Gentle slopes relatively stable; moderate slumping on steeper slopes.

Altitude.—2500–3500 ft. Internal relief up to 500 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Long gentle slopes 5–10° and up to 3000 yd long	Mainly gleyed plastic heavy clay soils of Lombo and Tumundan families, locally humic brown clay soils of Nenja family	Lowland hill forest	VIe.s3, some VIe
2	Small	Low hills and ridges	Probably humic brown clay soils of Nenja family		VIe–VIIe
3	Small	Long hummocky slopes up to 1 mile long on mudstones	Mainly shallow, gleyed plastic heavy clay soils of Tibiri family, minor humic brown clay soils of Nenja family		VIe.s3, some VIe
4	Very small	Channels			

*Unmappable inclusions: Duma, Digumu, and Ambum land systems.

(17) KAGUA LAND SYSTEM (25 SQ MILES)

Plains and terraces.

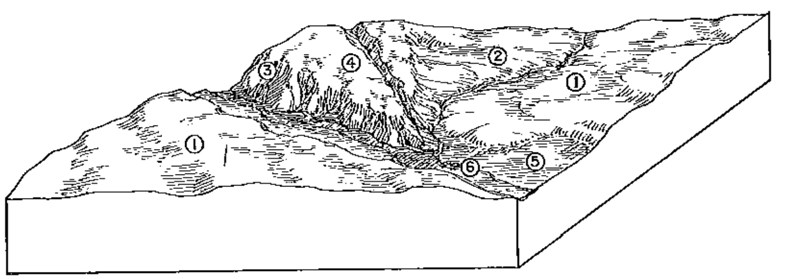
Geology.—Mesozoic and Tertiary marl, siltstone, greywacke sandstone; partly covered by Pleistocene ash and fine-textured alluvium of Recent age.

Landscape Description.—Plains and marginal colluvial fans, aprons, and toes. Traversed by meandering channels and subject to irregular flooding. Marginally dissected up to 150 ft by a dendritic pattern of local drainage.

Landscape Dynamics.—Rapid slumping of valley slopes and related rapid flood-plain extension. Slow alluviation in meander tracts.

Altitude.—4500–5500 ft. Internal relief up to 150 ft.

Population and Land Use.—3400 people. All land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Gently undulating plains up to 2500 yd in extent, with slopes less than 4°	Gleyed plastic heavy clay soils of Lombo family, peaty soils of Tirriraga family, humic brown clay soils of Nenja family on well-drained sites	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* and *Ischaemum* grasslands. *Leersia* swamp, sedge bog. Remnants lower montane rain forest (oak, beech, and bog)	IVs3; locally I–IIe, VIId in depressions
2	Medium	Moderate slopes of colluvial fans and plain margins, attaining 9° and up to 1000 yd long	Humic brown clay soils of Vakari family, humic brown clay soils of Wapenamanda family on ash, minor gleyed plastic heavy clay soils of Tumundan family	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* grassland. Some *Leersia* swamp. Lower montane oak rain forest	IIe–IIIe, IIs3
3	Very small	Steep slopes 15–35° and up to 100 yd long, with convex upper sectors 5–10°; slump scars with short, very steep bounding slopes	Gleyed plastic heavy clay soils of Tumundan family on steep slopes, humic brown clay soils of Wapenamanda and Vakari families on upper sectors	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* grassland. Remnant lower montane oak rain forest	VIe–VIIe
4	Small	Gently undulating terrace surfaces	Gleyed plastic heavy clay soils of Tumundan family, some humic brown clay soils of Nenja family	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* grassland. Remnant lower montane oak forest	IIs3
5	Small	Alluvial plains up to 1500 yd in extent, locally boggy and including swampy flood-plains up to 100 yd wide	Medium-textured recent alluvial soils, peaty soils of Tirriraga family, poorly drained deep dark clay soils of Tupisanda family	*Imperata* and *Ischaemum* grasslands. *Leersia* and *Phragmites* swamp. Sedge bog. Remnant lower montane oak rain forest. *Casuarina* plantations. Gardens and garden regrowth	IId–IIId, IVf.d, VIId on peat soils
6	Very small	Graded channels up to 10 yd wide and up to 15 ft deep; poorly graded channels up to 5 yd wide and up to 10 ft deep, with boulder gravel			

(18) Nose Land System (100 sq miles)

Rugged mountains on intrusive rocks.

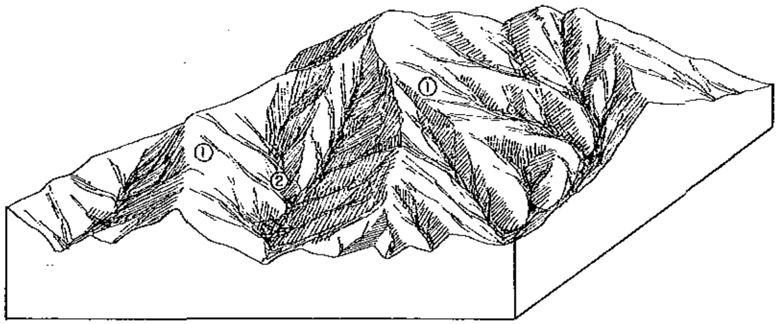
Geology.—Basic intrusive rocks of Pliocene age; dolerite, gabbro, and diorite; probably also andesitic volcanic rocks. Partly covered with Pleistocene ash.

Landscape Description.—Mountains densely and strongly dissected into branching rounded spurs. Dense dendritic to subparallel drainage pattern.

Landscape Dynamics.—Slopes fairly stable, moderate slumping in areas of ash cover. Active stream erosion.

Altitude.—5000 generally to 8000 ft, up to 9000 ft in southern occurrences. Internal relief 500 to 1500 ft.

Population and Land Use.—Unpopulated. Small area of land used for cultivation adjacent to heavily populated land systems.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep slopes of mountains and ridges	Unknown. Probably mainly humic brown clay soils of Vakari family with some reddish clay soils of Herep family	Mostly lower montane mixed and beech rain forest. Locally gardens and garden regrowth and sword grass and shrub regrowth	VIe–VIIIe
2	Small	Channels			

(19) Silim Land System (50 sq miles)

Hills and mountains on intrusive rocks.

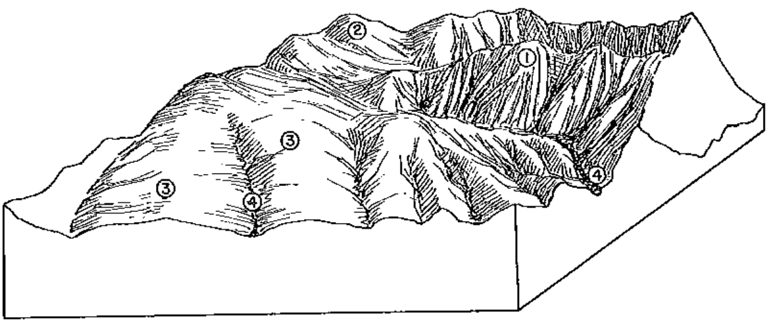
Geology.—Basic igneous rocks of Pliocene age; dolerite, gabbro, diorite, and andesite porphyry; generally thick ash cover.

Landscape Description.—Rounded hills and ridges including remnants of an upland surface. Moderately to deeply incised dendritic drainage.

Landscape Dynamics.—Slopes undergoing alternate weathering and slumping. Active stream erosion on steeper parts.

Altitude.—6500–8500 ft. Internal relief up to 1000 ft.

Population and Land Use.—1600 people concentrated on 16 sq miles of land used for cultivation (parts of units 2 and 3).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Medium	Sharp-crested ridges, densely dissected, slope 35–40°	Humic brown clay soils of Wapenamanda and Vakari families	Lower montane oak rain forest. Sword grass and shrub regrowth	VIIe–VIII
2	Medium	Rounded low ridges, slope 15–20°	Mainly humic olive ash soils of Meriunda family, minor reddish clay soils on sandstones and humic brown clay soils on gabbro	Lower montane oak rain forest. Sword grass and shrub regrowth. Locally gardens and garden regrowth	VIe
3	Medium	Long undulating gentle slopes 5–15°	Mainly humic olive ash soils of Klareg family, some gleyed plastic heavy clay soils of Tumundan family on sandstone		IIIe.s3 and IVe.s3
4	Very small	Small channels			

(20) Giluwe Land System* (65 sq miles)

Summit area of Mt. Giluwe.

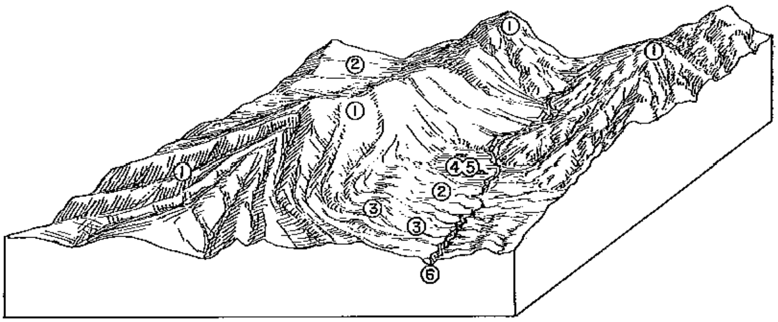
Geology.—Gently dipping Pleistocene andesitic lava and scoria flows, partly covered by late Pleistocene glacial, fluvioglacial, and colluvial deposits and by Recent peat.

Landscape Description.—Summit area of Mt. Giluwe and Mt. Hagen. Steep-sided ridges, towers, pinnacles, and cliffs with fossil glacial and periglacial land forms of alpine type including floors and lower slopes of amphitheatral, catenary glacial valleys, with prominent lateral moraines on interfluves in outer sectors, and extensive flights of low terminal moraines on valley floors. Disorganized internal drainage with numerous small ponds.

Landscape Dynamics.—An inherited, apparently stable landscape. Stream incision at outer margins

Altitude.—10,000–13,660 ft. Internal relief up to 2000 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep slopes and cliffs 30–90°, mostly rocky with many small rock ledges and scarps, minor scree slopes, relief up to 2000 ft	Mainly rock outcrop and shallow peaty soils of Giluwe family	Alpine grassland with islands of montane rain forest	VIII
2	Large	Smooth, gently undulating, or hummocky valley floors and summit plains; slopes 3–15° and up to 4500 yd long; structural rock ledges and scarps, minor roches moutonnées with slopes up to 20°; patchy morainic cover	Mainly shallow peaty soils of Giluwe family. Rock outcrop on ledges and scarps		VId.a with VIII
3	Small	Prominent lateral moraines 100–300 ft high, with sharp crests and steep slopes 25–30°; multiple terminal moraines 10–100 ft high, with slopes 15–25°	Shallow peaty soils of Giluwe family, commonly very stony	Alpine grassland and transition to montane rain forest	VIIe.a
4	Very small	Plains up to 300 yd in extent, with boggy surfaces, sloping less than 1°	Mainly peaty soils of Giluwe family, commonly very deep	Alpine grassland and alpine peat bog	VIId
5	Very small	Lakes 6–18 in. deep, with level floors mainly up to 50 yd in extent; in units 2 and 4		Alpine peat bog	
6	Very small	Steep-sided, trench-like channels up to 75 yd wide and 50–300 ft deep	Unspecified clays and mucky clays	Alpine grassland and alpine peat bog	VIId

*Comparable with Wilhelm and Astelia land systems of the Goroka–Mt. Hagen area.

(21) Ialibu Land System* (100 sq miles)

Rugged volcanic mountains.

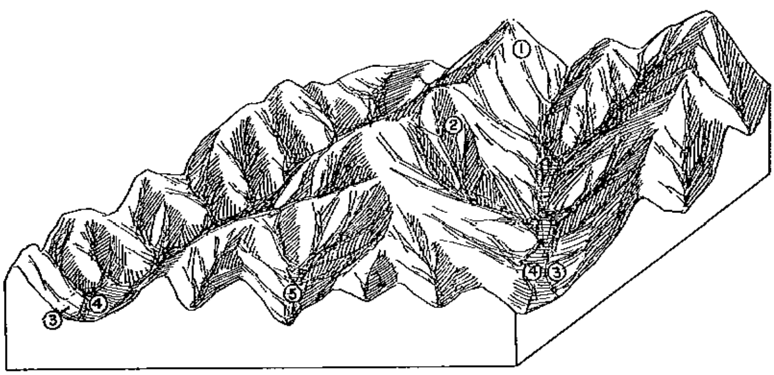
Geology.—Pleistocene andesitic and rhyolitic rocks, locally covered by Pleistocene ash.

Landscape Description.—Rugged volcanic mountains, with steep or precipitous slopes; minor gentle colluvial foot slopes along major valleys and alluvial slopes at their exits; radial or subdendritic pattern of valleys up to 1500 ft deep.

Landscape Dynamics.—Presumably moderate slumping on steep slopes; active stream erosion.

Altitude.—Mostly 7000–10,000 ft, locally as low as 4000 ft. Internal relief up to 1500 ft.

Population and Land Use.—Unpopulated. Small area of land used for cultivation (part of unit 3).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep and precipitous slopes 30–70° and up to 500 yd long, with sharp salients and re-entrants	Probably some outcrop with stony humic brown clay soils of Vakari family. Locally humic brown clay soils of Wapenamanda family	Lower montane rain forests (oak, beech, or mixed). Sword grass and shrub regrowth	Mainly VIII
2	Small	Rocky cliffs up to 500 ft high, slopes above 70°	Minor amounts of stony skeletal soils, mainly rock outcrop	Lower montane beech rain forest	VIII
3	Small	Gentle colluvial foot slopes 5–20° and up to 100 yd long	Probably humic brown clay soils of Vakari family on lava, with Wapenamanda family and humic olive ash soils of Meriunda family on ash	Gardens and garden regrowth. Sword grass and shrub regrowth. Planted *Pandanus* groves. Lower montane oak rain forest	VIe.st
	Small	Alluvial fills with undulating surfaces up to 50 yd wide, attaining 5°	Probably mainly stony humic brown clay soils of Vakari family	Lower montane rain forest (oak or mixed). Sword grass and shrub regrowth. *Ischaemum* grassland	Vst
5	Very small	Channels up to 20 yd wide and 20 ft deep, mainly ungraded beds locally with rapids or waterfalls			

*Unmappable inclusions: Nemarep land system.

(22) Doma Land System* (330 sq miles)

Volcanic mountains and hills.

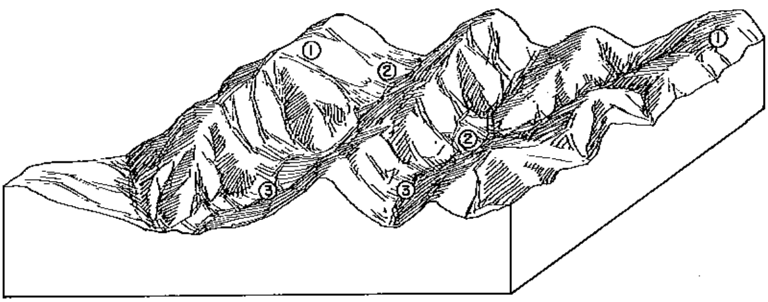
Geology.—Pleistocene basaltic and andesitic lava flows with minor scoria and agglomerate. Locally covered by Pleistocene ash.

Landscape Description.—Mountain and hill ridges with steep slopes; minor gentle colluvial foot slopes along major valleys; radial or subdendritic pattern of valleys.

Landscape Dynamics.—Moderate slumping on steep slopes; active stream erosion.

Altitude.—3500–8000 ft. Internal relief up to 500 ft.

Population and Land Use.—1600 people concentrated on 27 sq miles of land used for cultivation (lower parts of land system in Benaria census division).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep slopes 15–60° and up to 300 yd long	Humic brown clay soils of Vakari family, humic brown clay soils of Wapenamanda family on ash, local rock outcrop	Lower montane oak, beech, or mixed rain forest. Sword grass and shrub regrowth. Minor gardens and garden regrowth	VIIe–VIII
2	Small	Gentle colluvial foot slopes 5–20° and up to 200 yd long	Probably humic brown clay soils of Nenja and Vakari families, humic brown clay soils of Wapenamanda and Tabunaka families on ash	Gardens and garden regrowth. Sword grass and shrub regrowth. Lower montane oak rain forest	IIIe and VIe
3	Very small	Channels up to 20 yd wide and 20 ft deep, graded and ungraded beds			

*Unmappable inclusions: Nemarep, Ialibu, Kwandi, Tari, and Kaugel land systems.

(23) Sugarloaf Land System* (95 sq miles)

High-altitude volcanic plateaux.

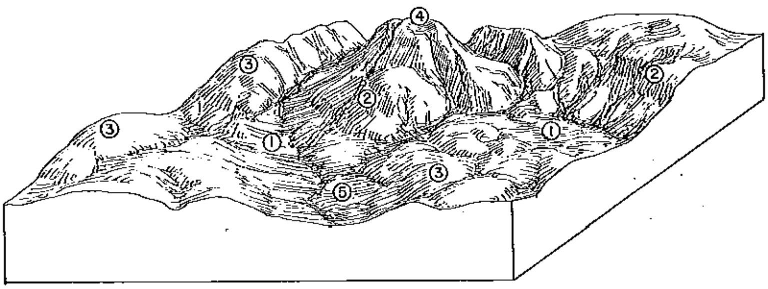
Geology.—Mainly andesitic lava, with local exposures of underlying sedimentary rocks.

Landscape Description.—Undulating to hilly volcanic plateaux in mountain summit areas; rather sparse pattern of incised meandering streams.

Landscape Dynamics.—Slumping on steeper slopes and stream incision at margins. Active peat formation.

Altitude.—9000–13,000 ft. Internal relief mainly less than 500 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Poorly drained flat to undulating surfaces, with boggy areas	Probably deep peaty soils of Mango family, some Kiakau family	Lower montane and alpine grassland, with sedge bog and alpine peat bog on swampy parts	VId.a–VIII
2	Medium	Steep slumped hill and valley slopes with local benches 200–400 ft high	Shallow peaty soils of Wapu family, humic brown clay soils of Nenja family	Mainly alpine grassland, locally lower montane beech rain forest	VIIe.a
3	Medium	Moderately dissected rounded low hills and ridges 200–400 ft high	Humic brown clay soils of Nenja family, with minor shallow peaty soils of Wapu family	Lower montane beech rain forest	VIe.a
4	Small	Dome-shaped hills, mostly 200–600 ft high, 1500 ft for The Sugarloaf dome	Shallow peaty soils of Wapu family, with humic brown clay soils of Nenja family	Lower montane beech rain forest and montane rain forest, commonly lower montane grassland on lower slopes, and alpine grassland on summit of The Sugarloaf	VIIe.a
5	Small	Flood-plains and colluvial valley slopes	Mainly peaty soils of Tirriraga family with some medium-textured recent alluvial soils high in organic matter	Mainly sedge bog, some grass–sedge bog	VIId.a

* Unmappable inclusions: Wongum and Ambum land systems.

(24) Dibibi Land System (25 sq miles)

Upland basins on volcanic rocks in Doma Peaks area.

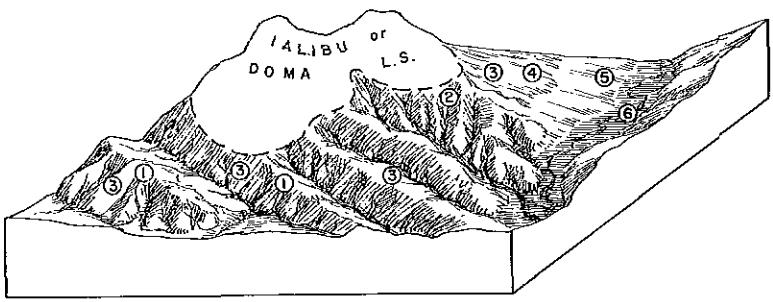
Geology.—Pleistocene andesitic lava and agglomerate, with a cover of Pleistocene ash of variable thickness. Colluvium of presumably Pleistocene and Recent age.

Landscape Description.—Upland basins on faulted and eroded volcanic deposits. Subdued rounded ridges, colluvial aprons and valley fills. Subparallel pattern of valleys incised up to 300 ft. Drainage channels absent in lower-order valleys.

Landscape Dynamics.—Rapid slumping on ridge slopes, causing active accretion of colluvial surfaces; creep on gentle surfaces.

Altitude.—7500–9500 ft. Internal relief up to 300 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Small	Ridge crests with undulating surfaces up to 50 yd wide, attaining 5°	Humic olive ash soils of Meriunda family	Sword grass and shrub regrowth. *Imperata* grassland. Lower montane grasslands on higher sites	IVe.s3.a
2	Small	Steep ridge slope 25–45° and up to 100 yd long, straight or indented by slump alcoves with steep back walls	Humic brown clay soils of Tabunaka family	Sword grass and shrub regrowth, merging with altitude to lower montane grasslands. Minor lower montane beech rain forest with many included conifers	VIIe.a
3	Large	Concave–convex ridge slopes 15–25° and up to 100 yd long, covered by many stabilized slump alcoves with concave bounding slopes 15–20°	Humic olive ash soils of Meriunda family	Lower montane grasslands. Sword grass and shrub regrowth. *Imperata* grassland	VIe.a
4	Small	Upper sectors of colluvial aprons with even, boggy slopes 2–10° and up to 150 yd long	Humic olive ash soils of Meriunda family	Lower montane grassland. Sword grass and shrub regrowth. *Imperata* grassland. Wettest places with sedge bogs	IVe.s3.a
5	Small	Lower sectors of colluvial aprons with even slopes less than 2° and up to 100 yd long, subject to irregular flooding	Probably poorly drained deep dark clay soils of Muriraga family and some humic olive ash soils of Meriunda family	Sword grass and shrub regrowth. *Imperata* grassland. Sedge bogs in dampest places	IVd.a
6	Very small	Channels up to 5 yd wide and 10 ft deep, with graded beds		Fringing low trees including conifers with sword grass intermixed or in pure stands	

(25) Lava Land System (10 sq miles)

Gently sloping margins of the summit area of Mt. Giluwe.

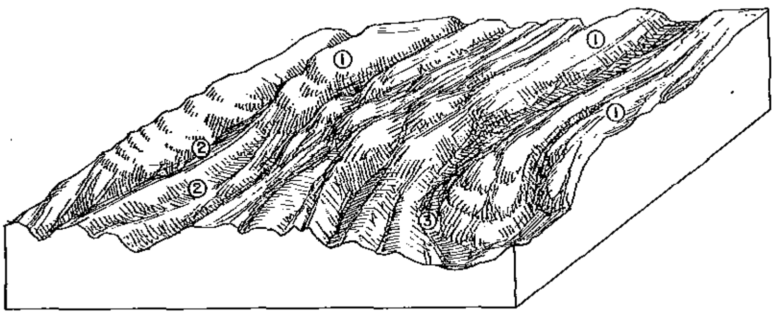
Geology.—Pleistocene andesitic and basaltic lava and scoria flows.

Landscape Description.—Relatively undissected gentle upper volcanic slopes characterized by minor slump features and extensively smoothed by colluvial deposition and peat formation. Radial pattern of slightly incised drainage with little tributary development.

Landscape Dynamics.—Minor slumping on steeper slopes and corresponding accumulation of colluvium. Active peat formation.

Altitude.—9500–11,500 ft. Internal relief up to 200 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Convex slope sectors with undulating to hummocky surfaces, mainly 5–15°, locally up to 20° and up to 300 yd long; structurally controlled steps, frequent shallow slump scars; local relief up to 30 ft	Mainly peaty soils of Dibibi family, some Giluwe family	Lower montane and alpine grasslands	VId.a
2	Medium	Colluvial slopes with slightly concave or straight smooth surfaces up to 200 yd long, 2–10°	Peaty soils of Dibibi family	Lower montane and alpine grasslands, alpine peat bog, and sedge bog	VIId.a
3	Small	Incised valleys up to 75 yd wide and 50–200 ft deep; steep, mainly straight bounding slopes 25–35°	Matted grass roots over bed-rock	Montane rain forests mainly on side slopes above lower montane grassland. Otherwise open alpine grassland	VIII

(26) Nemarep Land System* (650 sq miles)

Long gentle volcanic slopes.

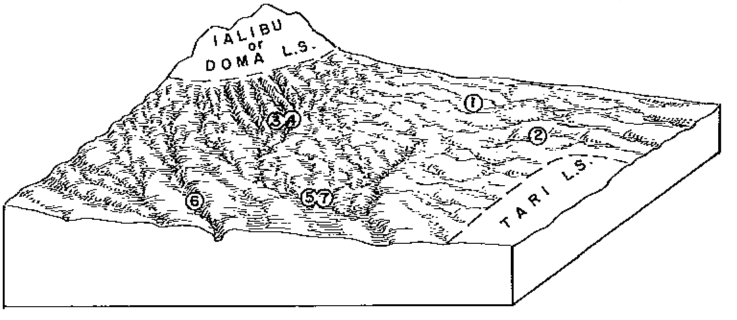
Geology.—Gently or moderately dipping Pleistocene andesitic lava flows, scoria, and laharic accumulations, covered by ash which increases in thickness downslope; minor Recent peat.

Landscape Description.—Volcanic slopes 2–10°, steepening to 10–20° on the south side of Mt. Giluwe, up to 15 miles long, partly dissected into subparallel ridges and spurs up to 200 ft high by radial drainage.

Landscape Dynamics.—Undergoing rapid modification by stream erosion, by slumping of regolith on steeper slopes, and by slow rotational slipping on gentler slopes.

Altitude.—5000–10,000 ft. Internal relief up to 200 ft.

Population and Land Use.—8600 people on 142 sq miles of land used for cultivation (lower parts of land system, below 8500 ft above sea level).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Medium	Gentle slopes with smooth or knobby surfaces, 2–10° and up to 5000 yd long	Humic brown clay soils of Wapenamanda family and humic olive ash soils of Meriunda family on ash. Humic brown clay soils of Vakari family and minor gleyed plastic heavy clay soils of Lumbi family on lava	Lower montane rain forests of mixed, oak, or beech type. Highest sites with montane rain forest. Sword grass and shrub regrowth below about 7800 ft	IIe.s3, IIc–IIIc, IVe.s3.a
2	Small	Depressions on gentle slopes, up to 500 yd in extent	Humic olive ash soils of Klareg family and peaty soils of Mango family	Sedge and grass–sedge bog	IVs3, VId, VId.a
3	Large	Spur and ridge crests and slopes with flattish or slightly rounded crests up to 1000 yd long and sloping up to 20°; local structural steps up to 100 ft high, with short slopes 10–25°, steep marginal slopes 25–35° and up to 200 yd long; numerous slump alcoves in herringbone pattern	Humic brown clay soils of Wapenamanda and Tabunaka families, humic olive ash soils of Meriunda family on ash, humic brown clay soils of Vakari family on lava	Lower montane rain forests of oak, mixed, or beech type merging into montane rain forests at upper altitudinal limits. Lower altitudes with sword grass and shrub regrowth. Garden and garden regrowth. *Imperata* and *Ischaemum* grasslands	Mainly VIIe.a and VIIe. Lower areas IIIe, VIe, and locally IIIe.s3
4	Very small	Slightly concave colluvial foot slopes 5–15° and up to 150 yd long	Humic olive ash soils of Klareg family and poorly drained deep dark clay soils of Muriraga family	Sword grass and shrub regrowth. Small sedge bogs	IIIe.s3, VId
5	Very small	Valley floors with slopes 2–10°, intermittent flood-plains and slip-off terraces in lower sectors	Humic brown clay soils of Wapenamanda family with humic olive ash soils of Meriunda family in poorly drained sites	Lower montane beech rain forest or montane rain forest with conifers. Some lower montane grassland	IVe.a, IVs3.a
6	Small	Gorges 35–90°, bare rock where slopes are more than 70°	Mainly rock outcrop	Bare rock. Sword grass and shrub regrowth. Lower montane rain forest	VIII
7	Very small	Channels with ungraded beds with boulder gravel			

* Comparable with Hagen land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Dibibi, Birap, and Trai land systems.

(27) Tari Land System* (210 sq miles)

Volcanic plains.

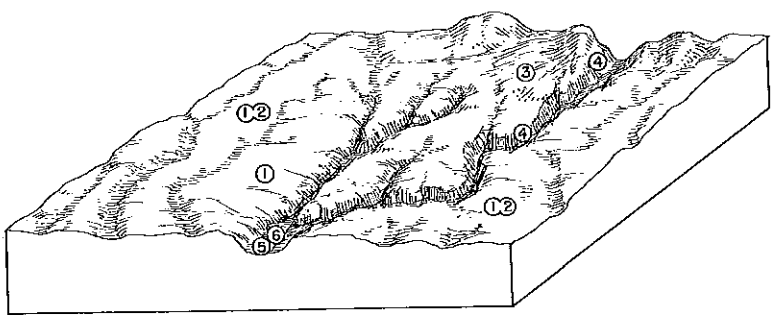
Geology.—Subhorizontal Pleistocene andesitic lava flows and agglomerate, scoria, and laharic accumulations, covered by ash of varying thickness. Recent peat. Recent fine-textured alluvium over boulder gravel.

Landscape Description.—Undissected and slightly dissected gently undulating volcanic plains. Widely spaced dendritic and subparallel pattern of drainage channels.

Landscape Dynamics.—Rapid slumping and earth flows on steeper slopes. Gentle slopes subject to rotational slipping and creep of ash. Flood-plain accretion. Peat growth on poorly drained surfaces.

Altitude.—5000–7500 ft. Internal relief up to 200 ft.

Population and Land Use.—18,900 people on 143 sq miles of land used for cultivation (most of non-cultivated land is in unit 2).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Gently undulating plains and ridge crests, slopes less than 4°, locally steeper on undulations	Mainly humic brown clay soils of Wapenamanda and Tabunaka families. Humic olive ash soils of Meriunda family in poorly drained sites	Gardens and garden regrowth. Sword grass and shrub regrowth. *Imperata*, *Ischaemum*, and *Capillepedium* grasslands. Lower montane oak and beech rain forest	I with IId in depressions
2	Large	Poorly drained plains with smooth, gently undulating surfaces, slopes 1–3°	Mainly humic olive ash soils of Klareg family, partly with peaty surface soils	Sword grass and shrub regrowth. Gardens and garden regrowth. Sedge and grass–sedge bog. *Capillepedium* grassland. Minor lower montane oak or beech forest, *Pandanus* swamp, or bog forest	Mainly Vd, VId–VIId in swampy parts
3	Small	Gentle slopes of low ridges, smooth, slightly concave surfaces, 5–15° slope and up to 300 yd long	Humic brown clay soils of Wapenamanda family, humic olive ash soils of Meriunda family, and locally gleyed plastic heavy clay soils of Lumbi family	Sword grass and shrub regrowth. Gardens and garden regrowth. *Themeda*, *Capillepedium*, *Ischaemum* and *Imperata* grasslands. Remnants of lower montane oak rain forest	IIIe, IIIe.s3
4	Small	Steep slopes of spurs and incised valleys, 15–35° and up to 200 yd long, many slump alcoves	As unit 3. Minor humic olive ash soils of Klareg family on alcove floors	Sword grass and shrub regrowth. *Imperata* and *Ischaemum* grasslands. Minor sedge bog and *Leersia* swamp	VIe–VIIe slopes, Vd floors
5	Small	Flood-plains up to 50 yd wide	Gleyed, fine-textured alluvial soils	*Ischaemum* grassland. *Leersia* and *Phragmites* swamps	VId
6	Very small	Channels up to 10 yd wide and 15 ft deep, graded and ungraded beds			

* Comparable with Egim land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Lai, Birap, Bemarep, Kandep, and Kaugel land systems.

(28) Tage Land System* (40 sq miles)

Long gentle volcanic slopes and low volcanic hills.

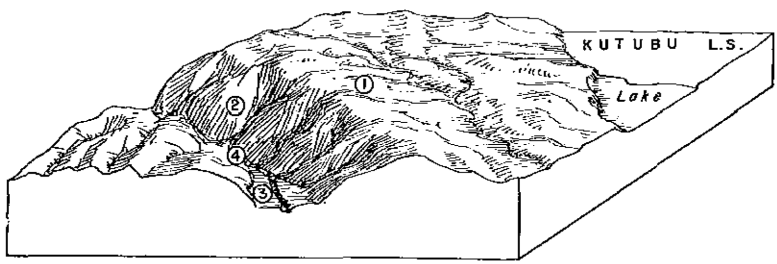
Geology.—Pleistocene andesitic and basaltic lava with agglomerate intercalations; presumably late Pleistocene and Recent fine-textured alluvium on boulder gravel.

Landscape Description.—Dissected volcanic plateaux and slopes, mainly broken into wide-crested ridges by a subdendritic pattern of valleys incised up to 300 ft, locally with small terraces in valley openings.

Landscape Dynamics.—Slow creep of weathering mantles on gentle slopes, and moderate slumping on steeper slopes.

Altitude.—2500–3500 ft. Internal relief up to 300 ft.

Population and Land Use.—Unpopulated. No land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Ridge crests and plateau remnants with gently undulating surfaces up to 400 yd in extent, attaining 5°	Mainly reddish clay soils of Kutubu and Herep families; minor humic brown clay soils of Nenja family	Lowland hill forest with scattered *Araucaria*, and many species of the lower montane rain forests	IIe.sl
2	Large	Slopes 10–25° and up to 100 yd long, many slump alcoves, with back walls attaining 40°		Lowland hill forest with many tall palms and bamboo	VIe.sl, VIIe.sl
3	Very small	Flood-plains up to 20 yd wide	Fine-textured recent alluvial soils	Lowland alluvium forest	IVd.f
4	Very small	Channels up to 10 yd wide and 15 ft deep		Fringing *Saccharum robustum*	

* Unmappable inclusions: Digumu and Kutubu land systems.

(29) KWANDI LAND SYSTEM* (75 SQ MILES)

Low volcanic ridges and valleys.

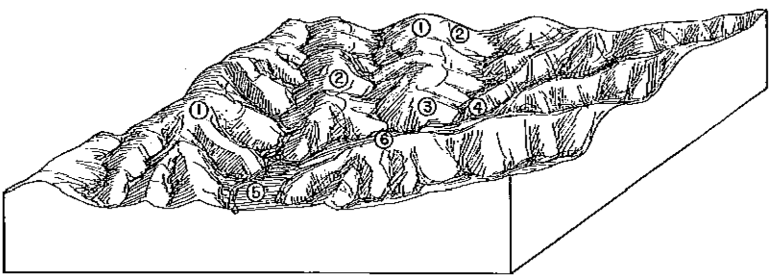
Geology.—Pleistocene ash covering Pleistocene andesitic lava and agglomerate. Tertiary sandstone, siltstone, and mudstone, locally exposed in strongly incised valleys. Recent fine-textured alluvium over boulder gravel.

Landscape Description.—Moderately dissected volcanic plains with wide round-crested ridges and parallel valleys incised up to 500 ft.

Landscape Dynamics.—Slow creep on gentle slopes. Rapid slumping on steep valley sides. Slow alluviation of flood-plains.

Altitude.—5500–7500 ft. Internal relief up to 500 ft.

Population and Land Use.—3700 people on 60 sq miles of land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Medium	Ridge crests with gently undulating surfaces up to 2000 yd in extent and attaining 12°; shallow slump alcoves	Humic brown clay soils of Wapenamanda family	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* and *Ischaemum* grasslands. Remnants of lower montane oak rain forest	IIe–IIIe
2	Large	Ridge slopes 15–30° and up to 300 yd long		Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* grassland	VIe–VIIe
3	Very small	Steepened slopes and cliffs 30–55° and up to 100 yd long, locally with sharp salients	Humic brown clay soils of Wapenamanda and Vakari families and local rock outcrop	Lower montane oak forest. Sword grass and shrub regrowth	Mostly VIII, some VIIe
4	Very small	Foot slopes attaining 10° and up to 200 yd long	Probably humic brown clay soils of Nenja family, minor Tabunaka family on ash	Sword grass and shrub regrowth. Lower montane oak rain forest remnants. Minor bog forest	IIe–IIIe
5	Very small	Flood-plains with locally undulating surfaces up to 100 yd wide	Probably fine-textured recent alluvial soils	Sword grass and shrub regrowth. *Imperata* and *Ischaemum* grasslands. Remnants of lower montane oak rain forest	IIId
6	Very small	Channels up to 15 yd wide and 15 ft deep, mainly graded beds			

* Unmappable inclusions: Doma and Tari land systems.

(30) Birap Land System* (30 sq miles)

Small conical hills.

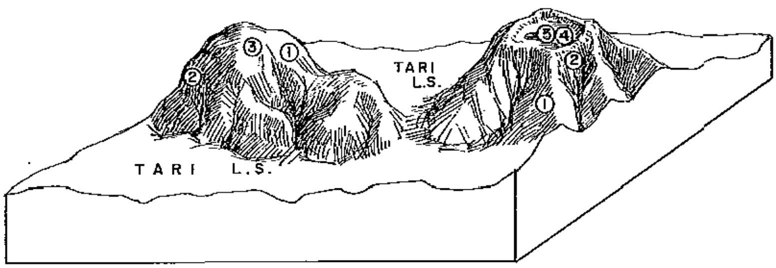
Geology.—Pleistocene andesitic and rhyolitic lava, scoria, and ash. Intrusive dolerite.

Landscape Description.—Ash and scoria cones, tholoids, becks, small lava flows and dykes. Partly dissected by small streams. No large streams.

Landscape Dynamics.—Moderate rate of stream erosion and slumping on steeper slopes.

Altitude.—5500–10,000 ft. Internal relief up to 500 ft.

Population and Land Use.—1400 people on 10 sq miles of land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Steep slopes 25–45° and up to 400 yd long, frequently gullied or dissected into low rounded ridges	Humic brown clay soils of Wapenamanda and Tabunaka families on ash, humic brown clay soils of Vakari family on lava	Sword grass and shrub regrowth, often with underlying *Sphagnum*. Gardens and garden regrowth. Lower montane rain forests (mixed, oak, or beech) as continuous cover or remnants	VIIe–VIII
2	Very small	Precipitous slopes 45–90°, bare rock when sloping more than 70°	Rock outcrop and shallow humic brown clay soils of Vakari family	Mainly bare. Sword grass and shrub regrowth	VIII
3	Medium	Gentle convex hill crests, and concave crater-like depressions, slopes attaining 15° and up to 150 yd long	Humic brown clay soils of Wapenamanda and Tabunaka families on ash, humic brown clay soils of Vakari family on lava	Sword grass and shrub regrowth. Lower montane beech or mixed rain forests. Gardens and garden regrowth	IIe–IIIe
4	Very small	Crater depressions up to 2500 yd in extent, floor slopes less than 3°	Peaty soils of Kiakau and Tirriraga families, humic brown clay soils of Wapenamanda family on slopes	Some bog forests of small extent, otherwise sword grass and shrub regrowth with associated grass-sedge bog and sedge bog	VIII with IIIe on slopes
5	Very small	Crater lakes up to 1000 yd in extent		Fringing sedges merging into bog forest	

*Many areas of this land system are too small to map and are included in other land systems, especially Nemarep and Tari.

(31) Poroma Land System* (30 sq miles)

Volcanic valley fills.

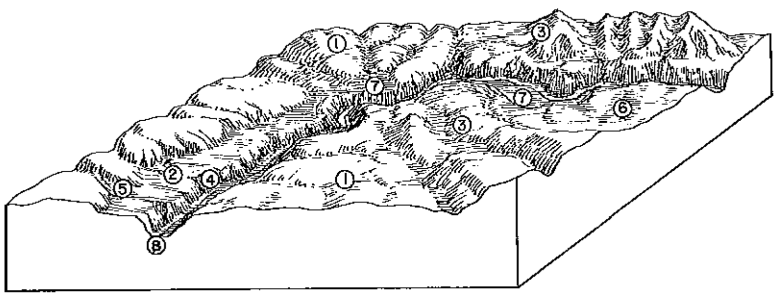
Geology.—Pleistocene andesitic lava, scoria, and ash, mainly bounded by and underlain by Tertiary limestone. Locally Tertiary greywacke sandstone and siltstone. Recent boulder gravel.

Landscape Description.—Marginally terraced valley fills forming elongate plains with low gradient, incised up to 1000 ft by large streams. Locally broken into irregular hills up to 300 ft high. Frequently with dolines along the margins. Dissected up to 50 ft by a subdendritic pattern of inactive wide channels.

Landscape Dynamics.—Rapid slumping of doline slopes due to solution in underlying limestone. Slow creep and shallow rotational slipping on gentler slopes.

Altitude.—3500–5500 ft. Internal relief mainly less than 50 ft.

Population and Land Use.—2400 people. Almost all land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Undulating plains up to 2000 yd in extent, with slopes generally less than 3° but locally attaining 5°	Humic brown clay soils of Tabunaka family	Gardens and garden regrowth. *Imperata* and *Ischaemum* grasslands. Sword grass and shrub regrowth. Remnants lower montane oak rain forest	I, some IIe
2	Small	Marginal terraces with undulating surfaces up to 100 yd wide and up to 1500 yd long	Humic brown clay soils of Tabunaka and Nenja families		I
3	Small	Moderate slopes 10–25° and averaging 250 yd long, with convex upper sectors 5–10°	Humic brown clay soils of Nenja family, reddish clay soils of Herep family on upper sectors		VIe
4	Small	Bounding slopes of actively incising channels and slump scars, 25–35° and up to 150 yd long	Humic brown clay soils of Nenja family		VIIe
5	Very small	Concave valley floors and colluvial toes, slopes 2–7° and up to 50 yd long			IIe
6	Very small	Shallow depressions up to 50 yd across and up to 10 ft deep; boggy floors, occasionally with ponds	Poorly drained deep dark clay soils of Muriraga family, gleyed plastic heavy clay soils of Laiagam family	*Imperata* grassland. Sword grass and shrub regrowth. Ponds surrounded by *Leersia* swamp	IIId and VId
7	Very small	Flood-plains with stony surfaces up to 200 yd wide	Fine-textured recent alluvial soils	Lower montane oak rain forest. *Ischaemum* grassland	Vst
8	Very small	Channels up to 15 yd wide and 10 ft deep, partly graded and with boulder gravel			

* Unmappable inclusions: Lai and Kaugel land systems.

(32) Lai Land System* (15 sq miles)

Steep-sided gorges.

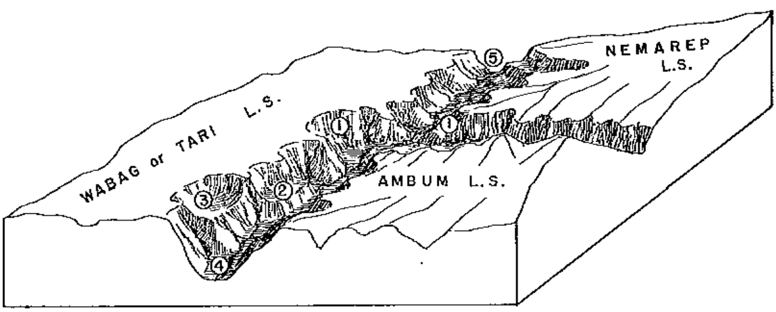
Geology.—Pleistocene volcanic rocks. Minor Mesozoic and Tertiary greywacke sandstone, siltstone, mudstone, and limestone. Recent fine-textured alluvium over boulder gravel.

Landscape Description.—Gorges and narrow valleys 200–1000 ft deep and more than 250 yd wide, with steep bounding slopes, small terraces, and intermittent flood-plains. Ungraded or graded stream beds, locally with rapids or waterfalls.

Landscape Dynamics.—Rapid modification of side slopes by landslides and slumps.

Altitude.—4000–7500 ft. Internal relief up to 1000 ft.

Population and Land Use.—Unpopulated. Only 4 sq miles of land used for cultivation (units 2 and 4).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Side slopes 25–90° with many salients and re-entrants, locally boulder-covered or rocky	Outcrop and shallow humic brown clay soils of Vakari and Wapenamanda families	Sword grass and shrub regrowth. Small areas *Imperata* and *Ischaemum* grasslands and lower montane oak rain forest	VIII with some VIe.st–VIIe.st
2	Very small	Terrace remnants up to 200 yd long and up to 50 yd wide, slopes less than 5°; backing colluvial toes	Humic brown clay soils of Tabunaka family, humic olive ash soils of Meriunda family	Gardens and garden regrowth. Sword grass and shrub regrowth. *Imperata* grassland. Remnants lower montane oak rain forest	I, IIs3
3	Very small	Amphitheatral landslide embayments with concave floor slopes, 15–25° and up to 150 yd long	Mainly humic brown clay soils of Wapenamanda family, some Tabunaka family	Sword grass and shrub regrowth. *Imperata* and *Ischaemum* grasslands. Small *Leersia* swamps. Remnants lower montane oak rain forest	VIe
4	Very small	Flat flood-plains up to 100 yd wide, containing disused channels up to 10 yd wide	Old alluvial clay soils	Gardens and garden regrowth. Sword grass and shrub regrowth	I
5	Very small	Channels up to 50 yd wide and 15 ft deep, sand and gravel bars up to 300 yd long			

* Many areas of this land system are too narrow to map and are included in other land systems.

(33) Tambul Land System* (20 sq miles)

Alluvial valley fill.

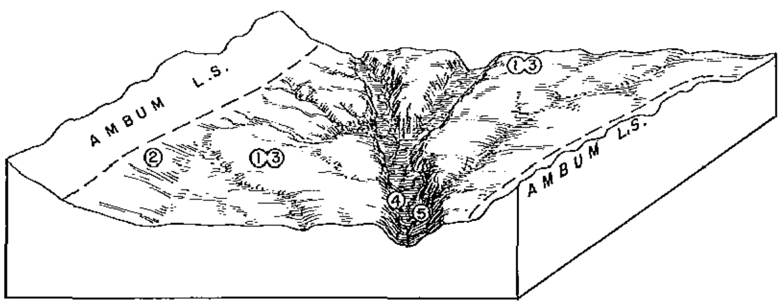
Geology.—Pleistocene stratified deposits ranging in texture from clay to boulder beds. Locally covered by layers of volcanic ash. Extensive sub-Recent to Recent, mostly shallow and fibrous peats.

Landscape Description.—Flat to gently undulating plains with steeper marginal fans. Little organized surface drainage but traversed by deeply incised major streams.

Landscape Dynamics.—Mainly stable surface. Moderate slumping on steep slopes adjacent to major streams. Peat formation.

Altitude.—6800–7300 ft.

Population and Land Use.—4500 people. All land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Flat to gently undulating plains, slopes less than 2°	Humic olive ash soils of Meriunda and Klareg families	Sword grass and shrub regrowth	IId–IIId
2	Small	Marginal colluvial slopes up to 4°	Mainly humic brown clay soils of Wapenamanda family	Sword grass and shrub regrowth. Gardens and garden regrowth. Sedge and grass–sedge bog	IIe–IIIe
3	Small	Boggy plains	Peaty soils of Tirriraga and Mango families		VII–VIId
4	Very small	Steep slopes of valleys	Humic brown clay soils of Wapenamanda family	Sword grass and shrub regrowth. Some gardens and garden regrowth	VIIe, some VIII
5	Very small	Flood-plains and channels in valleys	Mainly fine-textured recent alluvial soils		IVs3 and Vst

* Comparable with Tambul land system of the Goroka–Mt. Hagen area. Unmappable inclusions: Lai and Kaugel land systems

(34) Winjaka Land System* (4 sq miles)

Low hilly country in the Kaugel valley.

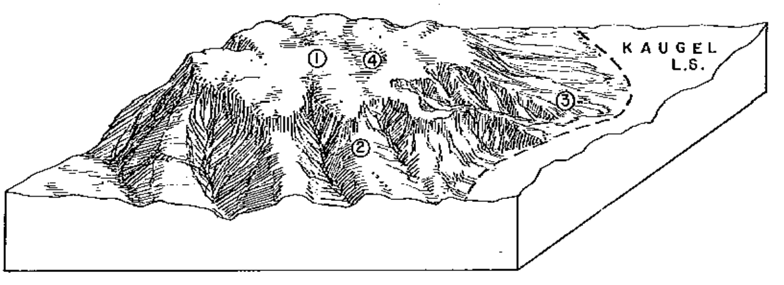
Geology.—Pleistocene to Recent stratified deposits, ranging from clays to gravels, locally covered by volcanic ash.

Landscape Description.—Dome-shaped hill with steep and deep radial gully dissection.

Landscape Dynamics.—Rapid slumping on steeper slopes. Active stream erosion.

Altitude.—7200–7800 ft. Internal relief 600 ft.

Population and Land Use.—300 people. All land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Small	Terrace remnant with gently undulating surface	Mainly humic brown clay soils of Wapenamanda family	Gardens and garden regrowth. Sword grass and shrub regrowth	IIe–IIIe
2	Large	Steep hill slopes strongly dissected by radial pattern of small streams	Humic olive ash soils of Meriunda and Klareg families	Gardens and garden regrowth. Sword grass and shrub regrowth. Remnants lower montane oak rain forest in deep gullies	VIe–VIIe
3	Small	Gentle foot slopes			IVs3
4	Very small	Shallow swampy depressions in unit 1	Peat soils of Tirriraga family	Sedge swamp	VIId–VIII

* Comparable with Winjaka land system of Goroka–Mt. Hagen area.

(35) Wabag Land System (60 sq miles)

Dissected valley fill, mainly in La iand Tschak valleys.

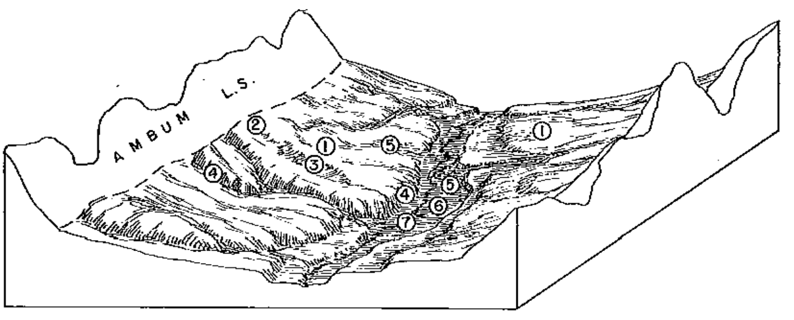
Geology.—Colluvial and alluvial deposits derived from greywacke, volcanic ash, and lavas.

Landscape Description.—Terraced valley fills and associated colluvial fans. Deeply dissected by narrow streams.

Landscape Dynamics.—Terrace and fan surfaces fairly stable. Moderate slumping on steep valley slopes.

Altitude.—5000–7500 ft.

Population and Land Use.—16,000 people. All land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Undulating to flat high and middle terraces, slopes <5° on middle and lower sectors of valleys, but up to 15° in head-water sectors	Mainly humic brown clay soils of Wapenamanda and Tabunaka families, uppermost slopes may be stony and bouldery	Gardens and garden regrowth. Sword grass and shrub regrowth	I–IId, some IIIe.st
2	Small	Undulating convex fans, slopes 5°–10°, adjacent to bounding mountains	Humic brown clay soils of Nenja family		IIe–IIIe
3	Small	Depressions in high terraces	Gleyed plastic heavy clay soils of Pumakos family with concretions	*Leersia* and *Phragmites* swamp	VIId–VIII
4	Medium	Steep valley slopes	Humic brown clay soils of Wapenamanda family, minor skeletal stony soils	Sword grass and shrub regrowth. Gardens and garden regrowth	VIIe, some VIII
5	Very small	Swampy flats and drainage depressions on high terraces and on flood-plains	Peaty soils of Kiakau, Tirriraga, and Mango families	*Phragmites* swamp. Sedge bog	VIId–VIII
6	Small	Flood-plains 200–1000 yd wide, 5–20 ft above river bed	Mainly fine-textured recent alluvial soils, locally stony and bouldery	Sword grass and shrub regrowth. *Casuarina* plantations	IVs3 and Vst
7	Very small	Channels			

(36) Ko Land System* (60 sq miles)

Alluvial fans.

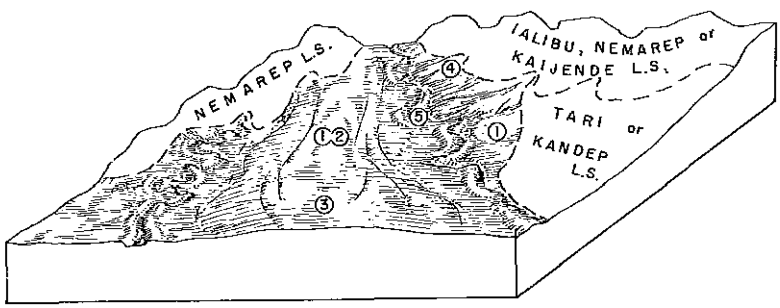
Geology.—Mainly Recent, partly Pleistocene colluvium and alluvium, mainly derived from volcanic ash, locally with limestone-derived material; lenses of boulder gravel.

Landscape Description.—Mainly undissected, gently sloping fans drained by subradial channels.

Landscape Dynamics.—Slow to moderately active stream deposition. Peat growth in swampy areas above 6000 ft.

Altitude.—5000–7500 ft.

Population and Land Use.—10,700 people. All land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Fans surrounding Kandep land system, up to 1 mile long and sloping 1–3°	Probably mainly humic olive ash soils of Meriunda and Klareg families. Gleyed plastic heavy clay soils of Laiagam family on limestone-derived material	Gardens and garden regrowth. Sword grass and shrub regrowth. *Imperata* and *Ischaemum* grassland. *Phragmites* and *Leersia* swamp. *Casuarina* plantations	IIs3–IVs3
2	Medium	Middle sectors of alluvial fans adjacent to volcanic mountains, slightly concave slopes 1°30′–3°	Poorly drained deep dark clay soils of Muriraga family, old alluvial clay soils, and shallow peaty soils of Mango family	Sword grass and shrub regrowth. *Imperata* and *Ischaemum* grasslands. *Phragmites* and *Leersia* swamp	IIId, IIIe.st, locally VId
3	Medium	Lower sectors of fans adjacent to volcanic mountains, up to 1500 yd long and sloping less than 1°30′	Peaty soils of Tirriraga and Mango families	Grass–sedge and sedge bog. Sword grass and shrub regrowth. *Leersia* and *Phragmites* swamp	VIId
4	Small	Colluvial slopes 3–9° and up to 1500 yd long but normally much shorter	Probably humic brown clay soils of Wapenamanda family on ash, humic brown clay soils of Nenja family, very stony humic brown clay soils of Vakari family	Sword grass and shrub regrowth	IIe–IIIe, Vst
5	Very small	Channels up to 10 yd wide and 10 ft deep, graded and ungraded beds			

* Unmappable inclusions: Kaugel land system.

(37) Kandep Land System* (100 sq miles)

Swampy alluviated upland valleys.

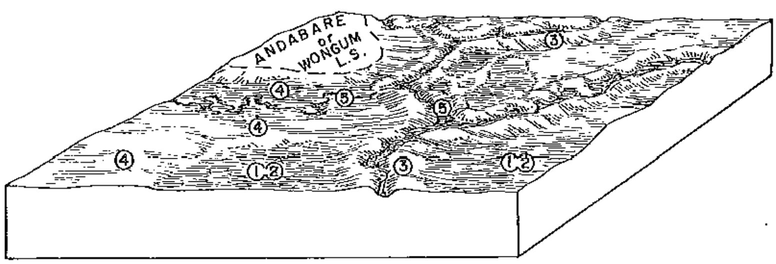
Geology.—Recent, mainly fine-textured alluvium and peat.

Landscape Description.—Swampy plains and stream flats with low gradient; traversed by meandering stream channels with levees.

Landscape Dynamics.—Subject to irregular flooding with moderately active alluviation along streams and on fans; active peat formation.

Altitude.—6500–9000 ft.

Population and Land Use.—350 people concentrated on 9 sq miles of land used for cultivation (parts of unit 4 about 8500 ft above sea level).



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Bogs up to 1500 yd in extent; water level up to 18 in. above ground level	Peaty soils of Kiakau family	Sedge bog. Minor lower montane bog rain forest and highland *Pandanus* swamp	VIII
2	Medium	Bogs up to 2500 yd in extent and sloping less than 1°10′; water level not more than 3 in. above ground level	Peaty soils of Tirriraga family, fine-textured recent alluvial soils	Sedge and grass–sedge bog. Sword grass and shrub regrowth	VIId
3	Very small	Levees up to 50 yd wide, with back slopes of 1–3°	Old alluvial clay soils and recent medium to fine-textured alluvial soils	Sword grass and shrub regrowth. *Capillepedium* grassland. Sedge bog	IIId
4	Medium	Flood-plains up to 100 yd wide and terraces up to 1000 yd wide, locally waterlogged	Mainly old alluvial clay soils and poorly drained deep dark clay soils of Muriraga family. Gleyed plastic heavy clay soils of Pumakos family in depressions	Sword grass and shrub regrowth. Gardens and garden regrowth. *Imperata* and *Ischaemum* grasslands. Remnants lower montane oak rain forest. Lower montane grassland above 8000 ft	IVd.f and VIs3.f
5	Very small	Channels up to 15 yd wide and up to 30 ft deep		Open water or sedge bog	

* Unmappable inclusions: Ambum, Andabare, Ko, and Kaugel land systems.

(38) Kaugel Land System* (7 sq miles)

River flood-plains.

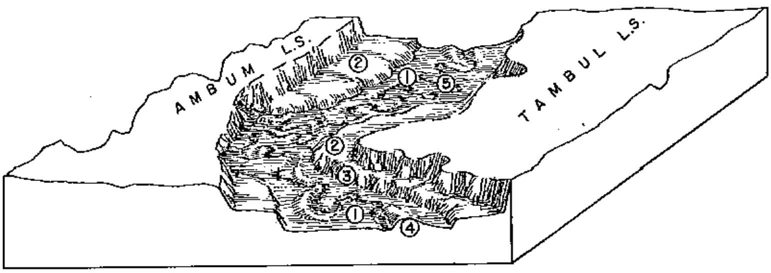
Geology.—Recent fluviatile deposits of varying texture; clays to gravels.

Landscape Description.—Flood-plains and discontinuous river terraces along major rivers. Meandering and distributary drainage.

Landscape Dynamics.—Active alluviation on flood-plains. Peat formation.

Altitude.—4000–8000 ft.

Population and Land Use.—800 people. All land used for cultivation.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Flood-plains up to 500 yd wide, normally much narrower, subject to infrequent inundation	Fine-textured recent alluvial soils, peaty soils of Tirriraga and Mango families	*Leersia* and *Phragmites* swamp. Grass–sedge bog. Lower montane bog rain forest	VIId
2	Large	Terraces with gently undulating or even surfaces up to 400 yd wide, locally waterlogged	Old alluvial clay soils. Gleyed plastic heavy clay soils of Pumakos family in depressions	*Imperata* and *Ischaemum* grasslands, *Leersia* swamp. Grass–sedge bog. Sword grass and shrub regrowth. Lower montane oak and bog rain forest	IIId and IVs3
3	Very small	Steepened slopes on dissected inner margins, 25–40° and up to 75 yd long, with many slump scars	Humic brown clay soils of Vakari family	Sword grass and shrub regrowth	VIIe
4	Very small	Levees up to 25 yd wide, back slopes less than 2°, locally consisting of boulder gravel	Shallow peaty soils of Mango family, fine-textured recent alluvial soils	*Ischaemum* grassland and *Leersia* swamp. Sword grass and shrub regrowth	VId
5	Very small	Channels up to 50 yd wide and 20 ft deep, partly with sand and gravel bars; distributary channels up to 5 yd wide, up to 5–6 ft deep, frequently with boulder-covered beds			

* Comparable with Asaro land system of the Goroka–Mt. Hagen area. Many areas of this land system are too narrow to map and are included in other land systems.

(39) Kutubu Land System (35 sq miles)

Swampy flood-plains near Lake Kutubu.

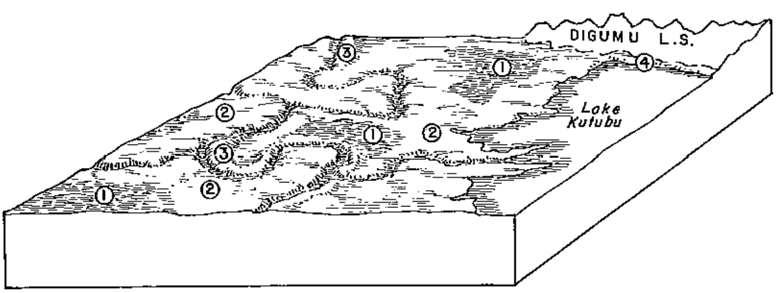
Geology.—Recent fine-textured alluvium.

Landscape Description.—Flood-plains and plains of combined alluvial and lacustrine origin around lake margins. Traversed by meandering, sluggishly flowing streams.

Landscape Dynamics.—Subject to irregular flooding. Moderate alluviation close to channels.

Altitude.—Below 2800 ft.

Population and Land Use.—1000 people concentrated on 1 sq mile of land (unit 3) but harvesting sago from unit 2.



Unit	Area	Land Form	Soil	Vegetation	Land Class
1	Large	Permanent swamps up to 2000 yd in extent, water level up to 2 ft above ground level	Recent fine-textured swampy alluvial soils often covered with organic muds	Lowland *Pandanus* swamp	VIII
2	Large	Swampy alluvial plains with waterlogged surfaces up to 500 yd in extent	Mainly poorly drained fine-textured recent alluvial soils	*Campnosperma*–sago palm forest and *Campnosperma coriacea* and *Casuarina* swamp woodlands. Alluvium forest	VIId
3	Small	Levees and better-drained plains up to 75 yd wide and up to 6 ft above units 1 and 2	Imperfectly drained medium-textured recent alluvial soils		IId
4	Very small	Lake-shore platforms up to 50 yd wide, presumably dry during low water levels	Probably organic muds	*Phragmites* swamp	VIII

PART IV. CLIMATE OF THE WABAG–TARI AREA

By E. A. FITZPATRICK*

I. INTRODUCTION

(a) *Principal Climatic Features*

At the lowest elevations in this area, the climate can be described according to the Köppen (1931) and Thornthwaite (1931) classifications as wet tropical (*Af* and *AA'r* types respectively). With the lower temperatures at higher altitudes the climate has a distinctive character, resembling in some ways the moist, maritime temperate or "mesothermal" condition of higher latitudes, but having an even more restricted annual range of temperature.

The most conspicuous feature is the lack of seasonal contrast in virtually all elements. The annual range of mean temperature is about 4°, or only about one-fifth of the average daily temperature range. Rainfall is high over the whole of the area, the lowest observed mean annual amount being 85 in. In the northern part of the area a period of lesser rainfall over several months is characteristic, but nowhere are the falls so light or infrequent as to justify reference to this interval as a "dry" season.

(b) *Climatic Controls*

The principal broad climatic controls are linked with the seasonal northward and southward shift of the thermal equator and the accompanying changes in the latitudinal position of the subtropical anticyclonic centres to the south, and in the Asiatic monsoonal wind systems to the north and west. These changes are experienced within and around the island of New Guinea, primarily in the seasonal alternation in the direction of prevailing winds. Two major wind systems can be identified: the north-west monsoons between December and March, and the south-easterlies (trades) from May to October. These systems are normally separated by brief "doldrum" periods during which light and variable wind conditions are characteristic. For details of these controls and their relation to the observed character of weather and climate within the whole of Papua–New Guinea, readers are referred to the descriptive accounts given in publications of the Bureau of Meteorology (1940) and Department of National Development (1951).

The area is centrally situated with respect to moist air masses originating to the north-west over the Bismarck Sea and to the south-east over the Coral Sea and Gulf of Papua. Being elevated above the broad Sepik Plain and the lower foothills and coastal plain at the head of the Gulf of Papua, the area is exposed to rain influences associated with both the north-west monsoons and the south-easterlies. This is in contrast to many parts of the island that are much more strongly exposed to one system than to the other. Seasonal contrasts in rainfall are therefore less than in most parts of the island.

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

Locally, differences in the relative exposure to the two systems produce a complex pattern in the amount and seasonal distribution of rainfall. Some indication of these local orographic controls can be found in the available rainfall data; however, the network of stations is much too sparse in relation to the amount and complexity of local relief for any detailed picture of these effects to emerge.

Temperatures and humidities are also controlled by broad seasonal changes in the wind systems, although probably to a lesser degree than where a combination of continental and marine influences occurs at higher latitudes. Warm and humid conditions are associated with the north-west winds, and in general, cooler weather accompanies winds from the south-east, particularly when these have had a very long passage over cold southerly waters. Hot and dry conditions, characteristic over much of northern Australia between September and November, are generally absent. Normally air from this source has been greatly modified in regard to both temperature and humidity before reaching the area.

Of some significance as temperature controls are winds of purely local origin which are related to the immediate terrain and to the daily cycles of incoming and outgoing radiation. Valley winds generated by the heating of the valley floors and lower slopes during the day, and mountain or gravity winds produced by downslope flow of cold air from higher elevations at night, are usually prominent in such mountainous areas. No data are available to assess the significance of such controls in the area. However, the characteristic cloudiness effectively diminishes diurnal radiational contrasts (incoming and outgoing), so that winds of this type are likely to be more irregular in their occurrence than in some mountainous regions where fine clear weather is common. Owing to the central inland location of the area, and also to some degree of local sheltering by the complex pattern of relief within adjacent highland areas, the effect of sea breezes is less pronounced than in most parts of the island.

II. General Climatic Characteristics

(a) *Rainfall*

No detailed interpretation of rainfall characteristics is possible because of the limited number of years over which observations have been made. No station within or near the area has records extending back further than the end of World War II, and in a few instances only do the records exceed eight years. Interpretation is made difficult also by frequent short-period gaps in the records. In areas with little local orographic control over rainfall, it may be possible to extend the standard period artificially by utilizing overlapping records and assuming constancy of the ratios of the observed rainfalls at nearby stations (Conrad 1946). This procedure was not considered feasible here because of pronounced local topographic effects upon the areal distribution of rainfall.

Monthly and annual means were obtained first for all stations in and near the area, using all records available. Stations were then selected which, with few exceptions, had unbroken records over the period 1954 to 1960 inclusive. From these data, monthly and annual seven-year "normals" were obtained, and these were compared with means calculated from longer records where available. No

TABLE 2

MEAN RAINFALL IN INCHES (*a*), MEAN NUMBER OF DAYS WITH RAIN (*b*), AND HIGHEST AND LOWEST ANNUAL TOTALS ON RECORD FOR ELEVEN STATIONS

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Highest Annual	Lowest Annual
Laiagam	(*a*)	8·5	11·0	9·1	11·2	5·7	3·5	2·3	4·4	6·2	7·0	8·5	7·1	84·5	101·9	64·0
	(*b*)	26	22	26	26	16	13	14	17	18	19	21	21	239		
Wabag	(*a*)	12·9	11·7	13·6	13·3	8·0	4·7	4·7	6·4	9·5	8·0	9·7	12·4	114·8	131·9	99·9
	(*b*)	25	24	27	26	19	16	16	20	22	22	23	24	264		
Wapenamanda	(*a*)	18·8	9·6	11·0	11·4	5·1	3·9	5·0	5·2	8·0	6·1	7·5	9·3	90·9	100·9	82·2
	(*b*)	24	25	26	24	18	18	23	24	28	22	27	31	290		
Baiyer River	(*a*)	11·2	13·5	14·7	13·3	5·7	3·7	3·0	4·1	6·4	6·1	9·3	12·7	103·8	123·4	90·2
	(*b*)	24	24	25	24	14	13	12	12	16	17	18	23	222		
Mt. Hagen	(*a*)	10·7	10·4	11·9	12·2	7·3	3·5	5·1	6·9	7·5	7·8	7·4	10·3	101·1	112·8	81·7
	(*b*)	24	23	24	23	17	16	20	21	22	18	20	21	249		
Togoba	(*a*)	11·8	13·5	12·1	14·3	6·9	4·5	6·4	6·9	8·4	7·3	8·2	11·7	112·0	121·8	97·9
	(*b*)	25	25	27	26	20	17	22	25	23	19	20	25	274		
Tari	(*a*)	6·9	10·4	8·4	10·3	8·5	5·6	7·0	7·1	8·0	8·7	7·9	7·6	96·4	107·3	90·2
	(*b*)	21	25	25	25	22	23	26	25	25	22	19	23	281		
Mendi	(*a*)	7·0	9·5	8·8	9·7	7·8	6·9	10·1	10·2	11·9	7·9	8·4	8·5	106·8	117·6	97·0
	(*b*)	24	24	25	25	22	21	24	25	26	23	22	23	284		
Ialibu	(*a*)	9·2	13·4	11·9	12·6	8·0	9·1	12·2	11·0	14·11	13·63	12·6	12·9	140·7	157·3	132·8
	(*b*)	23	22	27	24	22	20	24	25	25	24	22	26	284		
Lake Kutubu	(*a*)	12·1	15·7	11·3	18·1	17·9	10·9	15·8	12·2	18·9	16·7	12·1	15·3	176·9	191·6	156·6
	(*b*)	22	23	23	26	25	23	26	26	24	24	19	20	281		
Erave	(*a*)	10·5	15·3	9·1	12·7	9·1	10·8	11·9	9·5	13·5	10·1	8·8	10·6	131·9	141·4	112·3
	(*b*)	25	25	23	26	22	23	23	24	24	21	20	22	278		

large differences were found, and it was considered that the seven-year period could be taken as generally representative. It is appreciated that this period is too short to establish very stable normals, but this method was considered preferable for regional comparative purposes to one that made reference to discordant records of unequal length or obtained over different periods. The seven-year monthly and annual means are given in Table 2, and a generalized map showing mean annual rainfall according to these data and taking into account other information and the likely general influence of basic terrain features is given in Figure 2. Doubtless the "true" pattern is much more varied than that presented here but, with the limited data available, no attempt has been made to show such detail. The highest and lowest annual totals observed during the seven-year period are also shown in Table 2. Observed annual rainfall ranges from 85 in. at Laiagam in the somewhat sheltered valley of the Lagaip River to 177 in. at Lake Kutubu with an exposed south-easterly aspect in the southern part of the area. In general, the mean annual rainfall within the area is of the order of 100 in., but lesser amounts occur in sheltered localities and much higher amounts—probably up to 200 in. in some local areas—can be expected in the more exposed situations.

TABLE 3

MEAN DURATION OF RAINLESS PERIODS AND LONGEST RAINLESS PERIODS OBSERVED (IN DAYS) FOR EACH MONTH AT THREE STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Wabag (8 yr, 1953–60)											
Mean	1·9	1·8	1·3	1·6	2·6	2·6	3·1	2·4	1·6	1·9	1·9	1·7
Longest observed	5	7	4	3	11	7	12	11	4	5	6	5
	Tari (8 yr, 1953–60)											
Mean	1·7	1·4	1·7	1·7	2·3	1·9	1·8	1·6	1·4	2·1	2·1	1·6
Longest observed	8	4	6	4	15	6	5	5	4	9	8	5
	Mendi (10 yr, 1951–60)											
Mean	1·6	1·6	1·5	2·9	2·6	2·2	1·9	1·8	1·6	2·1	1·8	1·9
Longest observed	5	3	5	6	22	10	6	4	3	11	9	7

Over the northern portion of the area a distinct period of lesser rainfall occurs during the south-east season. Laiagam, for example, has mean monthly falls of less than 5 in. from June to August, and Wabag has means below this level during June and July. In the southern part of the area there is very little seasonal contrast in mean rainfall. At Lake Kutubu and Mendi the monthly means fluctuate about mean levels of approximately 15 in. and 8 in. respectively throughout the year; much of the month-to-month variation has probably resulted from the small number of years over which the means have been taken. At these two stations, which may be taken as representative of the southern part of the area, there is no obvious seasonal trend in rainfall, but there is some suggestion of a slight maximum during the south-east season.

Records are too short to give any clear impression of year-to-year variability of annual rainfall. A general examination of the highest and lowest annual totals given in Table 2 suggests that annual departures from the mean by as much as 25 in.

TABLE 4

PERCENTAGE OF RAIN DAYS WITH RAINFALLS WITHIN SPECIFIED LIMITS

Amount (in.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Laiagam						
0·01–0·24	56	46	53	37	54	68	76	67	53	50	44	50
0·25–0·99	40	43	41	52	42	29	24	29	39	47	44	43
1·00–1·99	4	11	5	10	3	3	—	4	7	3	12	7
2·00–3·99	—	1	1	—	—	—	—	—	1	—	—	—
Mean no. of rain days	26	22	26	26	16	13	14	17	18	19	21	21
						Wabag						
0·01–0·24	41	46	44	36	40	63	61	59	48	43	42	42
0·25–0·99	49	41	39	53	54	31	9	36	39	47	50	46
1·00–1·99	9	12	15	10	5	5	5	4	11	8	8	11
2·00–3·99	1	1	2	1	1	1	—	1	1	1	1	1
Mean no. of rain days	25	24	27	26	19	16	16	20	22	22	23	24
						Tari						
0·01–0·24	58	42	52	49	51	65	59	64	55	49	47	58
0·25–0·99	35	48	42	42	42	32	37	31	33	42	44	35
1·00–1·99	7	9	6	8	5	4	4	4	7	7	7	5
2·00–3·99	—	1	1	1	2	—	—	—	—	2	2	1
Mean no. of rain days	21	25	25	25	22	23	26	25	25	22	19	23
						Mendi						
0·01–0·24	53	45	54	46	56	57	55	49	45	49	47	48
0·25–0·99	38	45	37	46	37	37	36	42	44	38	43	43
1·00–1·99	9	9	9	7	5	4	7	8	9	9	9	8
2·00–3·99	—	1	—	—	1	1	2	1	3	1	1	1
Mean no. of rain days	24	24	25	25	22	21	24	25	26	23	22	23
						Lake Kutubu						
0·01–0·24	46	40	50	36	35	59	42	45	34	32	43	39
0·25–0·99	39	37	33	34	41	29	38	35	39	44	33	43
1·00–1·99	10	14	14	23	19	10	15	17	15	13	17	13
2·00–3·99	5	8	3	8	6	3	5	3	11	10	7	5
4·00–5·99	—	1	1	—	—	—	—	—	1	1	—	—
Mean no. of rain days	22	23	23	26	25	23	26	26	24	24	19	20

would be uncommon. Relative to the high rainfalls that occur, this apparently represents a lower degree of year-to-year variability than is generally characteristic of localities in coastal areas of tropical Australia.

The very rainy character of the climate of the area is evident from the high monthly averages of the number of days with rain. Even during the period of lesser rainfall in the northern part of the area (e.g. Laiagam and Wabag), rainfall occurs on about half of all days. In the southern part of the area rain has been observed on an average of between 70% and 90% of all days. As might be expected with such high percentage frequencies, runs of consecutive rainless days are never very long. Table 3 gives the mean duration of rainless periods for three stations and the longest runs that have occurred since the commencement of observations. The data for Wabag show a definite tendency for longer breaks to occur between daily falls from May to August. This can be regarded as typical of the northern part of the area. It is notable, however, that even during this period, a run of 10 rainless days is uncommon. No clear seasonal pattern is evident from the data for Tari and Mendi. There appears to be some tendency for slightly longer breaks in this southern portion of the area from April to June and again in October and November, but records are too short for this to be stated with any certainty. The high extremes shown in Table 3 for these two stations in May both occurred in 1953.

The frequency of extreme daily rainfalls can be only crudely assessed because of the limited length of records. A simple tabulation of the percentage of rain days with daily totals within specified limits is given in Table 4. Only at Lake Kutubu, the wettest station, have daily falls greater than 4·00 in. been observed. From Table 4 it would appear that, in general, the high total rainfalls characteristic of the area are not so much a result of any abnormal propensity for very heavy falls of limited duration as of the very frequent occurrence of falls of up to 1·00 in. per day. At Laiagam and Wabag the highest daily totals are distinctly associated with the north-west season. Between May and August only a small percentage of the falls are greater than 1·00 in. At Mendi and Lake Kutubu, the percentage of falls in the 1- to 2-in. range is very consistent throughout the year. At Mendi, daily falls between 2 and 4 in. have not occurred often during the north-west season, but have been observed a number of times during the middle part of the south-east season. The reverse of this occurs at Lake Kutubu, where the percentages of falls within this range and higher are generally less during the south-east season than at other times during the year. An overall tendency for the heaviest falls to occur during the closing months of each season and during the transitional months is suggested in the data, particularly at Lake Kutubu.

(*b*) *Temperature*

The very small annual range of temperature and the marked effect of altitude upon temperature are evident from Figure 2 and from the data given in Table 5. Lake Kutubu is the only station in the area below 3000 ft for which temperature data are available. Here all monthly mean temperatures are between 71 and 75°F, but the months of July and August are distinctly the coolest. No complementary clearly defined time of maximum occurs in the annual mean temperature curve, the values differing by not more than one half-degree between October and May. At Wabag, at an elevation somewhat less than 7000 ft, mean monthly temperatures range from 60 to 63°F throughout the year. Examination of mean annual temperatures of all stations in or near the area in relation to their elevation shows an average lapse rate of approximately 3 degF per 1000 ft.

The mean daily temperature range is close to 20°F throughout the year at all stations. Mean maximum temperatures show a somewhat greater annual range than do the minimum temperatures. Highest mean maximum temperatures generally occur during the transition periods between the north-west and south-east seasons.

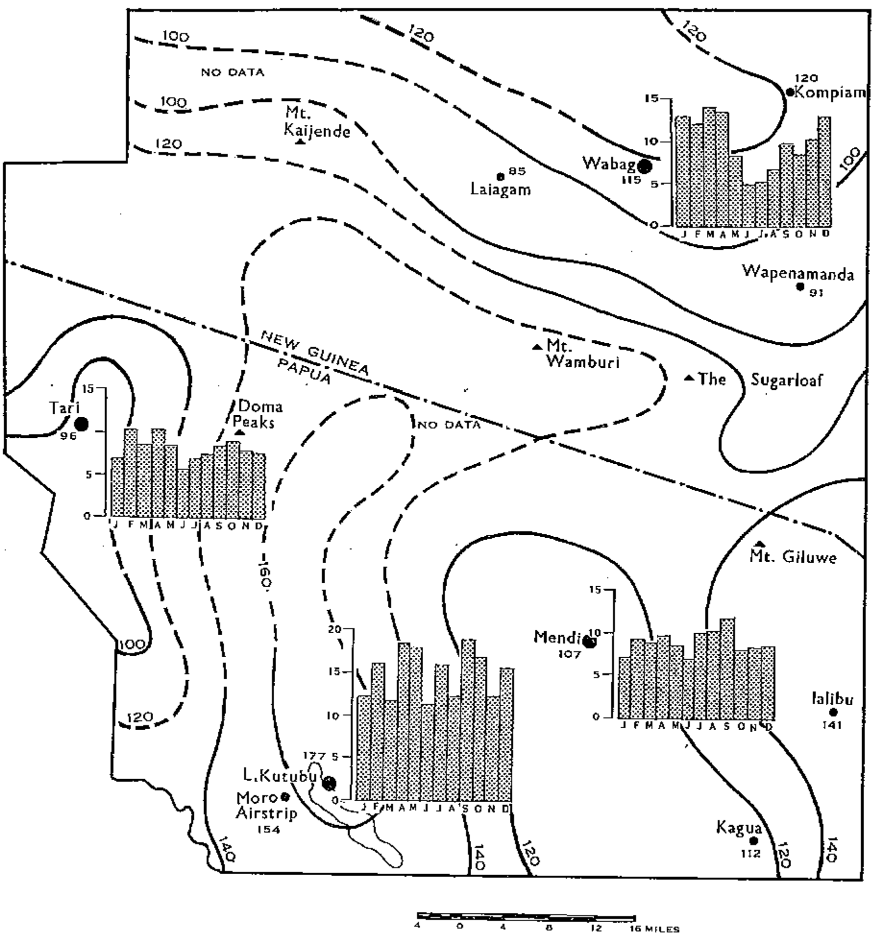


Fig. 2.—Isohyetal map showing generalized distribution of mean annual rainfall. Diagrams for selected stations show mean monthly distributions.

On a day-to-day basis, the range of temperature can be expected to be very closely related to daily differences in the amount of cloud, the range being greatest at those times of least cloudiness.

Records are not long enough to give any clear indication of the incidence of extreme temperatures. Figure 3 and Table 5 include the highest and lowest temp-

TABLE 5

MEAN MONTHLY AND ANNUAL TEMPERATURES AND HIGHEST AND LOWEST TEMPERATURES (°F) ON RECORD AT FOUR STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Wabag (6800 ft)													
Mean maximum	73·3	72·7	73·2	72·3	73·1	72·9	71·2	71·4	72·2	72·6	73·6	73·0	72·6
Mean	62·9	62·9	63·2	62·6	62·6	61·7	60·6	61·1	61·5	61·6	62·1	62·7	62·1
Mean minimum	52·5	53·1	53·2	52·9	52·2	50·6	50·1	50·8	50·8	50·6	50·6	52·5	51·6
Highest maximum	79·0	79·0	78·0	77·2	81·0	79·0	76·0	76·2	84·4	79·0	81·2	77·0	—
Lowest minimum	42·9	46·3	44·6	45·3	44·0	40·4	41·0	41·9	36·9	39·7	41·8	44·0	—
Tari (5250 ft)													
Mean maximum	75·6	76·0	76·4	76·5	76·6	74·9	73·7	74·2	74·0	76·0	76·2	76·1	75·5
Mean	65·9	66·4	66·1	66·6	66·5	65·1	64·9	64·9	65·0	65·3	65·7	66·1	65·7
Mean minimum	56·2	56·9	55·9	56·8	57·3	55·3	56·2	55·6	56·0	54·6	55·2	56·1	56·0
Highest maximum	80·2	87·5	82·6	84·0	82·0	90·0	82·0	91·0	82·1	85·2	83·0	92·5	—
Lowest minimum	47·5	47·0	45·5	50·0	48·2	38·0	46·5	45·1	35·0	36·8	40·0	46·2	—
Mendi (5500 ft)													
Mean maximum	75·3	74·9	75·1	74·7	74·8	73·2	72·1	71·9	73·1	74·6	75·0	74·9	74·1
Mean	65·3	65·5	65·4	65·4	65·0	63·4	63·1	63·2	64·4	64·2	64·5	65·2	64·5
Mean minimum	55·2	56·2	55·7	56·0	55·3	53·7	54·1	54·5	55·8	53·8	54·0	55·5	55·0
Highest maximum	82·1	81·4	81·0	82·6	79·0	79·3	80·2	77·5	78·6	82·2	94·1	88·7	—
Lowest minimum	47·4	49·3	47·0	48·6	48·4	40·8	45·0	43·3	37·6	40·1	45·0	46·0	—
Lake Kutubu (2650 ft)													
Mean maximum	83·8	83·6	83·8	84·1	83·2	82·0	79·9	78·4	81·7	84·6	84·7	84·3	82·8
Mean	74·4	74·4	74·1	74·5	74·1	73·1	71·8	71·1	72·9	74·6	74·3	74·1	73·6
Mean minimum	65·0	65·2	64·4	64·9	65·2	64·2	63·8	63·8	64·2	64·5	63·8	63·9	64·4
Highest maximum	88·8	89·0	92·0	93·0	91·0	89·5	87·5	85·5	88·0	90·0	92·5	90·1	—
Lowest minimum	53·0	61·0	53·0	61·0	52·8	52·8	41·0	54·0	52·9	52·0	57·0	44·0	—

eratures on record for each station. These extremes are generally 5 to 10 degF above and below the mean maximum and minimum temperatures respectively, but they have on occasion differed from the means by as much as 20 degF.

At the low elevation of Lake Kutubu, daily maximum temperatures over 90°F are not uncommon, but such extremes have not often occurred at Tari and Mendi, which are between 5000 and 6000 ft. The highest maximum temperature at Wabag is less than 85°F.

The lowest temperatures that have been observed at Lake Kutubu are above 40°, and it may be concluded generally that areas below 4000 ft are frost-free. At Mendi, Tari, and Wabag, screen temperatures between 35 and 40° have been observed

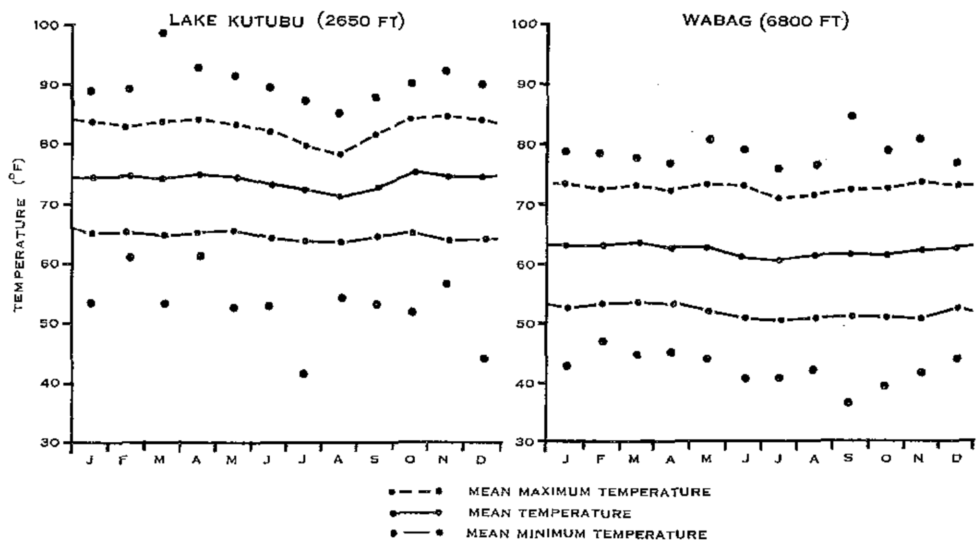


Fig. 3.—Monthly temperature conditions at two stations at different elevations. The points above and below the curves show the highest and lowest temperatures on record.

a number of times. On the expectation that on such occasions considerably lower temperatures would occur at radiating surfaces, a risk of frost apparently commences at about 5000 ft and increases with higher elevations, particularly where the immediate surrounding topography promotes concentration of cold air in surface depressions. From the lowest recorded minimum temperatures it would appear that there is a sharp increase in the risk of frost in June, and this risk continues until November. Frosts are common at elevations above 8000 ft. Snow occurs at times on the highest peaks within the area, but this does not normally remain long before melting.

(c) *Humidity*

As shown by the data in Table 6, humidity is high throughout the year at all stations. Mean monthly relative humidity at 9 a.m. ranges generally between 75 and 85% at Wabag, Tari, and Mendi, and between 85 and 90% at Lake Kutubu. At all stations the lowest values occur during October and November. The 3 p.m. mean values are naturally lower, but these do not generally fall below 60% and for some months are in fact only a few per cent less than the 9 a.m. values. At both Lake Kutubu and Mendi the 3 p.m. relative humidity ranges approximately between 70 and 80% throughout the year and is distinctly higher than at Wabag and Tari during the south-east season.

With such high relative humidity prevailing, the night-time fall in temperature generally results in saturated or near-saturated conditions during the early morning hours. Mean dew-point temperatures throughout the area are 2 to 5 degF higher than the mean minimum temperature over all months.

TABLE 6

MEAN MONTHLY AND ANNUAL RELATIVE HUMIDITY (%) AT FOUR STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
							Wabag						
9 a.m.	79	78	82	82	82	82	82	80	77	74	73	77	79
3 p.m.	71	70	71	63	59	62	64	61	72	62	67	69	66
							Tari						
9 a.m.	82	85	84	84	82	84	86	85	81	79	79	83	83
3 p.m.	66	67	71	65	69	69	72	73	74	72	69	71	70
							Mendi						
9 a.m.	77	81	78	79	76	77	81	81	79	75	76	77	78
3 p.m.	67	72	69	73	75	73	78	80	78	73	71	70	73
							Lake Kutubu						
9 a.m.	85	85	85	86	86	87	88	88	86	83	81	82	85
3 p.m.	74	74	73	76	74	76	80	81	79	70	67	78	75

(*d*) *Cloud, Sunshine, and Total Incoming Radiation*

All parts of the area have much cloudy weather. Table 7 gives the mean cloudiness at 9 a.m. and 3 p.m. expressed as the percentage of sky covered. As shown by these data, cloudiness increases markedly during the day over the whole area. The mean afternoon amount is almost always greater than 75% and in some cases only slightly below the maximum of 100% representing completely overcast conditions. At Wabag, which may be taken as generally representative of the northern part of the area, appreciably less cloud occurs during the south-east season than during the north-west season, especially during the morning hours. An interesting aspect of the cloud data in Table 7 is the persistently lower percentages at Lake Kutubu than at Mendi at 3 p.m. Between June and October the 9 a.m. percentages at these two stations are about equal, and a very pronounced diurnal rhythm in cloudiness occurs at Mendi throughout this period. This appears to be related to a local orographic situation at Mendi that favours abnormally strong daytime convection. This is supported by a seasonal distribution of falls greater than 2·00 in. at Mendi which is in many ways distinctive within the area (Table 4).

No data are available for duration of sunshine from stations within the area. At Nondugl about 45 miles to the east of the area, the monthly averages range generally between 120 hr and 160 hr. The mean rainfall at Nondugl is roughly similar in amount and seasonal distribution to that at Laiagam, and these durations may be taken to be approximate for the northern part of the area.

Using mean monthly cloudiness data for Mendi, estimates of total incoming (global) radiation have been obtained from an empirical relationship given by Budyko (1958). These range from about 275 to 335 cal cm^{-2} day^{-1}, the lowest occurring in January and July and the highest during September and October. No total radiation measurements are available from Papua–New Guinea, and the reliability of these estimates cannot be assessed. If correct, the mean daily total radiations throughout the year are about 135 to 200 calories less than mean observed levels during the middle wet season at Darwin (Loewe 1956).

TABLE 7

MEAN MONTHLY AND ANNUAL CLOUDINESS (%) AT FOUR STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
							Wabag						
9 a.m.	82	84	82	81	63	55	65	69	66	66	75	82	73
3 p.m.	92	96	94	90	84	76	85	82	86	88	91	93	88
							Tari						
9 a.m.	71	75	70	70	63	65	70	75	65	62	61	64	68
3 p.m.	75	86	78	88	82	78	86	86	88	88	78	85	83
							Mendi						
9 a.m.	80	79	76	75	68	64	65	66	61	61	69	74	70
3 p.m.	94	96	88	94	94	86	95	93	98	91	90	98	93
							Lake Kutubu						
9 a.m.	60	66	58	68	66	63	66	69	66	50	53	56	62
3 p.m.	79	79	70	78	72	75	75	81	79	75	65	75	75

(*e*) *Evaporation*

No direct observations of evaporation have been made and only crude data are available to estimate this. For Lake Kutubu, Tari, Mendi, and Wabag, mean maximum temperature and vapour pressure data have been used to estimate the equivalent evaporation from the standard Australian tank (Fitzpatrick 1963). At Lake Kutubu the estimates are between 3·0 and 5·5 in. per month, giving an annual total of about 50 in. The only months during which the estimated evaporation exceeds 5·0 in. at this station are October and November, when high mean maximum temperatures and the lowest mean vapour pressures occur together. This is in agreement with the time of the maximum observed tank evaporation at Port Moresby (Hounam 1961). At the three other stations the monthly estimates are within the range 2·7–4·0 in. and the annual totals are about 40 in.

III. Climate, Plant Growth, and Land Use

The area is generally free from lengthy periods of either very low temperature or large water deficiency, and optimum climatic conditions for plant growth normally prevail throughout the year.

In Figure 4, monthly rainfall totals between 1954 and 1960 are shown for Wabag, Mendi, and Lake Kutubu in relation to an evapotranspiration requirement assumed

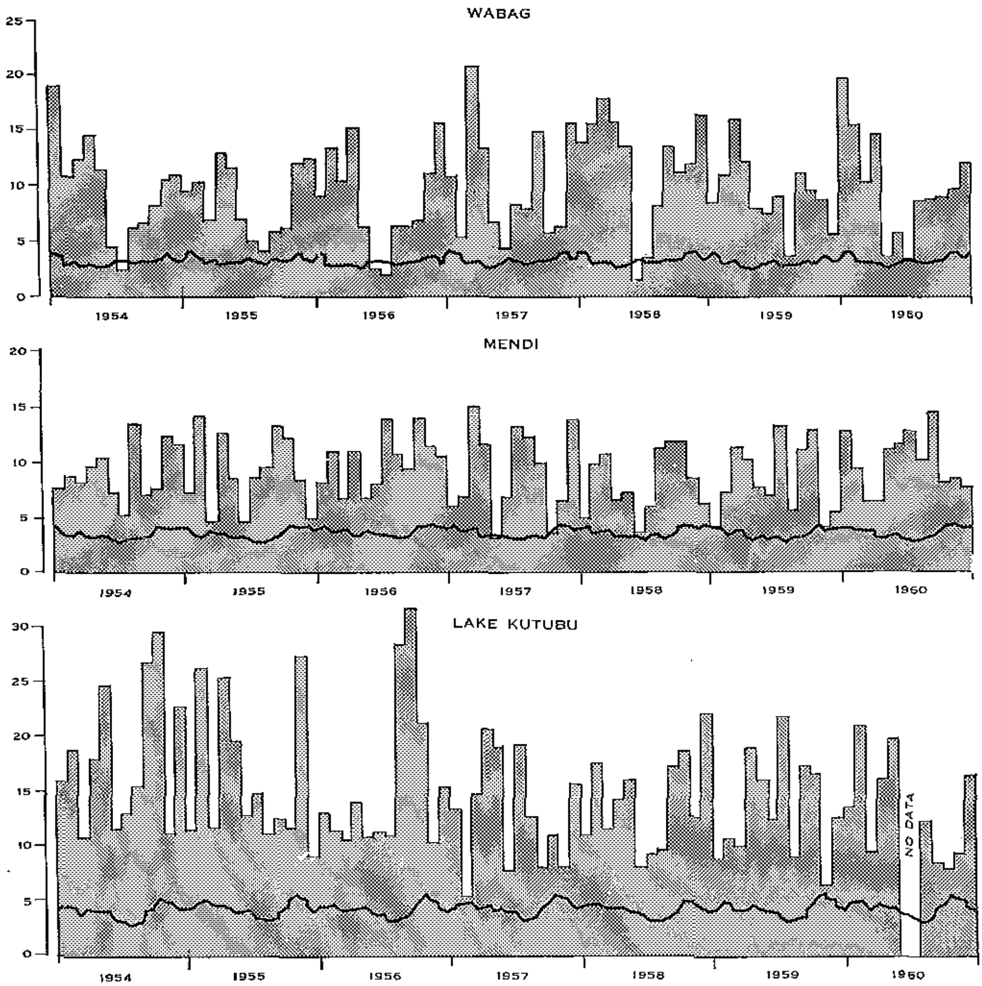


Fig. 4.—Relationships between mean monthly rainfalls (bar graphs) and estimated mean evapotranspiration (curves) at three stations.

to be equal to the estimated mean monthly tank evaporation. Although this assumption may involve some overestimation of evapotranspiration, it is unlikely to be greatly in error under high-rainfall conditions where the falls occur at frequent intervals and where vegetation has a high leaf area and aerodynamic roughness. From Figure 4 it is apparent that only on a few occasions at Wabag and Mendi have the monthly totals been less than this assumed need. At Lake Kutubu, only twice during the seven years was rainfall so low as to even approach this level. Assuming that up to 4·00 in. of available water in soil storage could be drawn upon over those intervals when rainfall failed to meet evapotranspiration, it seems unlikely that there would ever have been a case with soil moisture reserves so low as to inhibit growth.

These water balance assessments are crude in as much as they make reference only to data over coarse monthly intervals and neglect year-to-year variations in evapotranspiration which may result from changing meteorological or soil moisture conditions. However, since the intervals between falls of rain are known to be short (Table 3) and since the variability of rainfall can be expected to be much greater than that of evapotranspiration, these methods are considered adequate for general purposes.

As noted previously, frosts occur with generally increasing frequency upward from about 5000 ft. From field observation, frosts are known to have very severe effects upon elements of the natural vegetation and are seriously detrimental to native agriculture in some localities. At all elevations, the risk is much increased in areas that are low-lying relative to the immediate surrounding topography. Vegetation within these low areas has been found severely "burnt" by frost, while that on higher surrounding sloping country had apparently been unaffected. Frosts probably represent a dynamic selective mechanism in the natural vegetation, and they also pose a major agroclimatic problem needing careful consideration in any projected commercial agricultural land use in the area. With respect to most annual crops, any practice that allows maturation during the period of greatest frost risk would also necessitate a completion of seed-bed preparations and cultivation during the rainiest part of the year.

Lack of a definite period of drier and sunnier weather, needed for successful maturation and harvesting of many crops, seriously limits the range of feasible commercial crops. Both the amount and persistence of rainfall may present special problems for mechanized agricultural operations and also for the maintenance of soil fertility. The prevailing cloudiness, coupled with the absence of a season with extended day length, greatly reduces energy input throughout the year. This aspect of the climate may present agronomic difficulties for some crops. In all these respects, the northern part of the area would appear more favourable.

Generally good agroclimatic features are the comparatively low risk of very heavy daily rainfalls in most areas and the relatively low degree of year-to-year rainfall variability. The lack of concurrent high radiation, high temperature, and low humidity—common in tropical Australia, and liable to create internal water stress in plants even when soil moisture is adequate—is also an asset. The generally mild temperature conditions found at higher altitudes should be an advantage in any future livestock economy.

IV. Acknowledgments

The author is grateful to Mrs. A. Komarowski and Mr. K. J. Granger, who have carried out most of the computations used in this paper.

V. References

Budyko, M. I. (1958).—"The Heat Balance of the Earth's Surface." Trans. Nina A. Stepanova. (U.S. Dep. Commerce: Washington.)

Bureau of Meteorology (1940).—"Results of Rainfall Observations made in Papua, Mandated Territory of New Guinea, Solomon Islands, New Hebrides, etc." (Govt. Printer: Melbourne.)

Conrad, V. (1946).—"Methods of Climatology." (Harvard University Press: Cambridge, Mass.)

Department of National Development (1951).—"The Resources of the Territory of Papua and New Guinea." (Govt. Printer: Melbourne.)

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

Hounam, C. E. (1961).—Evaporation in Australia. Bur. Met. Aust. Bull. No. 44.

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

Loewe, F. (1956).—Notes on global radiation in Australia. *Aust. Met. Mag.* **15**: 31–41.

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

PART V. OUTLINE OF THE GEOLOGY AND GEOMORPHOLOGY OF THE WABAG–TARI AREA

By R. A. Perry*

I. Introduction

In this account, the geology is based mainly on published papers and on unpublished records of the Bureau of Mineral Resources, Geology, and Geophysics. The geomorphology is largely from field observations and the air-photo interpretation of M. J. Bik.

The central cordillera of New Guinea is about 1500 miles long and in West New Guinea attains 16,400 ft. The Wabag–Tari area forms part of the broadening of the central cordillera associated with the change in trend from west-north-west in the west to north-west in the east. The area is characterized by a series of ranges and high basins and has very rugged topography. It lies mainly between 5000 and 10,000 ft altitude, but ranges from a little over 2000 ft in the south-western corner to 13,660 ft on the summit of Mt. Giluwe.

The area has undergone intense orogeny and uplift at a fairly late stage in geologic history, as shown by the occurrence of folded and faulted marine Miocene rocks at altitudes exceeding 10,000 ft locally, and frequent earth tremors indicate that earth movements are still proceeding. Strong youthful relief reflects the dominating influence of a young and active tectonic history. In particular, north-west–south-east trending fold structures are expressed in striking longitudinal patterns of relief and drainage, whilst more recent vulcanism has given rise to major land forms.

II. Regional Drainage

A feature of New Guinea is that although in detail drainage follows structure, the island-wide picture is one of transverse drainage escape from the cordillera. The waters of the area enter the sea in four rivers (Fig. 5): the Sepik, which flows into the Bismarck Sea to the north of New Guinea, and the Fly, Kikori, and Purari, which flow into the Gulf of Papua to the south of New Guinea. Within the area the headwaters of all these rivers rise above 10,000 ft. Tributaries of the Sepik River leave the north-eastern part of the area at altitudes of 3000–5000 ft, those of the Fly River leave the north-western portion at 5000–7000 ft, and those of the Kikori and Purari Rivers cross the southern boundary at about 2000 ft above sea level.

The divides between the four river systems are shown in Figure 5. In only two short lengths do the divides depart significantly from the regional strike, namely those parts of the Fly–Purari divide east of Mt. Wamburi and of the Sepik–Purari divide from Mt. Hagen to about 8 miles west of The Sugarloaf. In the first case, that part of the divide across the strike follows a little-dissected upland surface (Nop land system). The anomalous section of the Sepik–Purari divide is probably due to disruption of drainage by the large accumulation of volcanic material from Mt. Hagen. Faulting appears to have changed regional drainage to a considerable extent.

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

Over much of their length the main divides are above 8000 ft, attaining 13,000 ft at The Sugarloaf and Mt. Hagen. It is notable, however, that the highest mountains in the area, Mt. Giluwe (13,660 ft) and Doma Peaks (13,000 ft), are not on major divides, indicating that the regional drainage was established prior to the formation of these volcanic mountains.

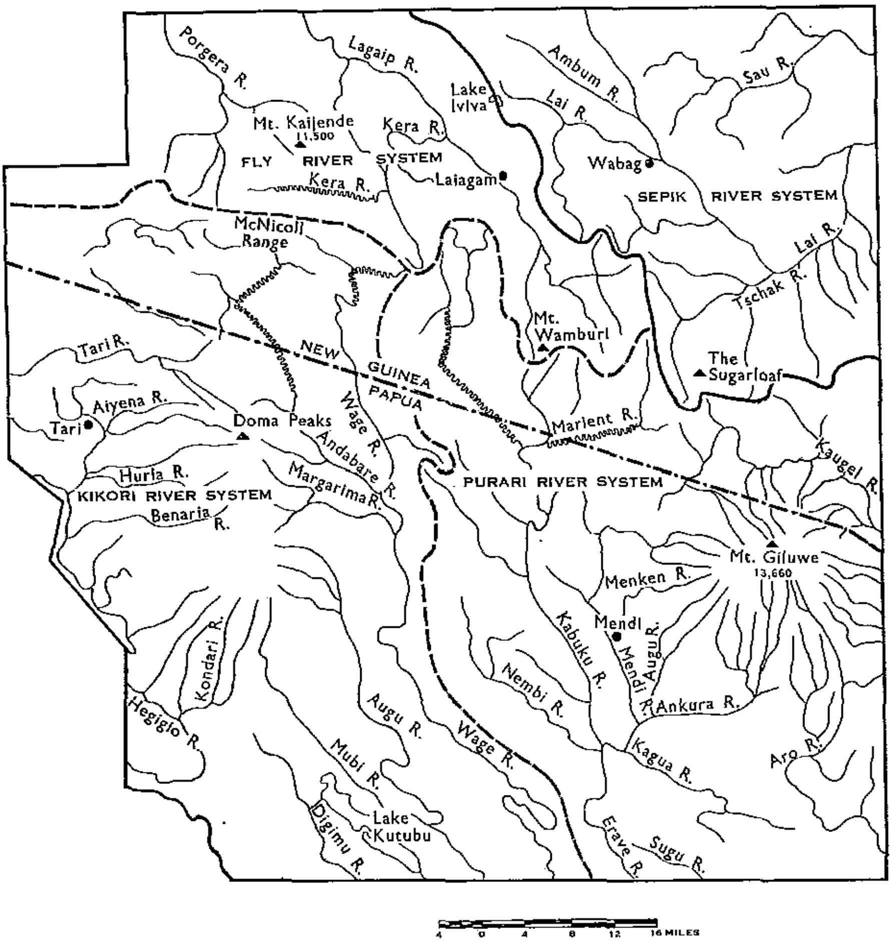


Fig. 5.—Drainage systems.

III. Geologic and Geomorphic History

The aim of this account of the geological history of the area is to provide a background for the consideration of the relationship between present landscapes and geology. It is based on published papers and on unpublished records of the Bureau of Mineral Resources. The most useful sources were Australasian Petroleum Company Proprietary (1961), Rickwood (1955), Dow (unpublished data 1961), and Ward (unpublished data 1949). Reports also used were those on adjacent or nearby areas by Noakes (unpublished data 1939) and Dow and Dekker (unpublished data 1963). Some use was also made of the broad general account of the geology of Australian New Guinea by Montgomery, Glaessner, and Osborne (1950).

(a) Mesozoic Subsidence and Sedimentation

During later Mesozoic time the whole area was part of the Papuan Geosyncline, a subsiding belt beyond the north-eastern margin of the Australian continent, and great thicknesses of marine sediments were laid down. During the Jurassic period, a north-

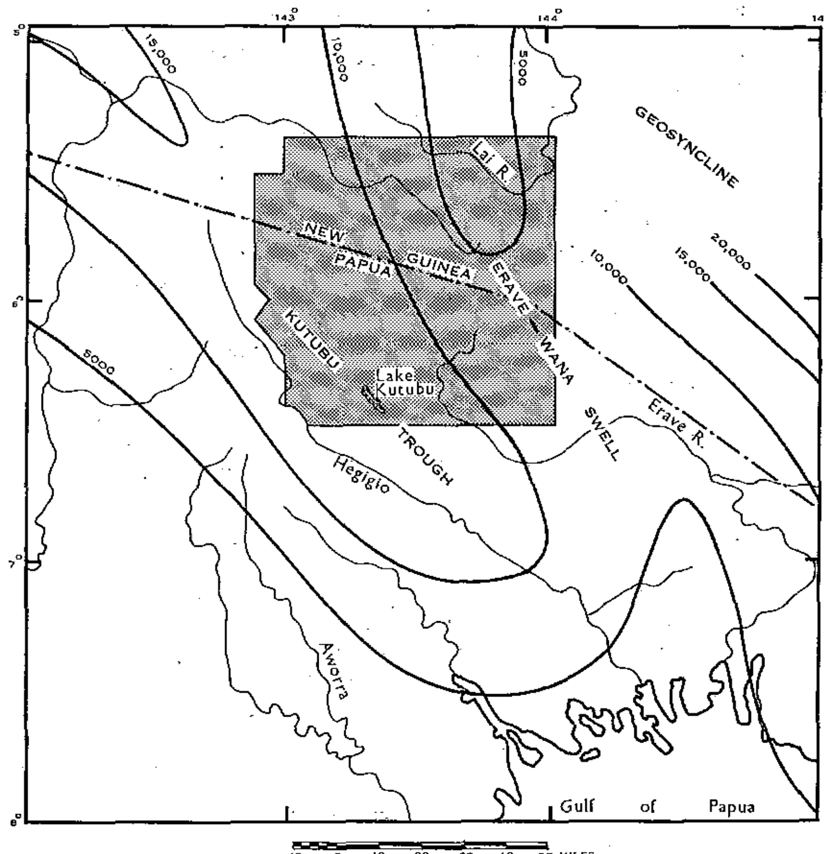


Fig. 6.—Mesozoic isopach map.

west–south-east trending belt stretching from about the present Mt. Ialibu to beyond the Lai valley was emergent. Although submerged in Cretaceous times it remained as a locally high part in the geosyncline (Fig. 6), the "Erave–Wana" swell (Australasian Petroleum Company Proprietary 1961). To the south-west of and roughly parallel to the swell was a belt of rapid subsidence and deposition called the Kutubu Trough. The total thickness of Mesozoic sediments was about 14,000 ft in the Kutubu Trough and about 5000 ft over the Erave–Wana swell.

Only in a few places in the area do Mesozoic sediments crop out and so directly affect the present landscape. In the Kagua valley about 2000 ft are exposed. The exposure consists of 250 ft of mostly soft-weathering and friable sandstones, overlain by 800 ft of shales and silts that grade upwards into about 1000 ft of marls. These marls have been correlated with the more calcareous Mango Marls exposed near Mendi and described by Rickwood (1955). Cretaceous marls also crop out along the Lagaip River.

(*b*) *Upper Cretaceous to Early Tertiary Emergence*

Throughout the area there is a gap in the stratigraphic sequence between the youngest Mesozoic beds and the overlying Tertiary sediments, but with little angular discordance. Warping began as early as late Jurassic, but the final stage resulting in emergence did not occur until late in the Upper Cretaceous. A period of erosion followed.

(*c*) *Early to Mid Tertiary Sedimentation*

Following the period of erosion, a gentle downward tilting of the land surface occurred to the east and north-east and all except the south-western corner of the area suffered a marine transgression, during which the Erave–Wana swell was not in evidence.

During the Lower Miocene the sea invaded the entire area. The Australasian Petroleum Company Proprietary (1961) considers that this inundation was not simply a more widespread continuation of the Eocene–Oligocene transgression. On the evidence of derived Eocene fossils and fragments of Eocene and Oligocene rocks in basal Miocene deposits, they postulate a widespread emergence and exposure of Palaeogene rocks to erosion before the sea returned and submerged the whole area during Lower Miocene times.

In the Miocene, the Erave–Wana swell was again a feature of the Papuan Geosyncline, but it was located near the present Erave River and thus was considerably south of its Mesozoic position (Fig. 7). A belt of rapid subsidence and heavy deposition to the west and south-west of the Erave–Wana swell has been named the Omati Trough.

In their tentative isopach map, Australasian Petroleum Company Proprietary (1961) shows the thickness of Eocene deposits to range from nil near the present Lake Kutubu to between 1000 and 2000 ft near the Lai valley. More recently Dow (unpublished data 1961) has measured, near the Lai River, a north-west trending sequence of beds 5500 ft thick which he has assigned to the Eocene and named the Linganas Beds. They are predominantly fine-grained marine sediments. Rickwood (1955) considered some fine-grained cream unfossiliferous limestones near Mendi to be possibly Eocene. Samples collected during the survey confirmed this and suggest that Eocene limestones were deposited up to 50 miles north-west and 40 miles west of the locations mapped for the Tschak valley by Rickwood (M. J. Bik and G. R. T. Terpstra, private communication). Dow (unpublished data 1961) has suggested that an 18,000-ft north-west trending sequence (Kompiam Beds) of arenaceous marine sediments and basic volcanic rocks that crop out in the vicinity of Kompiam ranges in age from Eocene through Oligocene and into Lower Miocene. He considers that the coarser nature of these sediments indicates increased tectonic activity during Oligocene time. Dow correlates the Kompiam Beds with a 10,600-ft sequence of greywacke over shale, described by Rickwood (1955), from the Lai valley and assigned to Lower and Middle Miocene. As far as is known Oligocene sediments are restricted to this north-east corner of the area. Over more than half the area the present land surface

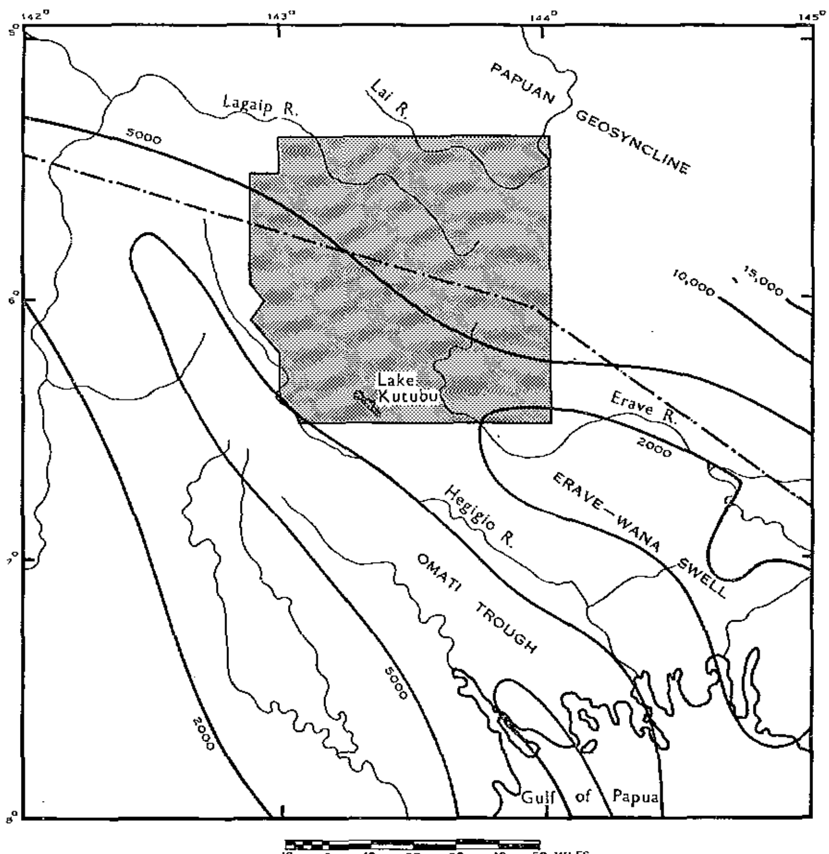


Fig. 7.—Lower Miocene isopach map.

is formed on sedimentary rocks, the majority of which are of Miocene age. Most of the present sedimentary landscapes are dependent on the nature of these rocks. Broadly, they range from almost wholly limestone facies in the south-west, through a mudstone–limestone facies in the centre, to a coarse clastic facies in the north-east. Except for some of the limestones the rocks are soft and erodable.

To the west and south-west of the Erave–Wana swell the Lower and Middle Miocene are developed in thick deposits of shoal-type limestone facies. Most of the present-day land surface in the south-western part of the Wabag–Tari area is formed of these Miocene limestones, which are shown on the A.P.C. isopach map as being about 5000 ft thick in the Lake Kutubu area. Nearly double that thickness was found in Omati bore to the south of the area and nearer the axis of the Omati Trough.

In the Erave River area, the Lower and Middle Miocene rocks are exposed throughout in shoal-type limestone facies with an intermittent thin basal clastic member. Bedding is massive to medium and thin, and the thickness is 2000–3000 ft.

On the northern side of the Erave–Wana swell the Miocene beds are no longer developed wholly in a limestone facies. Of a 5400-ft sequence near Nembi (Australasian Petroleum Company Proprietary 1961), 3750 ft are mudstones.

Further north-east, in the Lai syncline, Lower Miocene beds are represented by coarse clastics and basic volcanics of the upper part of the Kompiam Beds (Dow, unpublished data 1961), the upper part (mostly greywacke) of Rickwood's (1955) 10,600-ft sequence, and Dow's Birip Beds, a formation of shallow-water, off-shore sediments predominantly conglomerate with igneous components at least 2500 ft thick.

Upper Miocene sediments are poorly represented in the area. The largest exposures are to the west of Lake Kutubu, where some marine mudstones have been mapped by the Australasian Petroleum Company Proprietary (1961).

(*d*) *Pliocene Orogeny, Intrusion, and Planation*

Although emergence possibly started as early as late Jurassic, the lack of any strong unconformity throughout most of the stratigraphic column indicates that most of the deformation occurred during a single orogenic phase at about the end of the Pliocene period and possibly extending into the Pleistocene.

The folding had a north-west–south-east trend which is directly reflected in the trend of the strike ranges. Over most of the area folding was accompanied by faulting, but in the lower country of the south-west (Lake Kutubu area), closer to the stable shelf area of south-western Papua, faulting was less important in the tectonics.

The Timun Intrusives mapped and described by Dow (unpublished data 1961) in the north-east of the area are probably associated with this orogeny. They are predominantly basic igneous rocks and intrude the Miocene and older Kompiam Beds. From air-photo interpretation another larger area to the south-west of the Lai valley has been mapped as intrusives.

Remnants of a subdued land surface on mountain summits in the north-eastern half of the area suggest a period of planation following folding, but prior to the major uplift.

(*e*) *Pleistocene Uplift and Dissection*

Following uplift, vigorous erosion by rivers produced a strike range landscape with relief largely attaining the present dimensions. Much of the present drainage pattern was established in this period.

The broad valleys (e.g. Andabare, Kandep, and Marient) with gorges below them probably developed as a result of successive stages of faulting during uplift.

(*f*) *Pleistocene Vulcanism*

The most striking feature of the Pleistocene period was the intermittent volcanic activity, during which great thicknesses of basic volcanic rocks were accumulated. These are mainly represented in the large volcanoes, Mt. Giluwe, Mt. Hagen, and Mt. Ialibu in the east and several centres collectively named Doma Peaks in the west. The bodies of these volcanoes consist of layered basalt and pyroclastics which were extensively covered by agglomerate and volcanic ash during a later paroxysmal phase. The ash deposits thicken downslope and cover wide foot zones. The great cones and surrounding piedmont slopes of these mountains are a spectacular feature of the present landscape. Less spectacular is The Sugarloaf, where a considerable area was covered by flows from a number of small volcanoes.

The products of the vulcanism were spread much wider than the cones and their surrounding piedmont slopes: extensive ash showers blanketed a large part of the area and in many places still cover the landscape.

Since they became extinct the main volcanoes have undergone considerable erosion. All trace of the old craters has been removed, and in places gorges up to 2000 ft deep dissect the upper slopes.

Small, little-dissected cones and minor lava flows are common in the eastern part of the area. Most are probably younger than the main volcanoes.

(*g*) *Pleistocene to Recent Alluviation and Incision*

Vulcanism led to alluviation in two ways—by direct obstruction of streams by volcanic growth and lahar flows as in the case of Mt. Hagen and the Lai River, and by overloading as a result of ash showers. Extensive areas of alluvium were deposited in the Lai, Tschak, and Kaugel valleys. The alluvia consist mainly of volcanic detritus accumulated from ash showers via the catchment slopes or directly to the valley floor.

Since then the Lai River has cut a deep gorge northwards from Yaramanda and is now deeply incised in the alluvial fill of the Lai valley.

The alluvial plains of the upper Andabare, Kandep, Marient, and several other smaller mature upland valleys (produced during steady stages in the uplift of the area) are of more recent origin and are probably at least partly associated with differential warping. Narrow areas adjacent to these streams are still subject to slow to moderate alluviation.

(*h*) *Pleistocene Glaciation*

Studies by Bik (unpublished data) show that about 65 sq miles of the summit plateau of Mt. Giluwe at 10,000 to 12,000 ft above sea level was covered by a late Pleistocene ice cap, from which a number of valley glaciers descended to about 8500 ft on the south and 9500 ft on the north.

Very well-developed lateral moraines indicate an ice thickness of up to 300 ft and a snow line at about 11,700 ft. One of these valley glaciers shows two distinct sets of terminal moraines about 600 yd apart, but elsewhere only a single complex terminal moraine is present. On the plateau, stages in the shrinking of the ice cap are marked by four or five sets of closely spaced, subparallel low moraines. There does not appear to have been a particularly favourable orientation for glacier development. Apart from the material in the moraines themselves, there is virtually no till and thin grassy peat rests directly on ice-polished bed-rock showing little or no sign of weathering.

Active periglacial action is not in evidence. Former periglacial action during or after deglaciation is indicated by old screes now completely covered by grassy peat, found above 11,700 ft. Intense colluviation is active in grass-covered areas between 8500 and 11,500 ft, but it is not periglacial and is related to high rainfall. Scattered field evidence indicates that such colluviation occurred to as low as 5500 ft during the Pleistocene.

According to air photos, traces of glaciation occur on Mt. Hagen and Mt. Mano and possibly on the Burgers Mountains and Mt. Kerewa. On Mt. Hagen, well-developed cirques with garlands of terminal moraines occur on the south side at, or above, 11,500 ft. Possible cirques, modified by colluviation, exist on the north side as well.

The glacial features have not been disturbed by vulcanism, indicating that glaciation post-dates volcanic activity. On the basis of freshness of land forms it is suggested that the glaciation is Upper Pleistocene, possibly of the Wurm age. No evidence exists for more than one glaciation. Reiner (1960) has described the glaciation of Mt. Wilhelm, which lies about 50 miles east of Mt. Hagen.

(*i*) *Current Processes*

Alternate weathering and slumping or rotational slipping are active on all steep slopes, and creep on almost all slopes. Weathering is rapid because of the wet climate and the unresistant nature of most of the rocks. These processes lead to the formation of colluvial aprons and mantles.

Limestone rubble flows can extend a mile or more from the foot of limestone scarps (e.g. in the Porgera valley). It is uncertain whether these are due to current processes or relate to a phase when climatic belts shifted downwards.

In the limestone areas weathering is mostly through solution, a process that is rapid in the area because of plentiful supplies of water which, under the relatively cool climate and dense vegetation, has a fairly high carbon dioxide content. The karst morphology of the limestone parts of the area has been described and discussed by Jennings and Bik (1962).

The very active mass movement of slopes is the result of vigorous downcutting by streams, which maintains overall steep slopes in most parts of the area.

Current alluviation is restricted to very small areas of fans and narrow flood-plains adjacent to parts of most larger streams.

Active peat formation is a feature of small, poorly drained parts of the area, particularly at altitudes above 7000 ft, where it has been recorded on slopes as steep as 5°.

IV. Structural and Relief Units

The area can be described in three main structural and relief units (Fig. 8) directly associated with its geological history.

(a) *Strike Ranges of the Imbricated Zone*

This unit falls in the "Imbricated Zone" defined by the Australasian Petroleum Company Proprietary (1961). Within it, subparallel faults cause much repetition of formations. It occupies most of the area and consists, in the main, of uplifted, mainly subparallel, north-west–south-east trending, steep-sided strike ranges separated by narrow valleys commonly 2000 ft deep. Most of it lies between 5000 and 10,000 ft altitude.

Broadly, that part south-west of the north-west–south-east diagonal of the survey area is formed mainly of limestones and is characterized by spectacularly steep mountains set in fields of karst lands. In this part drainage is mostly by percolation and organized surface drainage is characteristically absent. It is traversed by a series of long, subparallel, through-going, major streams (Hegigio, Augu, Wage, and Kabuku Rivers) carrying run-off from areas of volcanics and non-calcareous sediments and receiving few short tributaries from the limestone areas.

In contrast, that part to the north-east of the diagonal is formed on unresistant non-calcareous rocks—mostly greywacke, siltstone, and mudstone—and is characterized by steep-sided strike mountains with occasional intermittent almost sheer limestone cliffs. It is drained by a dense, structurally controlled pattern of streams. Small areas exhibit a more mature topography and may represent remnants of land surfaces formed during halt stages in the uplift.

Several broad upland valleys with mature streams meandering through alluviated floors occur within the strike ranges. The largest are associated with the headwater or near-headwater tracts of the Andabare, Wage, Kabuku, Marient, and Kera Rivers. Down-valley the rivers either plunge over waterfalls or enter deep gorges. The broad mature valleys were probably partly formed during halt phases in the uplift. Differential warping is probably a factor in their survival in particular valleys but not in others, and also in the nature of present alluviation within them.

(b) *Kutubu Lowlands*

This unit is part of the "Strongly Folded Belt" of the Australasian Petroleum Company Proprietary (1961). It occupies only the south-western corner, which is closer to the stable shelf area of south-western Papua than the previous unit. The gentler folding, relative absence of faults, and lesser uplift are reflected in a less rugged topography in terms of larger features. The land surface is mostly formed on limestone and consists of broad fields of karst lands and steep limestone cliffs commonly associated with deeply incised through-going major channels. The karst lands are almost devoid of organized surface drainage. Lesser areas of alluvial plains are associated with Lake Kutubu and the Mubi valley.

The Kutubu lowlands mostly lie between 2000 and 3500–4000 ft above sea level. The altitudinal break between them and the strongly folded and faulted strike ranges roughly corresponds to the altitude associated with the change from lowland rain forest to lower montane rain forest.

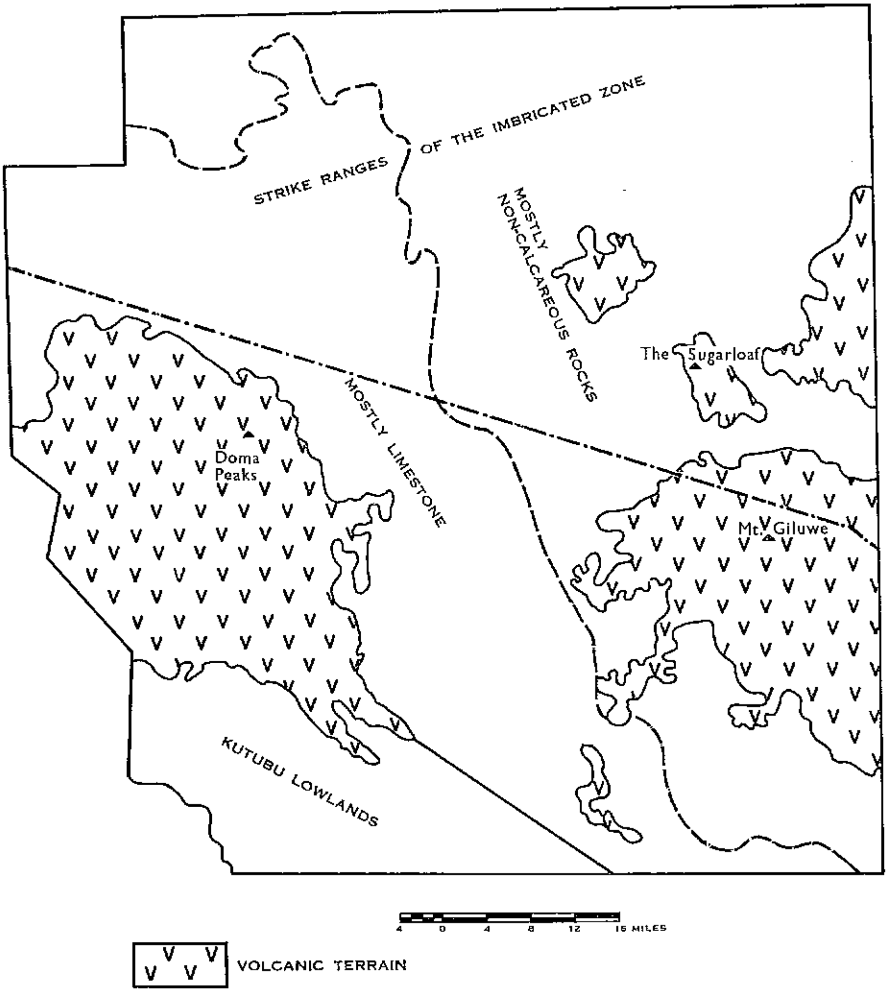


Fig. 8.—Structural and relief units.

(c) *Volcanic Terrain*

This mostly consists of the large volcanoes—Mt. Giluwe, Mt. Hagen, Mt. Ialibu, and Doma Peaks—and their surrounding piedmont slopes and plains. The summits of the mountains are all in the vicinity of 13,000 ft above sea level. Those of Mt. Giluwe and Mt. Hagen show evidence of Pleistocene glaciation and now form an apparently stable land surface. The crest areas of Mt. Ialibu and Doma Peaks and a zone flanking the glaciated summits of Mt. Giluwe and Mt. Hagen have been deeply dissected by a close radial drainage pattern into sharp-crested ridges up to

1500 ft high. Surrounding this zone on Doma Peaks is a lower zone less deeply dissected into mountains less than 1000 ft high. The lahar and ash deposits that formed the gentle lower slopes of the volcanoes partially survive as long, flat-crested, gently sloping interfluves. The outermost zone consists of irregular plains at 5000–7000 ft above sea level, in part poorly drained, with occasional small lava and ash cones.

The volcanic areas are drained by a radial stream pattern. In the case of Mt. Giluwe the radial streams are tributary to a series of streams—Mendi, Kaugel, and Iaro Rivers on the west, north-east, and south-east respectively—that encircle the base of the mountain and are themselves all tributary to the Erave River, which is part of the Purari system. Similarly, the radial streams from Doma Peaks collect into the Hegigio, Augu, and Wage Rivers, which are part of the Kikori system.

V. The Land Systems in Relation to Geology and Geomorphology

Over the whole area the land surface is fairly recent and land forms are closely related to lithology. For this reason the land systems have been classified into five main groups according to lithology. Within most of the main groups, subgroups have been defined on the basis of relief (Table 1).

(*a*) *Land Systems Mainly on Limestone*

Most of the land surface in the south-western half of the area is formed on limestone; in other parts of the area, discontinuous bands of limestone of varying thickness occur within the succession of sedimentary rocks. Throughout, limestones form most of the prominent ridges and cliffs. In many places limestone cliffs are more than 1000 ft high, and the sheer north-facing slope of Mt. Kaijende rises 3000 ft above the surrounding country. Large areas of limestone exhibit a karst topography.

(i) *Massifs and Precipices.*—This subgroup comprises two land systems: Kaijende in the strongly folded and faulted ranges and Duma in the Kutubu lowlands. Both are characterized by very steep slopes, but whereas Kaijende land system consists of sharp-crested mountain ridges and escarpments, Duma land system tends to occur more as cliffs flanking karst lands. Internal relief in Kaijende land system is commonly greater than 1000 ft and attains 3000 ft, but in Duma lan system it is normally less than 1000 ft.

(ii) *Karst Lands.*—This group of land systems is most prominent in the south western half of the area. It is characterized by karst topography and little organized surface drainage. Mostly, the karst lands consist of fields of enclosed depressions varying in diameter from 50 yd to over a mile and in depth from 50 to 500 ft.

Pinnacle land system consists of steep-sided, mainly pyramidal hills and spire-crowned towers with precipitous rocky slopes, interspersed with enclosed depressions. Nembi and Digumu land systems consist of fields of enclosed depressions, interspersed with pyramids and towers, and occur in the strongly folded and faulted ranges and Kutubu lowlands respectively.

Although Sumu land system is developed on interbedded greywacke, siltstone, shale, and limestone, the landscape is mainly a limestone one, and consists of fields of enclosed depressions separated by mountains and ridges. It has little surface drainage but more than Pinnacle, Nembi, and Digumu land systems.

(b) Land Systems Mainly on Unresistant, Non-calcareous Sedimentary Rocks

This group of land systems, developed on sedimentary rocks other than limestones, is more extensive than any other group and occupies most of the north-eastern half of the area.

The rocks consist of strongly folded and faulted, gently to moderately dipping greywacke sandstone, siltstone, mudstone, minor conglomerate, shale and marl with thin intercalations of limestone, and derived colluvium. Much of the country has been blanketed by showers of volcanic ash. The rocks are readily weatherable and under the wet climate the slopes undergo alternate weathering and slumping at moderate rates. The resultant topography consists mainly of north-west–south-east trending steep-sided mountains with smaller areas of hills and benchlands.

(i) *Mountains*—This group of three land systems occupies 1640 sq miles. Nop land system consists of mountain summit areas with rounded hill and mountain ridges and little surface drainage. The extensive Ambum land system consists of steep-sided hill and mountain ridges with a local relief up to 2000 ft, developed mainly on interbedded greywacke sandstone and siltstone.

Tou land system consists of steep-sided mountain ridges with a local relief up to 2000 ft developed on thick massive sandstones. It occurs only on the western side of the area near the northern margin.

(ii) *Hills and Benchlands*.—In this group of land systems local relief is mostly less than 500 ft.

Yalis land system consists of saucer-shaped plateau surfaces bounded by precipitous escarpments and is mainly developed on sandstone and conglomerate. It occurs only in the north-eastern corner of the area.

Wongum land system consists of low hills and ridges with rounded crests. It mostly occurs in summit areas but locally in valley situations. Local relief is generally less than 250 ft, and some parts may be remnants of an uplifted mature land surface. It is developed mostly on greywacke sandstone, siltstone, and shale.

Andabare land system consists of high-altitude upland valleys with a hilly topography, and is also developed on greywacke sandstone, siltstone, shale, and marl. The land system receives cold air drainage from above and is naturally treeless.

Tsang land system consists of chevron hill and mountain ridges, closely dissected, and with a local relief of 200–800 ft. It is developed on interbedded tuffaceous sandstone and sandstone and mudstone.

Laiagam land system consists of rolling country developed on mudstone and shale. These tend to be extremely unstable even on the relatively gentle slopes and the surface is subject to continuous slumping and sliding.

Tibinini land system consists of long gentle slopes developed on sandstone and siltstone, with derived colluvium. In parts it is dissected into flattish-crested ridges up to 100 ft high by subparallel drainage.

Hariu land system is similar to Tibinini but contains some low hills as well as long gentle slopes. It is restricted to the Kutubu lowlands.

Kagua land system consists of plains and colluvial fans and terraces, developed on marl, siltstone, and greywacke sandstone.

(c) Land Systems Mainly on Basic Intrusive Rocks

The two land systems in this group occupy 150 sq miles in the north-eastern corner of the area. They are developed on dolerite, gabbro, diorite, and andesite porphyry. Nose land system consists of closely and strongly dissected mountains with a local relief of 500–1500 ft. Silim land system consists of rounded hills and ridges including remnants of an upland surface. Local relief is less than 500 ft.

(d) Land Systems on Volcanic Materials

This group of land systems is mainly represented by the large central volcanoes Mt. Giluwe, Mt. Hagen, Mt. Ialibu, and Doma Peaks and wide foot zones.

Broadly, the volcanoes consist of a number of concentric zones which form the basis for the land system subgroups. The summit areas consist of rugged mountains. Upland basins and plateaux occur within and flanking the mountain zone, and also comprise the Sugarloaf area. Beyond these two zones are successively zones of long piedmont slopes and plains. In parts, the plains and the lower sector of the long slopes have been dissected into low hill ridges.

(i) *Mountains.*—The three land systems in this group comprise mainly the upper zone of the volcanoes.

Giluwe land system consists of the glaciated summit areas of Mt. Giluwe and Mt. Hagen. It consists of steep-sided ridges and cliffs up to 2000 ft high, and amphitheatral glacial valleys, all above 10,000 ft altitude.

Ialibu land system consists of rugged mountain ridges with steep or precipitous slopes up to 1500 ft high. It comprises the summit areas of Mt. Ialibu and Doma Peaks, which were not glaciated, and areas flanking the glaciated summits of Mt. Giluwe and Mt. Hagen.

Doma land system is similar to Ialibu land system but less deeply dissected, and occurs mainly in the Doma Peaks area.

(ii) *Plateaux and Upland Basins.*—The three systems in this subgroup occur at high altitudes, have relatively gentle topography, and carry mostly alpine or lower montane grassland vegetation. Sugarloaf land system consists of the undulating to hilly volcanic plateaux in the area of The Sugarloaf. Dibibi land system comprises upland basins mainly in the Doma Peaks area, and Lava land system the relatively undissected upper volcanic slopes of Mt. Giluwe.

(iii) *Piedmont Slopes.*—The long gentle slopes of the volcanoes formed of lava flows, scoria, and laharic and ash accumulations comprise Nemarep land system. The slopes are up to 15 miles long and 2–10° and are dissected up to 300 ft by radial drainage.

(iv) *Plains.*—Tari land system consists mainly of ash plains forming the outermost zone of the large volcanoes. It is gently undulating to strongly rolling, in part poorly drained, and has a widely spaced pattern of drainage channels incised less than 100 ft.

(v) *Low Hill Ridges*—The land systems in this group are restricted to the western part of the area.

Tage land system consists of wide-crested ridges and long gentle slopes and is dissected by steep-sided valleys less than 500 ft deep. It is restricted to the Kutubu lowlands.

Kwandi land system consists of round-crested ridges dissected from a volcanic plain by parallel valleys up to 500 ft deep.

(vi) *Younger Volcanic Features.*—Small adventive cones and other volcanic features more recent than the large volcanoes occur scattered over the volcanic piedmont slopes and plains, and to a lesser extent in areas of sedimentary rocks and alluvium. In the south there are several areas of lava plains formed on valley flows.

Ash and scoria cones, tholoids, necks, small lava flows, and dykes comprise Birap land system. Many occurrences too small to map are included in other land systems, especially Tari and Nemarep.

Poroma land system consists of gently sloping, elongate lava plains formed on valley flows. It is locally broken into irregular hills up to 300 ft high, and incised up to 1000 ft by large streams.

(vii) *Gorges.*—A few gorges up to 1000 ft deep cut mainly in volcanic ash and agglomerate have been mapped as Lai land system. Many others too small to map are included in other land systems, especially Tari, Nemarep, and Wabag.

(*e*) *Land Systems on Alluvium*

Alluvial deposits ranging in age from Pleistocene to Recent cover only a small part of the area (290 sq miles). The oldest deposits are valley fills and colluvial aprons associated with the disruption of drainage by Pleistocene vulcanism. Younger deposits comprise piedmont fans and lake and river plains.

(i) *Terraces and Fans, Largely Ash-derived.*—This group consists mainly of variously dissected old valley fills and colluvial aprons.

Tambul land system consists of flat to gently undulating valley floors formed of Pleistocene stratified fluviatile clay, sand, and boulder gravel with peats. It has been deeply but not densely dissected.

Winjaka land system consists of irregular low hilly country of strongly dissected Pleistocene stratified fluviatile deposits ranging from clay to gravel.

Wabag land system consists of terraced Pleistocene valley fills and associated fans, deeply dissected by a moderately dense pattern of narrow streams.

Ko land system consists of piedmont fans and plains of Recent fine-textured alluvium over boulder gravel.

(ii) *Lake and River Plains*.—The three land systems of this group are formed on Recent fine-textured alluvium.

Kandep land system consists of high-altitude swampy plains and stream flats, in part peat-covered, traversed by meandering channels with levees.

Kaugel land system consists of flood-plains and river terraces along major rivers. Many areas too narrow to map are included in other land systems.

Kutubu land system consists of flood-plains and plains of combined alluvial and lacustrine origin in the Kutubu lowlands.

VI. References

Australasian Petroleum Company Proprietary (1961).—Geological results of petroleum exploration in Western Papua, 1937–61. *J. Geol. Soc. Aust.* **8**: 1–133.

Jennings, J. N., and Bik, M. J. (1962).—Karst morphology in Australian New Guinea. *Nature, Lond.* **194**: 1036–8.

Montgomery, J. N., Glaessner, M. F., and Osborne, A. N. (1950).—Outline of the geology of Australian New Guinea. *In* "The Geology of the Commonwealth of Australia", by T. W. E. David. Vol. 1, pp. 662–85. (Arnold: London.)

Reiner, E. (1960).—The glaciation of Mount Wilhelm, Australian New Guinea. *Geogr. Rev.* **50**: 491–503.

Rickwood, F. K. (1955).—The geology of the western highlands of New Guinea. *J. Geol. Soc. Aust.* **2**: 63–82.

PART VI. SOILS OF THE WABAG–TARI AREA

By G. K. RUTHERFORD* and H. A. HAANTJENS†

I. INTRODUCTION

The information in this Part is based on samples from auger holes as well as from numerous road cuts along traverse routes. Apart from the skeletal soils, the profiles examined have been classified into eight major soil groups, which have been further subdivided into soil families. The groups have been defined to suit the local conditions and are considered to be soil-morphogenetic units. They have been given short descriptive names. The soil families, with the exception of those belonging to the group of alluvial soils, have been given locality names.

The skeletal soils have extremely shallow, undifferentiated profiles and are commonly associated with rock outcrop. They will not be further discussed. The distribution of the major soil groups and soil families in the land systems is shown in Table 8.

The very wet climate with its moderate temperatures appears to be the dominating soil-forming factor in the area. Together with the occurrence of generally soft, base-rich parent rocks, it leads to the rapid formation of rather deep, severely leached, acid soils, even on steep slopes. Such soils have generally high organic matter contents, uniform clayey field textures, high cation exchange capacity but small amounts of exchangeable bases, and a strong predominance of 1 : 1 clay minerals. The high rainfall also causes widespread poor drainage conditions, common even in situations that would normally be considered to have adequate external drainage. Thus gleyed and peaty soils are of frequent occurrence.

As the main orogenesis in the area ceased in the Pleistocene, the oldest soils, found on undissected surfaces, mainly of volcanic origin, are probably of late Pleistocene age. Erosional processes have been active up to the present, largely in the form of slumping and rotational creep. These have kept many soils in a semi-mature state of dynamic equilibrium. Profiles severely truncated by erosion are rare; very shallow soils are common only on very steep limestone slopes and unstable mudstone slopes.

II. SOIL MORPHOLOGY

In this section the general environmental conditions and profile characteristics are discussed for each major soil group as a whole, followed by brief notes on the distinguishing features of each component soil family. The descriptive terminology is that of the United States Department of Agriculture (1951). Soil colour names refer to moist soils and are in line with the Munsell soil colour chart. The major soil groups have been arranged from well-drained to progressively more poorly drained groups of residual soils, followed by the alluvial soils.

*Formerly Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T. Present address: Geography Department, Queen's University, Kingston, Ontario, Canada.

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

TABLE

SOILS* AND

Major Soil Group and Soil Family	Limestone						Mainly Non-calcareous Unresistant Sedimentary Rocks										
	Mountains		Karst Lands				Mountains			Hills and Benchlands							
	Kaijende	Duma	Pinnacle	Nembi	Digumu	Suma	Nop	Ambum	Tou	Yalis	Wongum	Andabare	Tsang	Laiagam	Tibinini	Hariu	Kagua
Humic brown clay soils																	
Wapenamanda						m	m	m		m	S		m		m		m
Tabunaka						m					m				m		
Kandep																	
Ivivar											m						
Vakari	*D*		m	m		*D*	*D*	*D*	S	*D*	m	m	*D*	S	m		m
Nenja	m		S	*D*	*D*	S	m	S			S			m	*D*	m	m
Reddish clay soils																	
Herep	m						m	m		m	m				m		
Kutubu																	
Shallow dark clay soils																	
Kaijende	S	S	S	S	S	m											
Deep dark clay soils																	
Tupisanda			m	m	m						m				m		m
Muriraga											m						
Humic olive ash soils																	
Meriunda											m						
Klareg																	
Gleyed plastic heavy clay soils																	
Lombo		m									m			m		S	S
Tumundan							m	m							m	S	m
Tibiri														*D*		m	
Laiagam								m				*D*					
Pumakos												m					
Lumbi																	
Peaty soils																	
Kiakau																	
Tirriraga												m		m			S
Mango								m		m				m			
Giluwe																	
Wapu																	
Dibibi																	
Alluvial																	
Old											m						
Medium-textured recent											m						m
Fine-textured recent												m		m			
Outcrops and skeletal	S	*D*	S	m	m	m		m	*D*	m							

* *D*, dominant; S, subdominant; m, minor.

8

LAND SYSTEMS

Basic Intrusive Rocks		Volcanic Materials														Alluvium						
		Mountains			Plateaux and Upland Basins			Piedmont Slopes	Plains	Low Hill Ridges		Younger Features		Gorges	Terraces and Fans				Lake and River Plains		
Nose	Silim	Giluwe	Ialibu	Doma	Sugarloaf	Dibibi	Lava	Nemarep	Tari	Tage	Kwandi	Birap	Poroma	Lai	Tambul	Winjaka	Wabag	Ko	Kandep	Kaugel	Kutubu
	S		m	m				*D*	S		*D*	*D*		m	m	m	*D*	m			
				m		m		m	m		m	S	*D*	m			m				
D	m		*D*	*D*				m			m	m		S				m		m	
				m	S					m	m		S				m	m			
m	m												m								
										D											
						m		m					m					m	m		
	m		m			*D*		S	m					m	S	S		S			
	m							m	S						S	S		S			
	m																				
													m					m			
								m									m		m	m	
								m	m												
					m							m					m		*D*		
					m							m			m		m	m	S	m	
					D			m							m	m	m	m		m	
		S					m														
					S																
							D														
														m					m	S	S
					m		m												m		m
									m	m	m		m				m		m	S	*D*
		S	m	m				m			m	m		S			m				

(a) *Humic Brown Clay Soils*

This is the dominant soil group in the area. These soils have developed on many kinds of parent rock including volcanic ash, lava, clastic sedimentary rocks, limestone, and alluvium. However, they are rarely encountered on the finest-textured sediments such as shales, marls, and mudstones. They occur on most well-drained sites, mainly between 4000 and 9000 ft. Mostly the soils in this group are covered by man-made grassland, but the vegetation ranges from lower montane rain forest to lower montane grassland.

The humic brown clay soils have strongly developed black to very dark grey-brown A_1 horizons, which abruptly or clearly overlie dark brown, yellow-brown, or strong brown subsoils. There is a slight increase in clay with depth. The A_1 horizons are friable and have a well-developed fine blocky to crumb structure. The subsoils are very weakly structured and generally friable to firm, although they commonly become sticky and plastic with depth. The soils are well drained and permeable.

The humic brown clay soils can be divided into two subgroups: those developed on volcanic ash (Wapenamanda, Tabunaka, and Kandep families) and those formed on sedimentary rock and lava (Vakari and Nenja families). The Ivivar family is transitional, having developed in thin ash layers overlying sedimentary rock. The following morphological differences between the two groups are generally characteristic. The soils on ash have the deepest profiles and the best developed A_1 horizons. Their subsoils are speckled by dark minerals, less clayey and more friable than those of the soils on sediments, which are frequently somewhat mottled. Upon drying, the soils on ash retain their colour or become slightly darker, whilst those on sediments become markedly lighter. The former are relatively soft when dry, the latter form hard, compact, blocky fragments. The soils on ash have thick paler C horizons of progressively sandier weathered ash, those on clastic sediments merge more rapidly into weathered broken-up rock, and those on limestone rest abruptly on the almost fresh parent rock. In practice these features overlap to a certain extent and distinction in the field can be difficult in places.

(i) *Wapenamanda Family*.—The A_1 horizon is generally more than 15 in. thick. The B horizon is yellow-brown to strong brown and contains dark minerals that give it a gritty texture. It merges very gradually into a paler sandier C horizon. In very wet areas above 7000 ft, a reddish band 1–2 in. thick is sometimes found between the A_1 and B horizons. This is often discontinuous, hardens on exposure, and appears to be a podzolic feature.

(ii) *Tabunaka Family*.—The A_1 horizon is generally less than 15 in. thick and overlies a distinct B horizon, 6–16 in. thick, of dark (yellow) brown colour, weakly fine blocky clay without speckling of dark minerals. This merges into horizons similar to the subsoils of the Wapenamanda family.

(iii) *Kandep Family*.—This resembles the Tabunaka family, but has a distinct dark red-brown clay horizon below the surface soil, approximately 6–12 in. thick, which appears to be a humus-rich B horizon.

(iv) *Ivivar Family*.—These soils have developed in two parent materials within 4 ft depth. The upper horizons are similar to those of the Wapenamanda family, but with a less-developed A_1 horizon. The deeper subsoil consists of brown, yellow-brown, or red-brown, commonly mottled plastic clay, in some cases containing weathered rock fragments.

(v) *Vakari Family*.—The A_1 horizon is generally 10–15 in. thick, the B horizon is yellow-brown to strong brown. Morphological differences from the Wapenamanda family have been discussed above. A shallow phase is recognized, in which the depth to weathered rock is less than 20 in. and in which weathered rock fragments commonly occur throughout the profile.

(vi) *Nenja Family*.—The A_1 horizon is generally rather thin and less dark than that of the other families. It overlies a dark brown clay to heavy clay B horizon, commonly 30 in. or more thick, which may become yellow-brown or strong brown with depth. Other morphological differences from the Tabunaka family have been discussed above.

(*b*) *Reddish Clay Soils*

These soils have a limited distribution and are most common at lower altitudes. They are rarely found above 5000 ft. At these higher elevations they are confined to local occurrences on crests and slope convexities, but at lower altitudes they occur also on steeper slopes. They have formed on sedimentary rocks and lava and occur under grassland and rain forest.

These clay soils have reddish colours, high clay contents, and firm to very firm consistence throughout the profile or only in the subsoil. They have poorly to moderately developed A_1 horizons.

(i) *Herep Family*.—Generally occurring above 4000 ft, these soils have an approximately 9-in.-thick, dark brown to black friable silty clay A_1 horizon, which overlies yellow-brown to strong brown friable clay horizons, approximately 18 in. thick and merging into red to yellow-red, firm, compact clay to heavy clay above a depth of 4 ft. A reddish C_2 horizon occurs at 36 in. or deeper.

(ii) *Kutubu Family*.—This family occurs below 4000 ft and has a rather poorly developed dark red-brown clay A_1 horizon with a clear boundary to a red firm silty heavy clay subsoil, which normally extends beyond a depth of 4 ft.

(*c*) *Shallow Dark Clay Soils*

(i) *Kaijende Family*.—These soils occur over a wide altitudinal range and are associated with very steep limestone slopes with much rock outcrop, steep colluvial slopes, and gentle but very stony outwash slopes below limestone escarpments. Although predominantly formed on pure limestone, they also occur on highly calcareous mudstones. The vegetation ranges from beech forest and scrub regrowth to grassland.

The soils range in depth from 6 in. to 26 in. They consist of black to very dark brown, and with depth commonly very dark grey, friable clay with a fine to medium blocky structure. In the deeper profiles this A_1 horizon overlies a brown to dark grey, plastic, structureless clay to heavy clay horizon. The soils rest abruptly on limestone or limestone boulders, and normally have limestone and chert fragments throughout the profile.

(*d*) *Deep Dark Clay Soils*

This group of soils is widespread, but nowhere dominant. They occur on lower gentle colluvial slopes, flat surfaces, and depressions as well as on doline floors and slump alcoves. The colluvial parent materials are derived from ash and sedimentary rocks including limestone.

These clay soils have black to very dark grey (brown) A_1 horizons at least 30 in. thick which overlie a variety of subsoils, depending on drainage status and parent material. The A_1 horizons are friable and have a moderately developed subangular blocky to granular structure; the subsoils are structureless and rather sticky and plastic. The limited analytical data indicate a very high organic carbon content (up to 20%) in the A_1 horizon.

(i) *Tupisanda Family*.—These well-drained soils carry a vegetation of grassland or rain forest. The A_1 horizon is generally black to very dark brown and has a rather well-developed structure. It has an abrupt boundary to a deeper subsoil of (pale) yellow-brown to strong brown clay to heavy clay, which contains specks of dark minerals when derived from volcanic ash. The field pH ranges from medium to slightly acid in the A_1 horizon and from slightly acid to neutral in the subsoil.

(ii) *Muriraga Family*.—These poorly drained soils carry a vegetation of bog forest, *Miscanthus*–sedge grassland, or *Leersia* grass. The A_1 horizon is generally black to very dark grey, has a poorly developed structure, and merges into a (dark) grey-brown to dark greenish grey deep subsoil of plastic and sticky clay to silty heavy clay which may contain peaty material or some weathered rock fragments. Water-tables were generally observed in the deeper subsoil, but are occasionally found close to the surface. The pH is 5·0 to 5·3.

(*e*) *Humic Olive Ash Soils*

This relatively common group of soils occurs on poorly drained ash plains and slump alcoves, as well as on steeper ash slopes in a very wet environment above 5000 ft, generally between 6500 and 9000 ft. Below 7500 ft the vegetation is mainly *Miscanthus* grassland and *Miscanthus*–sedge bog. At high altitudes the soils are generally covered with lower montane rain forest.

These deep soils are considered to be poorly drained counterparts of the humic brown clay soils on ash. They are characterized by well-developed (12–25-in. thick) black to very dark grey (brown) A_1 horizons, and by wet sticky, but not very plastic, structureless olive to olive brown subsoils or deeper subsoils. The subsoils are faintly to distinctly mottled and speckled by dark minerals that give them a slightly gritty texture. The soils appear to be slowly permeable.

(i) *Meriunda Family*.—The A_1 horizon has a well-developed subangular blocky structure and an abrupt boundary to a faintly mottled (dark) yellow-brown to strong brown structureless clay B horizon, which is normally 10 in. to 20 in. thick and merges into a mottled olive brown clay subsoil. The soils are imperfectly drained.

(ii) *Klareg Family*.—The A_1 horizon is somewhat thicker than that of the Meriunda family, but has only a moderate to weak structure. It rests abruptly on the olive to olive brown subsoil. The soils are poorly drained.

(*f*) *Gleyed Plastic Heavy Clay Soils*

Soils of this group are widespread in the area, at all altitudes, on terraces and fans, colluvial depressions, and slump alcoves, as well as on irregularly slumped moderate slopes. They have formed mainly on fine-textured sedimentary rocks such as shales, marls, and mudstones, and on alluvial and colluvial deposits derived from these rocks. They are covered by various types of rain forest, but also have tall grassland and semi-swamp vegetation.

The soils are characterized by very slowly permeable, plastic to very plastic, mottled or predominantly greyish, structureless heavy clay subsoils. They have variable, though generally not strongly developed, slightly coarser-textured and more friable A_1 horizons, with a weakly to moderately developed medium to coarse subangular blocky structure.

(i) *Lombo Family*.—These are deep soils developed on commonly calcareous sedimentary rocks. They have a poorly developed dark brown A_1 horizon, which merges gradually into a (pale) brown strongly greyish and reddish mottled subsoil.

(ii) *Tumundan Family*.—These deep soils, developed on sedimentary rocks, have a black to dark brown A_1 horizon 4–8 in. thick which abruptly overlies a distinctly to prominently mottled subsoil with a light to dark yellow-brown matrix colour in the upper 8 to 40 in. and light grey to blue grey in the deeper subsoil. The latter may contain many weathered rock fragments.

(iii) *Tibiri Family*.—These are shallow soils approximately 20 in. on siltstone, shale, and mudstone. They have thin, very dark grey-brown to dark grey A_1 horizons, resting abruptly on light grey, commonly mottled subsoils with many weathered rock fragments. This horizon merges into hard broken-up weathered rock.

(iv) *Laiagam Family*.—These deep soils, occurring on young alluvial fans, alluvial and lava terraces, and gentle colluvial slopes, have a thick black to dark brown or dark grey A_1 horizon, merging gradually into a dark grey to blue-grey, commonly brown mottled subsoil.

(v) *Pumakos Family*.—These soils, occurring on older slumps, fan features, and terraces, are similar to but more mature than the Laiagam family. They differ in having an abrupt boundary between the A_1 horizon and the subsoil, which is light grey in colour and normally more prominently yellow-brown to red-brown mottled.

(vi) *Lumbi Family*.—This family occurs only rarely, and then on elevated sites with apparently good to moderate surface drainage. The parent rock is probably sedimentary rock and lava. The deep soils are considered to be very mature. They have very dark grey to dark brown A_1 horizons up to 6 in. thick, abruptly overlying whitish subsoils with varying amounts of prominent brown mottles.

(*g*) *Peaty Soils*

These soils have developed under conditions of waterlogging that permit the accumulation of organic matter. The group can be subdivided into two major categories: bog soils of depressions, seepage areas, and extensive swamps throughout the area, and alpine peat soils of mountain summit areas above 9000 ft. The latter are climatically controlled and occur even on moderately steep slopes that remain saturated with water owing to the high rainfall : evapotranspiration ratio. The bog soils support hydrophytic vegetation ranging from reeds, sedges, grasses, and herbaceous plants to bog forest, whilst the alpine peat soils are covered by alpine and lower montane grassland with patches of montane forest.

The bog soils range from open-structured raw peats and soft organic muds to rather well-decomposed friable peaty clay soils of varying depth. The alpine peat soils are shallow well-decomposed peaty clay soils overlying almost fresh rock or thin mineral horizons. Some show podzolic features such as subsurface layers enriched in organic matter and thin iron pans.

(i) *Kiakau Family.*—These are more than 6 ft deep bog soils of (dark) brown poorly decomposed matted sedge, grass, and woody peat, commonly with many tree trunks at depth. They also include soft peaty muds with masses of dead and living roots. The water-table is at the surface.

(ii) *Tirriraga Family.*—These are more than 4 ft deep bog soils of dark brown to black, moderately to well-decomposed clayey peat to peaty clay. The water-table is at or near the surface.

(iii) *Mango Family.*—These black to brown peaty clay bog soils are 24 to 40 in. deep and overlie a clayey or gravelly substratum. They have variable water-tables, generally near the surface.

(iv) *Giluwe Family.*—These are shallow alpine peat soils with a (very) dark brown, mucky silty clay surface horizon (9–12 in. thick) abruptly overlying a black clayey muck horizon of similar thickness. This rests on stony glacial till and moraine of basaltic origin. On steep slopes above 12,000 ft the black horizon is absent.

(v) *Wapu Family.*—In these shallow alpine peat soils, a well-decomposed black peaty clay layer with a weak coarse subangular blocky structure overlies a brown mucky clay subsoil, resting on sedimentary rock, lava, or colluvial deposits.

(vi) *Dibibi Family.*—These alpine peat soils have a peaty surface soil, 6–18 in. thick, overlying a brown, and with depth yellow-brown, to strong brown clay subsoil. Thus this family forms a transition to the humic brown clay soils. The soils have developed on sedimentary rock, ash, and lava.

(*h*) *Alluvial Soils*

Alluvial soils are not common in the area, except in the lower-lying Lake Kutubu region to the south-west. Old alluvial soils are found on fan surfaces and river terraces, generally covered with grassland and regrowth. Recent alluvial soils occur on flood-plains, predominantly in the south-west of the area. They are mostly covered with rain forest and swamp forest.

Apart from a weak to strong development of an A_1 horizon and gleying due to high water-tables, the alluvial soils have undergone very little profile development. They commonly have stratified textural profiles, mainly in the medium- to fine-texture range.

(i) *Old Alluvial Soils.*—Many of these appear to be derived to a significant degree from volcanic ash. They have black to very dark grey A_1 horizons (up to 20 in.

thick), overlying deep, dark brown to grey-brown, slightly stratified subsoils, predominantly silty clay loam, sandy clay, and clay in texture. Gravel beds or peaty layers may occur in the deeper subsoil. In some cases there is a shallow water-table.

(ii) *Medium-textured Recent Alluvial Soils*.—These are well to imperfectly drained, olive brown to dark yellow-brown, slightly stratified soils, with textures ranging from friable sandy clay loam to firm clay. The deeper subsoils are commonly grey and brown mottled. They have poorly to moderately developed A_1 horizons. Shallow water-tables occur in some profiles.

(iii) *Fine-textured Recent Alluvial Soils*.—These are commonly mottled, very poorly drained to swampy, grey to blue-grey, very plastic and very sticky heavy clay soils. They have poorly to moderately developed, less plastic A_1 horizons. Water-tables at or near the surface are common.

III. Analytical Data

(a) General Considerations

The chemical data generally show considerable variation in values of most properties, often apparently independent of each other and of major soil groups and soil families. Thus their detailed interpretation is difficult and their usefulness for characterizing the various soils is limited. Nevertheless, there are certain trends that apply almost uniformly to all kinds of soils, thought to be a reflection of the dominant influence of the wet climate on soil formation. Nearly all soils are moderately to strongly acid, with the exception of shallow soils and some subsoils formed on limestone and marl. Base saturation is nearly always low to very low. Organic carbon contents of the A_1 horizon are almost uniformly high, whilst in many soils they remain relatively high even in the deeper subsoils, a feature that is particularly pronounced in soils derived from volcanic ash. Accompanying this are generally high nitrogen contents, although the C : N ratios vary greatly (generally between 8 and 17 and up to 25 in some peaty soils). Cation exchange capacities tend to be high to very high.

P_2O_5–HCl contents, although extremely variable, tend to be high. The average content of 0·18% is more than three times that of Australian soils and equals the highest average for great soil groups in the United States of America (Wild 1958). On the other hand, figures for available P_2O_5 are generally extremely low to low, indicating strong phosphate fixation in virtually all kinds of soil, probably by organic matter and iron–aluminium compounds. It is possible that one of the effects of the widespread practice of topsoil mounding in native agriculture, which leads to rather pronounced cycles of drying and wetting, is the liberation of phosphate as well as nitrogen (Birch 1960). Although for unknown reasons some individual samples of many soil families show high values (more than 100 p.p.m.), the only soils that contain consistently more than traces of available P_2O_5 are those of the Kaijende family (shallow dark clay soils), Lombo and Tibiri families (gleyed plastic heavy clay soils), Tirriraga, Giluwe, and Wapu families (peaty soils), and the alluvial soils. Here the values generally vary between 10 p.p.m. and 40 p.p.m.

TABLE 9

NORMAL VALUE RANGES OF SELECTED CHEMICAL AND GRANULOMETRIC PROPERTIES* OF SOIL FAMILIES

Major Soil Group and Soil Family		No. of Observations	Organic Carbon (%)	Cation Exchange Capacity (m-equiv. %)	Base Saturation (%)	pH 1 : 5	P_2O_5 – HCl (%)	Clay (%)
Humic brown clay soils								
Wapenamanda	T†	10	5–15	60–80	3–15	5·3–5·9	0·10–0·17	8–30
	S	16		35–70	3–20	5·5–6·2	0·05–0·13	1–18
Tabunaka	T	6	7–13	50–60	2–12	5·0–5·5	0·12–0·20	1–24
	S	7		35–50	1–6	5·3–5·6	0·04–0·24	1–29
Kandep	T	1	6	100	3	6·1	0·08	19
	S	2		50–90	3–5	6·5	0·12–0·19	5–35
Ivivar	T	1	14	70	5	5·5	0·03	11
	AS	1	3	50	2	5·3	0·06	8
	SS	1	0·4	23	22	4·9	0·12	58
Vakari	T	12	4–8	25–55	8–30	4·9–5·2	0·05–0·13	2–23
			13–18‡	90‡	3–4‡			
	S	23		15–50	10–40	4·8–5·4	0·06–0·19	10–50
					3–8‡			
Vakari on limestone	T	1	4	15	37	6·6	0·31	35
	S	1		6	95	7·6	0·58	63
Nenja	T	2	5–10	60	3	5·2–5·5	0·24–0·29	1–8
	S	2		15–20	4–20	5·2–5·7	0·26	1–6
Nenja on limestone	T	1	3	30	25	5·5	0·08	21
	S	3		15–20	30–90	6·2–6·6	0·10–0·12	55–80
Reddish clay soils								
Herep	T	4	2·5–7	20–40	5–15	4·9–5·7	0·04–0·07	8–30
	S	9		6–30	5–15	5·0–5·5	0·03–0·05	11–50
Shallow dark soils on limestone								
Kaijende	T	4	7–10	70–90	10–60	6·4–7·3	0·31–1·06	8–40
	S	1		15	100	8·5	0·37	6

Humic olive ash soils								
Meriunda	T	5	5–9	40–70	3–15	5·0–5·7	0·03–0·15	1–20
	S	5		30–60	1–7	5·2–6·3	0·08–0·18	2–8
Klareg	T	4	8–13	60–75	5–10	4·9–6·2	0·06–0·21	1–5
	S	3		10–45	1–6	5·2–5·9	0·02–0·17	1
Gleyed plastic heavy clay soils								
Lombo	T	3	3–9	35–50	3–20	4·9–5·3	0·09–0·39	12–40
	S	5		25–40	4–20	5·2–5·3	0·05–0·24	40–55
Lumbi	T	1	18	60	2	4·9	0·32	1
	S	2		30	15	5·3–5·6	0·32	2–5
Tibiri	T	3	5–9	40–65	35–40	5·6–6	0·22–0·23	20–35
	S	2		20–30	20–60	5·6–6·2	0·06–0·09	27–46
Peaty soils								
Kiakau		3	32–41	75–80	2–20	4·9–5·1	0·20–0·23	1–2
Tirriraga		5	15–40	50–95	1–20	4·5–5·4	0·26–0·44	1–24
Giluwe		8	T 8–14	20–40	4–20	5·0–5·3	T 0·14–0·17	1–4
			S 20–25				S 0·17–0·43	
			DS 6–10					
Wapu	T	2	21–22	90–120	2–4	4·8–5·1	0·16–0·19	13–15
	S	1	1–2	35	6	5·8	0·04	37
Alluvial soils								
Old alluvial clay soils	T	5	4–14	40–45	2–5	4·8–5·3	0·23	1–14
	S					5·6		
Medium-textured recent alluvial soils	T	1	4	45	40	5·7	n.d.	23
	S	1		35	35	5·6	n.d.	42

* Analyses carried out at the Royal Tropical Institute, Amsterdam.

† T, topsoil; S, subsoil; AS, ash subsoil; SS, sediment subsoil; DS, *deeper subsoil.*

‡ In profiles at high altitude.

The amounts of, and ratios between, exchangeable cations vary greatly and do not show any clear relationship with kind of soil. In most soils calcium is weakly to strongly dominant, but in several samples with very low base saturation, sodium or potassium is dominant. The amounts of exchangeable potash in topsoils are such that initial potash deficiencies are not generally expected.

A feature of most soils in the area is that they cause dispersion difficulties during granulometric analysis. The laboratory contents are generally much lower than expected from field texture and cation exchange capacity. That this is at least partly caused by air-drying of samples of soils that never become dry in their natural environment, is shown by the much higher yields of clay in many samples that were also analysed in their field moisture condition.

(b) Chemical and Granulometric Data of Major Soil Groups and Families

The following comments are based on data presented in Table 9. The group of deep dark clay soils will not be discussed, as sufficient data are not available. In other major soil groups data are not available for some of the component families.

(i) *Humic Brown Clay Soils*.—The variability in chemical properties mentioned above is well illustrated in this large group of morphologically similar soils. The data cover virtually the full range of values encountered in the area. There is rather a clear distinction between the soils on ash (Wapenamanda, Tabunaka, Kandep, and upper horizons of Ivivar family) and those on sedimentary rocks (Vakari, Nenja, and deeper subsoil of Ivivar family). The former have higher organic carbon contents and cation exchange capacities (amongst the highest of the mineral soils), lower base saturation, but, surprisingly, higher pH (except for the Vakari and Nenja profiles on limestone). Dispersion difficulties also tend to be greater in the soils on ash than in those on sediments, except for the Nenja family. This is well illustrated in the data for the Ivivar family developed in both kinds of parent material.

The differences between the Wapenamanda and Tabunaka families are small but significant. The latter have lower cation exchange capacity, base saturation, and pH, and high P_2O_5–HCl values. This is thought to be due to the greater maturity of these soils, with better crystallinity of the clay minerals leading to lower cation exchange capacity, and more advanced leaching leading to a relative accumulation of the immobile phosphate. It is also interesting to note that the Tabunaka family has properties very similar to those of the Nenja family, its mature counterpart of the soils on sediments. This suggests that the final products of zonal soil formation will be very similar on both types of parent rock.

In the Vakari family the much higher organic carbon contents and cation exchange capacity, and the lower base saturation in profiles at 9500 ft and higher, should be noted. Apart from their lower pH, such soils have similar properties to those developed on ash.

Morphologically indistinguishable profiles on limestone have been included in the Vakari and Nenja families, but their chemical properties stand out and clearly reflect the influence of this parent rock. This is more evident in the immature Vakari family than in the strongly weathered profile of the Nenja family. Dispersion difficulties are much smaller on these soils on limestone.

(ii) *Reddish Clay Soils.*—These strongly weathered soils have properties closely resembling those of the humic brown clay soils on sedimentary rocks. However, their organic carbon and P_2O_5–HCl contents are markedly lower and there is a more consistent relationship between low cation exchange capacity, low base saturation, and low pH. The absolute amounts of exchangeable bases are thus lower than in any other soil group. In combination with low nitrogen contents, these soils are considered to be of particularly low fertility and resemble the normal latosolic red soils of the lowlands and mid-mountains.

(iii) *Shallow Dark Clay Soils.*—This is the only group of soils in the area that is not acid but neutral in reaction and highly saturated. These soils also have the highest P_2O_5–HCl contents. In respect of organic carbon, cation exchange capacity, and dispersion difficulties they show the normal regional features.

(iv) *Humic Olive Ash Soils.*—These soils have chemical and granulometric properties similar to those of the humic brown clay soils on ash, although they are morphologically quite different. The organic carbon figures are not as high—which is surprising for these poorly drained soils—but they apply to thick A_1 horizons. This group of soils has the lowest base saturation values and the greatest clay dispersion difficulties.

(v) *Gleyed Plastic Heavy Clay Soils.*—The three families in this group for which data are available have distinctly different properties. Lombo and Tibiri families are characterized by their high laboratory clay contents, although these still do not agree with the field texture of heavy clay. On the other hand, the profile of Lumbi family shows very great dispersion difficulties. Whilst Lombo and Lumbi families are strongly acid and have low base saturation, the shallow soils on generally calcareous mudstone of the Tibiri family are only mildly acid and have much higher saturation. All families in this group are characterized by rather high P_2O_5–HCl contents and the most uniform and fairly high cation exchange capacity in the area.

(vi) *Peaty Soils.*—Apart from having the highest organic carbon contents, the peaty soils are the most acid in the area. They generally have very high cation exchange capacity and very low to low base saturation. These soils appear therefore to be of much lower fertility than many similar peat soils in the lowlands. This is probably due to the fact that most peat swamps in the area and all alpine peat soils are fed by rain water, or seepage water derived from highly leached regolith and soil.

In the Giluwe family the dark red-brown surface soil has a much lower organic carbon content than the black deeper layer. It is possible that this peculiar distribution of organic carbon is due to a podzolization process. Alpine podzolic soils have been reported from many parts of western New Guinea, where the parent rocks are more acidic (Reijnders 1960).

(vii) *Alluvial Soils.*—Both profiles of the old alluvial soils are at least partly derived from volcanic ash and agglomerate: their properties are similar to those of the humic brown soils on ash.

The profile of the medium-textured recent alluvial soils was sampled on a lower-lying flood-plain in the south-west and lacks the properties typical of the high mountain soils. Although the most fertile in the area, these are still chemically poor, like many other recent alluvial soils in high-rainfall areas of the tropics (Edelman and van de Voorde 1963).

(c) *Clay Minerals*

X-ray and differential thermal analysis data from various sources* have in some cases yielded somewhat conflicting information. This appears to be due mainly to the generally diffuse patterns obtained, probably as a result of poor crystallinity of the clay minerals, the presence of mineral complexes, and intimate bonds with finely dispersed organic matter. However, the general pattern that emerges shows that parent rock and degree of weathering are the major factors determining the clay mineral composition of the soils. Both clay and fine-silt fractions were investigated in the samples analysed in Norway. It was found that the silt fractions have essentially the same composition as the clay fractions, apart from an expected higher proportion of primary minerals. This is yet another indication that a large proportion of the silt consists of undispersed clay particles, due to the dispersion difficulties in the granulometric analysis.

Soils derived from volcanic ash (humic brown clay soils and humic olive ash soils) are generally characterized by gibbsite, its content decreasing with depth in the profile, and by allophane, which increases with depth. Allophane appears to be more common in the well-drained than in the poorly drained soils. In more mature profiles, mainly of the Tabunaka family, kaolin appears in the upper part of the profile. Other minerals commonly present are a montmorillonitic mineral (mainly in the surface horizons), quartz (mainly in the humic olive ash soils), chlorite, and vermiculite.

The principal clay minerals in soils derived from clastic sedimentary rocks are kaolin (decreasing with depth) and illite (increasing with depth), with variable amounts of quartz and a montmorillonitic mineral (mainly in surface horizons). The reddish clay soils have a similar composition, but kaolin is generally more abundant. In some cases gibbsite partly or completely replaces kaolin, particularly in humic brown clay soils at high altitude, formed in a very wet, cool environment. Similarly, the subsoil clay of an alpine peat soil of the Wapu family is strongly dominated by gibbsite and a montmorillonitic mineral. This latter mineral, probably nontronite, is dominant in a shallow, neutral humic brown clay soil on limestone, but appears to be replaced by kaolin and gibbsite in similar, but deeper and more acid soils.

The only soils dominated by montmorillonite belong to the Lombo family (gleyed plastic heavy clay soils). This is less unexpected than the absence of this mineral and the presence of much kaolin, together with illite, in the Tibiri family, another, but more shallow and less acid, member of the group of gleyed plastic heavy clay soils. The Lumbi family, belonging to the same group, is strongly dominated by kaolin, which would agree with the apparent high degree of maturity of these acid bleached soils. The presence of illite in the deeper subsoil suggests that the profile has developed on sedimentary rock, although it was collected in a volcanic ash landscape. This is the

* X-ray: Norwegian Forestry Research Institute, Vollebekk, and Australian Mineral Development Laboratories, Adelaide. DTA: Royal Tropical Institute, Amsterdam.

more plausible, as semi-buried sedimentary hills rise above the ash slopes in many places nearby. This white kaolinitic clay showed very promising ceramic properties in a preliminary firing test carried out by the Australian Mineral Development Laboratories.

Alluvial soils have a variable clay mineral composition, dominated by gibbsite, kaolin, or kaolin and a montmorillonitic mineral, whilst quartz is generally present in significant amounts.

IV. References

BIRCH, H. F. (1960).—Soil drying and soil fertility. *Trop. Agric., Trin.* **37**: 3–10.

EDELMAN, C. H., and VAN DE VOORDE, P. K. J. (1963).—Important characteristics of alluvial soils in the tropics. *Soil Sci.* **95**: 258–63.

REIJNDERS, J. J. (1960).—Voorlopige mededeling van het agrogeologisch onderzoek in het Sterrengebergte. *Tijdschr. Aardrijksk. Genoot. Tweede Reeks* **77**: 162–5.

UNITED STATES DEPARTMENT OF AGRICULTURE (1951).—Soil survey manual. U.S.D.A. Handb. No. 18.

WILD, A. (1958).—Phosphate content of Australian soils. *Aust. J. Agric. Res.* **9**: 193–204.

PART VII. VEGETATION OF THE WABAG–TARI AREA

By R. G. Robbins* and R. Pullen†

I. Introduction

The vegetation types of the Wabag–Tari area follow closely those recognized in the Goroka–Mt. Hagen area,‡ all being part of the central highlands of New Guinea.

The first-named author was plant ecologist with the team which surveyed the Wabag area in 1960, the second participated in the Mendi–Tari survey of 1961. This Part is the result of close collaboration between the two.

Classification of plant communities is on a regional basis. Such an approach best expresses the broad correlation between the vegetation and the land systems.

Identifications are based on material in the Herbarium Australiense, CSIRO, Canberra.

II. General Description of Vegetation

The predominating climax vegetation of the Wabag–Tari area is a dense rain forest which has developed under conditions of high and largely non-seasonal rainfall. Altitudes ranging from 2600 ft to 13,600 ft have modified the climate and a broad altitudinal zonation of the vegetation can be recognized as follows:

below 4000 ft: lowland rain forest with three tree layers;

3000–10,000 ft: lower montane rain forest with two tree layers;

10,000–12,500 ft: montane rain forest with one tree layer;

above 12,500 ft: alpine grasslands.

(*a*) *Environment*

Frosts are experienced as low as 5000 ft and affect garden crops as well as regrowth. At 8000 ft and above, the occurrence of natural lower montane grasslands appears to be associated with accumulation of cold air masses in montane valleys and basins. Above forest limits at 12,500 ft the landscape is covered with alpine tussock grassland and bog.

The influence of topography is twofold. Slope is important for control of soil drainage, whilst the arrangement of valleys and intervening ranges often controls local climatic conditions.

There does not appear to be any type of vegetation associated with a particular base rock. Limestones, basalts, siltstones, and sandstones have no mineral influence. A few species favour limestone areas but, since they are of minor importance in the community, do not alter the community aspect.

* Formerly Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T. Present address: Australian National University, Canberra, A.C.T.

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

‡ CSIRO Aust. Div. Land Res. Reg. Surv. Divl. Rep. No. 58/1 (1958).

Throughout the area rainfall is above the optimum requirements of the vegetation. The physical structure of the soil and its aeration assume some importance. Variations here affect mainly the early successional and disclimax communities, since by the time a forest climax is reached, the subsoil is providing mainly anchorage and the nutrients are supplied mostly from a developed and saturated humic layer.

(b) *Forests*

Three zonal forest formations occur. Many tree species vary in degree of environmental tolerance, causing some floristic overlap of communities in adjacent altitudinal climatic zones.

Canopy trees are tallest in the lowland rain forest (Lake Kutubu and Mubi valley), where they average 100 ft with occasional emergents up to 160 ft. The canopy of the lower montane rain forest is generally at 80 ft with very few emergent trees. An exception is the beech forest aspect, which can attain 100 ft. In the montane rain forest, structure is modified and there is a single canopy layer of trees at 30 to 40 ft.

The popular term "mossy forest" has been avoided in this report as almost any rain forest type has a very mossy aspect under certain local conditions, and the term tends to confuse critical and ecological classification.

Conifers form an important scattered element throughout the forests, particularly in the montane aspects where they form small local stands. The presence of various species of *Pandanus*, bamboo, palms, and rattans, as well as wild bananas, causes local physiognomic differences throughout.

Most of the survey area that is, or has been, under occupation by native peoples belongs to the lower montane zone where oak forest has dominated. Beech forests also cover much of this same lower montane zone but have not been greatly occupied because of their comparative inaccessibility and less amenable climate.

(c) *Regrowth Vegetation*

The agricultural activities of the inhabitants have resulted in deforestation of large areas, particularly in the lower montane zone. Forests have been cleared by felling and ring-barking, and gardening has been initiated. When the gardening phase (which varies considerably in length) is finished, the plot is abandoned to a weed community of herbs and grasses until the tall sword grass, *Miscanthus floridulus*, a type of "pit-pit", asserts itself.

Subsequent burning of this sword grass phase either for gardening or other purposes seriously reduces the potential for regeneration of forest through a regrowth tree and shrub succession. Where such interference is repeated the sword grass is eventually replaced by short grass communities (*Capillepedium*, *Themeda*, *Ischaemum*, *Imperata*), and over large areas these become stabilized and maintained. Much of the Western and Southern Highlands, however, still retains the dynamic successional phases of sword grass and shrub regrowth.

A feature of the highland landscape is the groves of *Casuarina* woodland. These may be domestic plantations or pioneer stands on river terraces and old land-slips.

(*d*) *Grassland, Swamp, and Bog Communities*

The only natural climax grassland communities are those described under lower montane and alpine conditions. Tall sword grass is considered a regrowth (i.e. successional) community that follows the initial clearing of the forest. It is at this stage that the short grasslands can be induced and maintained with repeated interference. Hence the various short grassland communities recognized in the highlands are considered to be disclimax vegetation, the area of which is currently increasing. They are composed mainly of grass species which have migrated from the lowlands.

Swamps, here defined as areas with free water above the surface, and bogs, which have a waterlogged substrate but little free water above the surface, are widespread in the area. Natural swamp communities include *Phragmites* and *Leersia* swamps and, in the lowlands, various swamp woodlands in which *Campnosperma*, *Pandanus*, sago palms, and *Casuarina* predominate. The bog communities include grass–sedge bog, sedge bog, alpine peat bog, and lower montane bog rain forest.

Aspects of alpine tussock grassland are found at 9000 ft and above.

III. Description of the Plant Communities

The plant communities and some of their features and environmental relations are set out in Table 10.

(*a*) *Lowland Rain Forest*

In the Southern Highlands the influence of a lowland humid climate is noticeable at altitudes below 4000 ft. In the region of Mubi valley and Lake Kutubu, large tracts of lowland rain forest are found. On undulating terrain the lowland forest is continuous, but on hilly country and particularly on limestone the pattern is more complex with beech forest, a lower montane formation, occupying the crests.

In the Western Highlands a limited intrusion of lowland rain forest occurs in the lower Sau River valley north of Kompiam patrol post. This is a river gorge site at 3300 ft, from which such lowland tree species as *Alstonia scholaris*, *Artocarpus incisa*, *Pometia pinnata*, *Vitex cofassus*, *Pangium edule*, and *Pimeleodendron amboinicum* were recorded.

Structurally, lowland rain forest has three tree strata, the uppermost being represented by a closed canopy at 100–120 ft with scattered emergents reaching to 160 ft. The bases of many of the trees are braced by plant buttresses.

The second stratum is a subcanopy layer at 60–70 ft, and the lowest tree layer is between 25 and 35 ft, both these lower strata being less dense than the canopy.

The ground layer is usually sparse. Rattans and lianes are frequent but not obstructive to movement except adjacent to watercourses. Palms and thin climbers are general. By contrast with the lower montane formations, movement is far less hindered by small-diameter trees and shrubs. Visibility across the forest floor is from 80 to 100 ft. Any opening of the canopy initiates a dense and competitive regeneration.

TABLE 10

PLANT COMMUNITIES AND SOME OF THEIR FEATURES AND ENVIRONMENTAL RELATIONSHIPS

Plant Community	Altitude (ft)	Remarks
Lowland rain forest	<4000	Three-layered
Alluvium forest	<4000	On flood-plains and lower terraces frequently flooded, 60–100 ft high
Lowland hill forest	<4000	On hilly or undulating country, not flooded, 100–120 ft high
Lower montane rain forest	3000–10,000	Two-layered
Oak forest	3000–7500	Undulating uniform canopy 60–80 ft high
Beech forest	Mainly 7000–9000	Dense uniform canopy 100–120 ft high
Mixed forest	3000–10,000	Canopy up to 100 ft high
Coniferous forest	Mainly 8500–10,000	Typically in narrow peripheral belts surrounding high mountain valleys with grassland. Canopy up to 120 ft
Bog forest	>7000	Wet sites. Canopy mostly 40–60 ft high
Montane rain forest	>10,000	Compact uniform canopy 30–40 ft high. Mosses and liverworts common
Campnosperma–sago palm forest	*c.* 2600	Canopy not closed, about 80 ft high
Swamp woodland	<3000	Mubi valley and Lake Kutubu regions
Campnosperma coriacea swamp woodland	<3000	Swampy sites. Open canopy up to 80 ft high
Casuarina swamp woodland	<3000	Better-drained alluvial areas, irregularly flooded. Canopy 60–80 ft high
Pandanus swamp		
Lowland *Pandanus* swamp	<3000	River alluvium. Trees 60 ft high
Highland *Pandanus* swamp	4000–7000	Wet sites. Trees up to 90 ft high
Casuarina woodland	4000–9000	River terraces and old hillslope slips. Trees up to 60 ft high
Secondary regrowth		
Gardens and garden regrowth	4000–8500	Gardens and regrowth to second or third year
Sword grass and shrub regrowth	5000–8000	Regrowth after second or third year. Dense cover about 10 ft high
Induced grasslands	5000–8000	Result of long-term biotic interference. Inhabited highland valleys
Capillipedium grassland	5000–8000	Lower valley slopes and floors. Even cover about 3 ft high
Themeda grassland	5000–8000	Drier sites. Cover 4–5 ft high
Ischaemum grassland	5000–8000	Wet to moist sites. Dense cover 3–4 ft high
Imperata grassland	5000–8000	
Phragmites swamp	5000–8000	Swampy conditions. Dense cover 10–20 ft high
Leersia swamp	5000–8000	Commonly in relatively deep water. 1–3 ft high
Grass–sedge bog	5000–8000	Water-table at or just above surface
Sedge bog	7000–11,000	About 2 ft high
Lower montane grassland	8000–9000	Valleys subject to cold-air drainage
Alpine grassland	>9000	Tussock grasses 2–3 ft high
Alpine peat bog	>10,000	Wet sites

(i) *Alluvium Forest.*—In this category are placed all the inundated aspects of lowland rain forest on alluvium. This forest occurs on the flood-plains and lower terraces of rivers in the southern part of the area. Here rainfall causes frequent flooding for short periods and to variable depth. Wide flood channels 2 ft to 8 ft in depth traverse the forest. The canopy of alluvium forest is extremely irregular and undulating in profile. Canopy height varies from 60 ft to 100 ft due to varying stature of the forest trees. Represented genera are *Artocarpus*, *Alstonia* (*A. scholaris*), *Pometia* (*P. pinnata*), *Sloanea*, *Aglaia*, *Dracontomelum*, *Terminalia*, *Buchanania*, *Chisocheton*, and *Pangium*.

The lowest layer contains trees of the family Annonaceae with *Horsfieldia*, *Leea*, *Poikilospermum*, and others.

The forest floor has a patchy cover of *Elatostema*, *Pilea*, *Selaginella*, etc. Climbing ferns such as *Stenochlaena* are common on the boles of trees, while rattans and d'Albertis creeper (*Mucuna*) ascend to the crowns. Along the flood channels small groves of sago palm occur.

(ii) *Lowland Hill Forest.*—This is typical of the general New Guinea lowland rain forest. It occupies hilly and undulating country free from flooding. The canopy is closed, fairly even, and 100 ft to 120 ft high. The floristic content is rich and varied, the dominance of any one species being difficult to ascertain. Meliaceae, Sapindaceae, Anacardiaceae, Apocynaceae, and Sterculiaceae are among the commonest families represented. In the Mubi valley–Lake Kutubu region, *Elmerillia* is very common. There is also some floristic overlap with the lower montane rain forest; trees such as *Castanopsis* and *Lithocarpus* are often encountered. Forests containing *Dillenia* as a canopy tree occur near the upper altitudinal limits of the community.

The ground layer is rather open. Fern growth is less prolific than in lower montane rain forests, but Urticaceae and Zingiberaceae 1–6 ft high are scattered throughout. Below the lower montane zone and restricted largely to karst topography of low relief, lowland hill forest occurs as a complex with beech forest. Here hill forest occupies the side slopes and gullies, and lower montane beech rain forest the pinnacle summits and doline rims.

(*b*) *Lower Montane Rain Forest*

This forest is distributed widely throughout New Guinea at altitudes ranging from 3000 ft to 10,000 ft and is the dominant forest cover of the Wabag–Tari area. Much has been cleared for gardens.

At its lower limits it merges, with some overlapping of species, into the lowland formation. At its upper limits there is usually a sharp demarcation from montane rain forest.

Essentially comprising two tree layers, lower montane rain forest varies considerably in the height and composition of these layers. For the most part a mixed aspect has a dense canopy at 80–100 ft and a subcanopy layer at 40–60 ft. In a few areas, individual trees of hoop pine (*Araucaria cunninghamii*) may rise emergent above the forest but are nowhere prevalent.

Pure stands of oak often constitute the lower levels of the lower montane forest zone while large tracts of tall beech (*Nothofagus*) forest occupy the upper levels. A dense ground cover of ferns, shrubs, and bamboo makes visibility through this forest more limited than in the lowland types.

Five aspects of lower montane rain forest have been recognized in the survey area.

(i) *Oak Forest* (Castanopsis–Lithocarpus).—This forest occupies the lowest levels of the lower montane forest zone, at 3000–7500 ft with optimum development at about 5000 ft. The oak forest zone is one most favourable to native agriculture; large tracts have already been cleared and converted either to short grassland or sword grass regrowth.

Small remnants remain in the populated area and secondary patches of oak forest have developed. In the north-west part of the Sau valley at 4000 ft above sea level a comparatively large tract of oak forest is currently being cleared.

The dominant species of oak is *Castanopsis acuminatissima* with typical rounded crowns of green foliage among which the brownish leaves of the more scattered *Lithocarpus molucca* are present in some places. The canopy is undulating but uniform at 60–80 ft, and apart from the oaks includes species of the Lauraceae, Cunoniaceae, Rutaceae, Elaeocarpaceae, and Myrtaceae. In the Kagua, Nipa, and Tari areas of the Southern Highlands emergent palms protruding above the canopy are a feature.

The second storey, at about 30 ft, is less dense and includes *Myristica*, *Ficus*, *Gordonia*, *Timonius*, and *Saurauia*. *Pandanus* and climbing bamboo are locally present. More frequently oak forest is remarkably open and the floor bare except for a few ground ferns. The drier atmosphere does not encourage moss growth as in the beech forests of higher altitudes.

(ii) *Beech Forest* (Nothofagus *Spp.*).—Pure stands of beech forest occur between 7000 and 9000 ft above sea level throughout the area. The dominant trees in this aspect of lower montane rain forest are species of *Nothofagus* or southern beech.

The trees are gregarious, forming small groves within the mixed forest particularly along ridges, or continuous tracts. Beech forest has a dense uniform canopy at 100–120 ft and stands out well on aerial photos of the area. A rather sparse second tree layer reaches 60 ft and includes *Weinmannia*, *Garcinia*, *Euodia*, *Mischocarpus*, *Elaeocarpus*, and conifers. Also, tall stilt-rooted *Pandanus* spp. and a rampant *Bambusa* are often characteristic features of this forest.

A field layer of small shrubs includes many common Rubiaceae, *Drimys*, *Daphniphyllum*, *Olearia*, *Paratrophis*, *Symplocos*, *Piper*, and tree ferns.

A dense ground layer of herbs—*Elatostema*, Zingiberaceae—and ferns together with small climbers, epiphytes, and a frequent development of moss cover add to the luxuriance of the forest.

Over much of the Western Highlands small groups of mature beech trees were dying. Such groups were visible on the air photos and could be counted in hundreds. Closer investigation revealed no obvious reason such as soil factors, lightning strikes, or biotic interference and it is suggested that they represent even-aged groves where groups of trees have reached over-maturity together and die, allowing vigorous beech regeneration. Below the lower montane zone and mainly on karst topography of low relief, beech forest occupies pinnacle summit and doline rims, with intervening side slopes and gullies covered by lowland hill forest.

(iii) *Mixed Forest.*—Mixed floristic composition is a widely occurring aspect of the lower montane rain forest. Further study will no doubt resolve this into more specific associations.

Generally the mixed forest contains some 40 to 50 tree species. Most are evergreen dicotyledonous trees, especially members of the Cunoniaceae, Elaeocarpaceae, and Lauraceae. However, there is a strong gymnosperm element, mainly Podocarpaceae.

At its lowest levels (about 3000 ft) this forest has an overlap of species with the lowland rain forest. On the other hand, like beech forest, this mixed lower montane forest extends 9000 to 10,000 ft above sea level. Here it either merges with minor physiognomic and floristic changes into the montane rain forest formation, or has a sharp transition according to local conditions.

The mixed forest typically has two tree layers. Common canopy trees that may reach 100 ft are *Astronia, Alphitonia, Cryptocarya, Elaeocarpus, Garcinia, Opocunonia, Planchonella, Schizomeria, Syzygium, Weinmannia,* and the gymnosperms *Podocarpus* spp., *Dacrydium, Papuacedrus,* and *Phyllocladus.*

The second stratum, between 30 and 50 ft tall, includes *Ackama, Daphniphyllum, Cinnamomum, Decaspermum, Gordonia, Euodia, Evodiella, Fagraea, Perottettia, Sloanea,* and *Timonius.*

A dense woody undergrowth of tall shrubs is characteristic. Among the many species are representatives of *Ardisia, Chloranthus officianale, Carpodetus major, Cyrtandra, Drimys, Geniostoma, Litsea, Ilex, Medinella, Clearia, Pittosporum, Piper, Pygeum, Psychotria, Polyosma, Paratrophis, Rapanea, Sympolocos, Sphenostemon, Schefflera, Sericolea,* and *Turpinia.*

Many small herbaceous epiphytes and climbers occur and ground ferns, herbs, and mosses abound.

(iv) *Coniferous Forest.*—A feature of the survey area is the occurrence of pure gymnosperm pine forest in small patches. The wet aspects of these are described under bog forest. Elsewhere it is apparent that other environmental factors have segregated the gymnosperm element from the mixed forest, although *Dacrydium novoguineense, Papuacedrus,* and *Phyllocladus hypophyllus* occur in varying combinations.

More typically, these stands form narrow peripheral belts surrounding high mountain valleys of alpine grassland. These grasslands, which are below the timber line, are controlled by cold-air drainage: it is believed that severe frosts have completely inhibited tree growth on the valley floor and precluded all but the hardy conifers from the lower slopes.

The stands occur on the well-drained lower slopes surrounding the grassy valleys and are several chains wide. This conifer belt has an abrupt transition into mixed lower montane rain forest at higher levels of the valley sides. There is a high stocking of trees per acre with the close, tall, spar-like trunks reaching 120 ft, where the small terminal crowns form a dense canopy.

Underlayers are sparse and include tree ferns, *Pandanus*, and bamboo together with shrubs.

In other conifer stands canopy height is 80–90 ft and here there is usually a mixed composition of several genera together with a few dicotyledonous associates.

(v) *Bog Forest.*—Small patches of bog forest are present throughout the area at altitudes above 7000 ft. They occur at the foot of colluvial slopes where drainage causes a flood-out, surround swampy basins whose centre is usually a sedge bog, or occupy shallow depressions in gently undulating valley floors. They are seldom more than a few square miles in extent.

Bog forest has a fairly rich floristic composition. The trees form a variable canopy at 40–60 ft, beneath which is a dense layer of smaller trees and shrubs. The floor is somewhat open with irregular hummocks separated by water pools.

Tree species include *Carpodetus major*, many Myrtaceae, e.g. *Decaspermum, Syzygium*, and *Zanthomyrtus*, together with *Glochidion*, *Homalanthus*, *Maesa*, and *Pandanus*, and locally *Nothofagus*.

Conifers are common, mainly *Dacrydium elatum* and *Podocarpus papuanus*.

Shrubs include *Geniostoma*, *Rapanea*, *Rhododendron*, *Vaccinium*, and *Sericolia*, while small herbs constitute a ground layer.

In some bog forest stands the community is dominated entirely by conifers. Many of these appear to be even-aged young stands of either *Dacrydium* or *Podocarpus* trees, 6 in. in diameter, growing closely together and reaching 50 ft to form a dense canopy. Sword grass forms a ground layer. However, bog forests of a more mature aspect containing *Dacrydium* trees 100 ft high were observed in the Mendi and Tari regions.

It is suggested that these purely coniferous bog forests have arisen through the selective action of extreme frosts which killed the broad-leaf dicotyledonous trees, allowing the pines to pioneer the site.

Evidence of frost damage to the non-coniferous species was frequently apparent in the stunted, small-crowned trees and die-back of the smaller twigs.

(*c*) *Montane Rain Forest*

At altitudes of 10,000 ft above sea level, the lower montane forest formations give way, mostly quite abruptly, to a single-tree-layered montane rain forest of changed floristic composition.

Prolonged daily cloud cover is an important controlling factor. The canopy is a compact uniform layer at 30–40 ft. *Pandanus* and climbing bamboos are noticeably absent, but tree-ferns and filmy ferns are more abundant. Mosses and liverworts mantle the sprawling roots, lower branches, and crooked trunks of the trees. Even the floor is covered with a thick, spongy, wet carpet.

Many of the lower montane tree species are absent, their place being taken by species of the Myrtaceae, Myrsinaceae, Vacciniaceae, Podocarpaceae, and Rubiaceae. Leaves are generally smaller, leathery, and dark green in colour.

At its higher level, montane rain forest may have many emergent trees of the conifer *Papuacedrus*, but where it adjoins the alpine tussock grassland taller trees are absent and the vegetation is an alpine shrubbery about 15 ft high, composed of *Quintinia*, *Olearia*, *Schefflera*, *Rhododendron*, *Drimys*, *Amaracarpus*, *Styphelia*, *Dimorphanthera*, *Coprosma*, *Vaccinium*, and *Eurya*.

(*d*) Campnosperma–*Sago Palm Forest*

Campnosperma coriacea is a large-leaved tree of the Anacardiaceae which grows to about 80 ft high. An oil called "tegaso" is extracted from the trunk by Mubi valley natives, and is traded extensively throughout the Southern Highlands to the north as a body oil for "sing-sing" decoration. The trees frequent the edges of alluvial plains, gully entrants at the alluvium margins, and river levees at about 2600 ft altitude in the Mubi valley. They do not usually form a close canopy but tend to be rather scattered with a substorey of sago palms and low *Pandanus*.

Both sago palms and this species of *Campnosperma* are planted by the natives on some favourable sites both along the Mubi valley and around the edges of Lake Kutubu.

(*e*) *Swamp Woodland*

In the Mubi valley and Lake Kutubu region of the Southern Highlands two types of swamp woodland occupy expanses of flood-plain alluvium.

(i) Campnosperma coriacea *Swamp Woodland*.—In this community *Campnosperma coriacea* dominates, always in conjunction with much low *Pandanus*. The woodland is rather open and very swampy. The *Campnosperma* trees, which may attain a height of 80 ft, are slender and sparsely crowned: this aspect combined with the grey trunks gives the impression from a distance of a forest of dead trees. The floor of the woodland is either soggy or water-covered from ankle depth to several feet, and is occupied by a disarrayed growth of tall sedges (e.g. *Rhynchospora corymbosa*), *Freycinetia*, *Nepenthes*, *Lycopodium*, *Melastoma*, *Nephrolepis*, and the slender, prickly prop roots of *Pandanus*. Knee-like roots of *Campnosperma* indicate the level of highest inundation.

(ii) Casuarina *Swamp Woodland*.—This type of swamp woodland has not been closely observed but it is dominated by large trees of *Casuarina papuana* from 60 to 80 ft high. At the eastern end of Lake Kutubu is an open area of clayey alluvium, where *Casuarina* swamp woodland occupies the better-drained portion and merges with an adjacent *Pandanus* swamp. The site seems to suffer irregular but frequent inundation by flooding.

(*f*) Pandanus *Swamp*

In some swampy areas *Pandanus* is locally dominant. An incomplete knowledge of the *Pandanus* species involved makes impossible at present an accurate correlation between the lower montane *Pandanus* swamps and those of the Mubi–Lake Kutubu region. They are separated here on a purely zonal basis.

(i) *Lowland* Pandanus *Swamp*.—On open areas of river alluvium below 3000 ft altitude a species of *Pandanus*, growing to about 60 ft and with slender, prickly, and irregularly spread prop roots, often dominates the vegetation aspect. In the presence of *Campnosperma coriacea* this becomes a swamp woodland, the two communities commonly adjacent to each other with the same associated sedges and shrubs.

(ii) *Highland* Pandanus *Swamp*.—A tall multi-branch species of *Pandanus* with bluish fronds, a round pendant fruit, and tall thick prop roots is a common element within many lower montane rain forests, where it often shares the canopy. However, on some small sites adjacent to or within the forest and where drainage conditions have inhibited growth of large trees, this *Pandanus* is dominant. It grows to 90 ft, individual trees being spaced 20–25 ft apart. Sword grass and stunted trees associated with bog forest habitats constitute a lower stratum. The upper altitudinal limit is about 7000 ft.

(g) Casuarina *Woodland*

A dry-land *Casuarina* species forms dense woodlands on river terraces and old hillslope slips. The trees grow close together up to 60 ft or more high and 8 in. in diameter. The interior of the grove is open except for a ground cover of *Setaria palmifolia*. These natural stands are the source of seedling trees which the highland natives transplant into their gardens and which later develop into the domestic plantations so characteristic of the inhabited landscape. Apart from their value as a long-term fallow they provide fuel and timber for housing and pig fences.

(*h*) *Secondary Regrowth*

(i) *Gardens and Garden Regrowth*.—Included here are all the stages of the native garden cycle from current cropping in newly cleared areas to short-term fallow pericds when the plot is abandoned to weed regrowth. The staple crop is the sweet potato, *Ipomoea batatas*. Stems of this vine are planted in gardens of mounded composted earth, the mounds rounded in shape and often divided by ditches. Sugar-cane, local spinaches, taro, potatoes, cabbages, and bananas are often grown in association with the main sweet potato crop. In the Lai valley (Western Highlands) these associated plants are often grown in a separate plot shaded by a cover of planted *Casuarina* trees.

Weed growth in gardens varies considerably and depends upon the initial conditions of the site, i.e. whether wet or dry, the time of the year when the plot is abandoned to fallow, and subsequent factors such as access of pigs to the plot.

Common pioneer weed grasses found on older garden sites are *Arthaxon hispidus*, *Setaria palide-fusca*, *Sacciolepis indica*, and *Oplismenus compositus*. This initial phase is eventually eliminated by competition from *Imperata cylindrica* or *Ischaemum polystachyum*.

Common pioneer herbs are also present and include *Polygonum*, *Amaranthus*, *Wahlenbergia*, *Cynoglossum*, and *Sida*, as well as many Compositae such as *Crassocephalum*, *Erechtites*, *Bidens*, and *Sigesbeckia*.

By the second or third year of fallow the plot is invariably dominated by the tall sword grass *Miscanthus floridulus*.

Near hamlets and individual houses many useful and ornamental plants and shrubs are planted for domestic purposes. These include bamboo, *Cordyline, Acalypha, Pandanus, Commersonia, Ficus dammaropsis, Ricinus,* and many small Urticaceae yielding fibres.

(ii) *Sword Grass and Shrub Regrowth.*—After the initial clearing of the forest and when regeneration is permitted, an association of tall sword grass, *Miscanthus floridulus,* appears, together with many associated small trees and shrubs. The sword grass is a tall cane similar to wild sugar-cane or "pit-pit", and now covers large areas of the Western and Southern Highlands, being second only to forest in extent.

It is regarded as successional vegetation following forest clearing which, without further interference, would return to forest. However, under constant biotic pressure of the populated highlands it is eventually replaced by short grass vegetation.

Hence many different phases of sword grass succession can be seen throughout the area. The associated shrubs are abundant to infrequent, of forest affiliated species, or of those more associated with open country. Scattered masses of *Gleichenia* fern are common. Sword grass plays a less important role only in the lower southern aspects of the area, where the normal lowland influences lead to a rapid woody regeneration. At altitudes between 5000 and 8000 ft sword grass predominates in the regeneration phases, covering large areas with a dense close cover 10 ft or more high.

Frequent shrubby associates are *Antidesma, Agapetes, Acalypha, Callicarpa, Decaspermum, Dodonaea, Ficus* spp., *Eurya, Grevillea, Glochidion, Homalanthus, Leucosyke, Maesa, Macaranga, Osbeckia, Pipturis, Rhododendron, Schefflera, Schuurmansia,* and *Wendlandia.*

(*i*) *Induced Grasslands*

The short grasslands of the inhabited highland valleys are man-made communities dominated for the most part by lowland short grass species of wide distribution. These are the result of a long-term biotic interference, clearing, burning, and gardening, on the original vegetation.

Within the area short grassland is of limited extent. Four main aspects have been recognized.

(i) Capillipedium *Grassland.*—Such grassland occupies the lower valley slopes and floors; a typical occurrence is in the Ialibu basin, where *Capillipedium parviflorum* dominates. *Arundinella setosa* is a frequent co-dominant but species composition is mixed and variable. Other grasses include *Eulalia trispicata, Apluda mutica, Ischaemum barbatum, Sorghum nitidum, Digitaria, Ophiuros exaltatus, Paspalum* spp., *Pogonantherum paniceum, Sporobolus, Setaria,* and *Themeda.*

A number of small herbs, ferns, and sedges are associated. The community forms an even cover about 3 ft high.

(ii) Themeda *Grassland.*—On drier sites such as ridge crests, kangaroo grass (*Themeda australis*) dominates in association with *Arundinella setosa.* This community can withstand much burning with little alteration and appears to be the ultimate short grass disclimax for much of the area.

(iii) Ischaemum *Grassland*.—This is a lush grass community found over wet to moist sites such as road-side ditches, wet depressions, and swamp margins. *Ischaemum polystachyum* forms a dense cover of trailing and 3–4-ft suberect stems. Minor associates are the moisture-loving sedges, grasses such as *Leersia* and *Isachne*, and herbs.

(iv) Imperata *Grassland*.—Above approximately 5500 ft altitude common kunai grass, *Imperata cylindrica*, frequently plays an important but short-term part in garden regrowth, commonly mixed with short grass communities. Below this altitude it grows much taller, is more persistent, and forms a distinct grassland community, notably in the Sugu and Nembi valleys south from Mendi. The sedges *Rhynchospora rugosa* and *Fimbristylis dichotoma* are common scattered associates within the grassland, which varies from 2 to 4 ft in height.

(*j*) Phragmites *Swamp*

Phragmites karka, often referred to as a tall swamp reed, is a cane grass growing under swampy conditions and forming dense cover from 10 to 20 ft high. It is adapted to both permanent swamp and sites of periodic inundation; thus it occurs in small peat swamps, local perched seepage hollows, and as a zone along the flood-plains of the rivers and around Lake Kutubu. It apparently favours wet sites where free drainage gives a continued supply of fresh nutrient minerals.

Peat swamp *Phragmites* stands are of small extent and usually merge into mixed grass swamp on one hand and Cyperaceae bog on the other. *Phragmites* forms a stand associated with the grasses *Ischaemum polystachyum*, *Leersia hexandra*, and *Isachne*, and the sedges *Scirpus mucronatus* and *Carex* sp. The substratum of peat may be several feet deep.

In many small poorly drained hollows characteristic of the colluvial slopes, *Phragmites* is found in small pockets over mottled plastic clays. Such occurrences are closely associated with mudstone- or siltstone-derived sediments and were also noted in the Goroka–Mt. Hagen area.

Tall dense stands of *Phragmites* are a common feature of fresh river alluvia where they are associated with open *Leersia* grass swamps. Such flood-plain stands are also found surrounding the recurrently inundated margins of Lake Kutubu.

(*k*) Leersia *Swamp*

The predominating grass in this community is *Leersia hexandra*. Often the depth of water is such that the whole vegetation is a floating mass but firm enough to walk over. The grasses are 1–3 ft high and include *Isachne* and *Ischaemum*, with *Typha*, ferns (*Blechnum*), and sedges such as *Gahnia*. Quite large expanses of bright green sward, particularly on distant flood-plains, proved to be grass swamp. Elsewhere *Leersia* formed small patches on poorly drained sites in mudstone and siltstone country.

(*l*) *Grass–Sedge Bog*

Although well defined both in extent and in floristic composition, grass–sedge bog occurs in habitats between swamps and bogs. The water-table is at or just above the surface and water rises at least above the ankles when the sward is compressed.

The characteristic grasses are *Dimeria dipteros*, *Isachne arfakensis*, and a *Paspalum* species. In the Ialibu basin at 6000 to 7000 ft above sea level *Agrostis reinwardtii* and *Arundinella furva* are present.

The sedges are many and quantitatively contribute most of the cover. Together with various swamp herbs they are generally those enumerated in the following sedge bog community.

Scattered dwarf shrubs some 2 ft high, namely, *Melastoma*, *Hypericum*, *Styphelia*, and *Haloragis*, are locally present.

(*m*) *Sedge Bog*

Small patches of bogs dominated by various Cyperaceae occur within a complex vegetation pattern on ash plains or undulating country dominated by sword grass, or form extensive valley floor bogs many square miles in area.

Generally sedge bogs are restricted to altitudes between 7000 and 11,000 ft and thus constitute the wetter aspects within alpine grassland.

Of the many different sedges and allied plants, some forming tussocks up to 2 ft high, *Machaerina rubiginosa* (syn. *Cladium glomeratum*) is the most frequent and often forms pure stands.

Others are *Cyperus globosus*, *C. unioloides*, *Carex*, *Elaeocharis congesta*, *Fimbristylis*, *Lipocarpha chinensis*, *Scirpus mucronatus*, *Schoenus curvulus*, and *Eriocaulon*. Bog herbs include *Dysophylla verticillata*, *Dichrocephala bicolor*, *Gunnera macrophylla*, *Jussiaea*, *Limnanthemum*, *Nymphoides*, *Sparganium*, *Salvia*, *Polygonum*, *Ranunculus*, *Viola*, *Utricularia*, and *Xyris*.

(*n*) *Lower Montane Grassland*

In this category are a number of discrete, mostly uninhabited grasslands occurring mainly in the Western Highlands. Typically occupying valleys at 8000–9000 ft, these grasslands are considered to be the result of frost-pocket conditions.

Diagnostic here are the grasses *Arundinella furva* and *Imperata exaltata*. Others are *Agrostis reinwardtii*, *Muehlenbergia arisanensis*, *Dichelachne novoguineensis*, *Anthoxanthum angustum*, *Deyeuxia brassii*, *Deschampsia klossii*, *Hierochloe longifolia*, and sedges. Drainage channels traversing the grasslands are typically filled or lined with *Machaerina rubiginosa* (syn. *Cladium glomeratum*) sedge.

The cover is often sparse with bare ground between the small tussocks. Small herbs and dwarf woody shrubs such as *Hypericum*, *Potentilla*, *Rhododendron*, *Styphelia*, *Gaultheria*, *Haloragis*, *Lycopodium*, and the fern *Gleichenia*, are a feature. Tree ferns also occur.

(*o*) *Alpine Grassland*

In this report alpine grassland embraces not only the tussock grasslands of the mountain summit areas which are above the tree line, but also some extensive valley grasslands below the forest limits. The Sugarloaf and McNicoll plateaux at about 9000 ft are examples where, due to cold-air drainage, tree growth has been locally inhibited and downward extensions of alpine tussock grassland from higher levels occur. These aspects are less endowed with associated alpine species than the true summit areas of Mt. Giluwe and The Sugarloaf.

The alpine grasslands are predominantly composed of tussock grasses in thick clumps 9–12 in. across and 2–3 ft high. Particularly common here are *Danthonia archboldii*, *Danthonia vestita*, *Dichelachne novoguineensis*, *Hierochloe longifolia*, *Deschampsia klossii*, *Anthoxanthum angustum*, *Deyeuxia brassii*, *Festuca papuana*, and *Poa crassicaulis*.

Small shrubs such as *Styphelia*, *Rhododendron*, *Vaccinium*, *Haloragis*, *Detzneria*, *Gaultheria*, *Anaphalis*, *Keysseria*, and *Coprosma* are present and in some places almost warrant an additional vegetation category of "alpine heath".

Between the tussocks many low or prostrate herbs occur, including *Ranunculus*, *Gentiana*, *Potentilla*, *Lycopodium*, *Euphrasia*, *Drapetes*, *Oreomyrrhis*, the ferns *Papuapteris linearis* and *Gleichenia vulcanica*, and mosses.

Numerous tree ferns, their gaunt forms rising from 2 to 12 ft, often give these grasslands an unusual local aspect, whence the popular name "tree-fern grassland". Small sedge bogs occur in wet sites.

(*p*) *Alpine Peat Bog*

This community is found only within the true summit alpine tussock grassland on Mt. Giluwe and Mt. Hagen. It comprises the wet vegetation on peaty bogs covering glacial till and bare rock, as well as the encroaching periphery of alpine tarns.

Here are small cushion plants such as *Oreomyrrhis*, with *Ranunculus*, *Drosera*, *Astelia papuana*, *Carpha alpina*, *Gahnia*, *Gleichenia vulcanica*, *Trachymene*, and *Epilobium*. *Isöetes*, *Callitriche*, and *Scirpus crassiusculus* occur at the edge of open water.

IV. Vegetation and the Land Systems*

The vegetation of the land systems is shown in Table 11, from which it is clear that the natural vegetation over most of the area is lower montane rain forest. When cleared and burnt, lower montane rain forest is replaced by secondary regrowth, mostly sword grass, and of the 39 land systems in the area, 26 are predominantly either lower montane rain forest or secondary regrowth. Of the other land systems, four in the Kutubu lowlands are dominantly lowland rain forest, and six at high altitudes are dominated by either montane rain forest, alpine grassland, or lower montane grassland. The remaining three land systems are lake and river plains and carry predominantly various swamp and bog communities.

*Contributed by R. A. Perry, Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T.

TABLE

VEGETATION* OF THE

Vegetation	Limestone						Mainly Non-calcareous Unresistant Sedimentary Rocks										
	Mountains		Karst Lands				Mountains			Hills and Benchlands							
	Kaijende	Duma	Pinnacle	Nembi	Digumu	Suma	Nop	Ambum	Tou	Yalis	Wongum	Andabare	Tsang	Laiagam	Tibinini	Hariu	Kagua
Lowland rain forest		*D*			*D*			m								*D*	
Lower montane rain forest	*D*		S	*D*	m	m	m	*D*	*D*	*D*	m		*D*	m	S		m
Montane rain forest			S				*D*										
Campnosperma–sago palm forest																	
Swamp woodland																	
Pandanus swamp														m			
Casuarina woodland										m							
Secondary regrowth	S			S	m	*D*		S	m	S	*D*			*D*	S		*D*
Induced grasslands						m		m		m	m			m	m		m
Phragmites swamp											m						m
Leersia swamp								m		m	m			m	m		m
Grass–sedge bog																	
Sedge bog											m	m					m
Lower montane grassland			m				m					*D*					
Alpine grassland							m										
Alpine peat bog																	
Bare rock	m	m	S	m	m	m			m	m	m						

* *D*, dominant; S, subdominant; m, minor.

11

LAND SYSTEMS

Basic Intrusive Rocks		Volcanic Materials														Alluvium						
		Mountains			Plateaux and Upland Basins			Piedmont Slopes	Plains	Low Hill Ridges		Younger Features		Gorges	Terraces and Fans				Lake and River Plains		
Nose	Silim	Giluwe	Ialibu	Doma	Sugarloaf	Dibibi	Lava	Nemarep	Tari	Tage	Kwandi	Birap	Poroma	Lai	Tambul	Winjaka	Wabag	Ko	Kandep	Kaugel	Kufubu
										D											m
D	*D*		*D*	*D*	S	m		*D*	m		m	S	m	m		m		m		m	
		m			m		m	m													
																					S
																					m
									m									m			S
m	S		m	m		S	S		*D*		*D*	*D*	*D*	*D*	*D*	*D*	*D*	*D*	m	m	
			m			m		m	m		m		m	m				m	m	m	
									m								m	m		S	m
									m				m				m	m		S	
					m			m	m			m			m			m	m	m	
					m	m	m	m	m			m			m	m	m	m	*D*		
					S	*D*	*D*	m											m		
		D			m		m														
		m			m		m														
								m				m									

PART VIII. FOREST RESOURCES OF THE WABAG–TARI AREA

By J. C. SAUNDERS*

I. INTRODUCTION

The aim of this Part and its associated map is to describe the forests of the area and to indicate their location and extent. Reference has been made to the analogous vegetation communities described in Part VII.

There is a wide altitudinal range in the area and this may be subdivided into four zones: lowland, below 4000 ft; lower montane, 4000–10,000 ft; montane, 10,000–12,500 ft; and alpine, above 12,500 ft. Forested land, covering 60% of the area, occurs in the lower three zones. The remaining 40% of the area is unforested primarily because of two factors, climate and man.

The influence of climate in limiting forest growth is found above about 8000 ft, where intramontane grassland basins occur due to cold-air drainage. Alpine grassland occurs above 12,500 ft.

The anthropogenic influence, however, is far the greater. The lowland and montane forests are virtually undisturbed, due to lack of population in the former and unsatisfactory growth environment for crops in the latter. The lower montane forest has been extensively cleared for indigenous agriculture, particularly up to the 8500 ft level. Within this lower montane zone, clearing has been confined mainly to the valley bottoms and lower slopes of major valley systems, but where the population is dense the forest has been cleared to higher altitudes and on rugged terrain.

Milling operations in the area are not extensive and are largely restricted to the main government centres, Mendi, Tari, and Wabag, with one Lutheran mission sawmill near Yeibos in the Lai valley. The sawn timber from these mills is used locally.

II. SURVEY METHODS

During preliminary air-photo interpretation, the forests in the area were divided into categories with distinct photo patterns. Traverses were then planned to visit each photo pattern as often as possible, bearing in mind accessibility and the time available.

Where possible field plots of 2 to 10 acres were located in the photo patterns. Information recorded for each tree exceeding 5 ft in girth at breast height outside bark (or above buttresses) included merchantable length, total height, botanical name, and local name. Qualitative information was augmented by continuous visual observation when passing through forested areas and by the observations of the ecologists. From the quantitative information collected in each plot, stocking rates were estimated for each forest type. These figures are a very approximate indication of timber volume and must be used with caution, as the sampling intensity was less than 0·005% of the forested area. Volumes quoted were based on a form factor of 0·5 and no allowance for internal defect was made.

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

Tree identifications were based on herbarium material held in the Herbarium Australiense at Canberra and on the comparison of wood samples with wood specimens supported by herbarium material.

The map of forest types is at a scale of 1 : 250,000. Areas of steep rugged topography, i.e. those with a general slope in excess of 30° or where land of lesser slope shows a very high degree of dissection, are depicted on it. Geomorphic units were the basic criteria used to delineate these areas. In borderline cases the Leitz (Hackman) Stereo Slope Comparator was used to determine actual slopes. All areas were estimated with a dot grid.

III. 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". Montane forest is the only exception to this. As stated in Section I, the forests of the area fall into three broad altitudinal zones: lowland, below 4000 ft; lower montane, between 4000 ft and 10,000 ft; and montane, above 10,000 ft. Because of the gradual transition from one zone to another, the altitudinal limits selected are approximate and floristic elements of one zone often penetrate deeply into another. This is particularly striking with *Nothofagus* and *Castanopsis*, which penetrate deeply into the lowland zone although generally considered lower montane genera. Within the zones, the forest has been classified into types based on characteristics observable on aerial photographs, namely, land form, species dominance in the canopy and emergent layers, density, and height. The types and their areas are listed in Table 12.

(*a*) *Lowland Zone*

Lowland forest covers an area of approximately 350 sq miles and occurs almost exclusively in the south and south-west near Lake Kutubu, with one very small occurrence in the Sau valley in the north-east.

It is generally a tall forest 100–120 ft high with occasional patches of scattered *Araucaria* emergents rising to 150 ft. The forest canopy is usually dense and uneven and is composed of relatively large crowns. The floristic composition is very mixed and no single species dominates. Exceptions to this general description occur under limiting environmental conditions, e.g. on ridge crests and on wetter sites.

Lowland forest has been subdivided into three forest types: alluvium forest which is confined to forest on alluvial deposits; hill forest found on hilly country where there is a low density of ridges; and beech–hill forest on hilly country possessing a high ridge density where beech on the ridge crests dominates the area.

(i) *Alluvium Forest* (< 10 sq miles).—This type is confined to forest on alluvium and its main occurrence is along the Mubi River. It varies from forest on well-drained alluvium with a closed canopy level of 100–120 ft and occasional emergents to 150 ft, through an occasionally inundated forest with a lower (60–80 ft), more open canopy, to the wetter sites where there is an open layer of *Campnosperma coriacea*, 80 ft high, over an under-storey of sago.

On well-drained sites *Pometia* spp., *Terminalia* sp., *Chisocheton* sp., *Dysoxylum* spp., *Ficus* spp., and Lauraceae are the main species in the canopy. On the occasionally inundated land *Laportea* sp., *Cedrela* sp., and *Nauclea* sp. are the main species.

The estimated stocking rate for this type is approximately 8000 super ft per acre from 7 trees per acre. The figure varies from 12,000 super ft per acre on the better, well-drained sites to 3000 super ft per acre on swampy sites.

TABLE 12

FOREST TYPES AND AREAS

Forest Type	Area (sq miles)
Lowland	
Alluvium forest	<10
Hill forest	180
Beech–hill forest	170
Total lowland	350 (approx.)
Lower montane	
Mixed forest	1030
Degraded mixed forest	350
Mixed–beech forest	550
Beech forest	80
Degraded beech forest	100
Beech–mixed forest	690
Stunted beech–mixed forest	250
Coniferous forest	<10
Coniferous–mixed forest	210
Open coniferous forest	<10
Total lower montane	3260 (approx.)
Montane	
Montane forest	120
Total forested area	3730
Other areas	2470
Total area	6200 (approx.)

Located in an area of very low population density and partly subject to inundation, alluvium forest remains virtually undisturbed.

The following trees were recorded in alluvium forest: *Aglaia*, *Albizia falcata*, *Alstonia scholaris*, *Artocarpus*, *Buchanania*, *Campnosperma*, *Cedrela*, *Chisocheton*, *Cryptocarya*, *Dracontomelum*, *Dysoxylum*, *Elaeocarpus*, *Ficus* spp., *Gymnacranthera*, *Laportea*, *Litsea*, *Nauclea*, *Pangium edule*, *Pometia*, *Sloanea*, *Terminalia*, and ?*Turpinia*.

(ii) *Hill Forest* (180 sq miles).—This type is found on hilly country where there is a low density of ridges. It occurs in the south of the area near Lake Kutubu with one very small patch in the Sau valley near Labilam.

The forest has a closed canopy 100–110 ft high with occasional patches of emergent *Araucaria* to 150 ft. Species composition is mixed and predominantly broad-leaf in nature, containing lowland and lower montane elements. The lower montane elements, *Nothofagus*, *Castanopsis*, and *Lithocarpus*, become dominant on the ridges and the lowland element dominates the forest in the gullies.

Girth sizes range between 5 and 15 ft but are mainly in the 5–10-ft range. The estimated stocking rate is approximately 8000 super ft per acre from 5 to 6 trees per acre.

Hill forest has been very little affected by clearing due to the very low population density in the area.

The following is a list of trees recorded within the type (L and H refer to predominantly lowland and highland trees respectively): *Alstonia scholaris* (L), *Araucaria* (H), *Artocarpus*, *Buchanania* (L), *Calophyllum*, *Campnosperma* (L), *Castanopsis* (H), *Celtis* (L), *Chisocheton* (L), *Cinnamomum*, *Cryptocarya*, *Dysoxylum* (L), *Elaeocarpus*, *Elmerrillia papuana* (H), *Engelhardtia*, *Eucalyptopsis*, *Ficus* spp. (L), *Garcinia* (L), *Garuga* (L), *Lithocarpus* (H), *Litsea*, *Mallotus*, *Meliosma*, *Myristica* (L), *Nothofagus* (H), *Opocunonia* (H), *Podocarpus* (strap leaf) (H), *Pometia* spp. (L), *Rhus* (L), *Sloanea* (L), *Syzygium*, *Terminalia* (L), and *Vitex cofassus*.

(iii) *Beech–Hill Forest* (170 sq miles).—This forest type covers hilly areas with a high density of ridges. It is found mainly on karst limestone topography in the south of the area near Lake Kutubu.

The canopy height is generally about 60–80 ft on limestone areas but can be 100–120 ft elsewhere. The high density of ridges carrying *Nothofagus* distinguishes this type from the hill forest described above. In other respects the two types are similar.

While some areas of the forest have been cleared for indigenous agriculture, the forest on limestone remains undisturbed.

(*b*) *Lower Montane Zone*

Lower montane forests are the most extensive in the area. They are of mixed floristic composition, mainly broad-leaf in nature, but some conifers are normally present. The forest is generally 80–100 ft high, and may have emergent conifers. The canopy appears less dense than lowland forest, due possibly to the relatively smaller average crown size.

On various sites, communities dominated by a single or a small group of species are found. These dominants are oak, beech, and conifers. Oak communities are generally found below 7500 ft as pure stands on ridge crests, with mixed forest on the side slopes and gullies. As many areas of oak forest are small, this community has been included in the mixed forest for convenience in mapping.

Beech is found throughout the lower montane zone and may occur as a pure stand on ridge crests only, with mixed forest on the side slopes and gullies, or it may cover all three sites. The forest is about 100 ft high, often 20 ft higher than adjacent forests.

Coniferous forest is found mainly above 8500 ft in areas where frost appears to inhibit the growth of broad-leaf species. The canopy is relatively open and is composed of typical conical crowns. *Papuacedrus* when present is often 20 ft higher than the other species.

Because of the complex distribution patterns of the major types within the lower montane zone and the small scale of mapping, it has been necessary in some cases to map complexes of forest rather than discrete areas of mixed, beech, and coniferous forest. At the same time, density and/or height have been used as criteria to subdivide the forest into types and permit allocation of reasonably uniform estimated stocking rates.

(i) *Mixed Forest* (1030 sq miles).—The mixed forest is the most extensive type in the area. It is distributed throughout the area above 3000 ft altitude, but is concentrated mainly above 7000 ft. Below this level extensive areas of mixed forest have been cleared for indigenous agriculture.

The mixed forest has a canopy height of 80–100 ft and is composed predominantly of broad-leaf species, but some conifers are normally present. Patches of emergent *Araucaria* are occasionally found at lower altitudes, particularly in the Tari basin and the Sau and Tagari valleys. The forest contains a wide range of species, none attaining dominance with the exception of oaks (*Castanopsis* and *Lithocarpus*) at lower altitudes on ridge crests.

Because of the wide altitudinal range of the mixed forest, variations in height and species composition occur. Towards its upper limits, height and girth size are smaller and conifers occur more frequently. In the following list, species showing a preference for low (L) or high (H) altitudes are indicated.

Girths are generally from 5 to 13 ft but the majority of trees fall into the 5–7-ft range. The stocking rate of the forest is approximately 9000 super ft per acre from approximately 9 trees per acre.

Up to 7000 ft altitude, and in some cases above, the forest is still being cleared for indigenous agriculture. This applies particularly to the less steep land, but some land on steep and rugged topography is also used.

The following is a list of trees recorded in the mixed forest: *Albizia fulva* (L), *Alphitonia*, *Alstonia*, *Araucaria* (L), *Ascarina* (H), *Astronia*, *Calophyllum*, *Casearia*, *Castanopsis* (L), *Cinnamomum*, *Claoxylon* (H), *Cryptocarya* spp., *Dacrydium* (H), *Dryadodaphne*, *Elaeocarpus* spp., *Elmerrillia* (L), *Euodia* (H), *Galbulimina*, *Garcinia* (L), *Halfordia* (H), ?Icacinaceae, *Ilex* (H), *Lithocarpus* (L), *Litsea*, *Mallotus*, *Mischocarpus*, *Neonauclea* (L), *Nothofagus* spp., *Opocunonia*, *Papuacedrus* (H), *Phyllocladus* (H), *Planchonella*, *Platea*, *Podocarpus* spp., *Pygeum* (H), *Quintinia* (H), *Schizomeria*, *Sloanea*, *Sterculia* (L), *Syzygium*, *Timonius* (H), *Weinmannia* (H), *Xanthomyrtus* (H), and *Zanthoxylum* (H).

(ii) *Degraded Mixed Forest* (350 sq miles).—This type of forest is scattered throughout the area in the lower montane zone, primarily associated with centres of population and indigenous agriculture.

The forest is 60–100 ft high with an open canopy, less dense than the mixed forest type, and may be either a partly exploited remnant of mixed forest or, when not affected by human interference, a result of poor site quality. Species composition is similar to the mixed forest type.

Girths range from 5 to 11 ft, but are mainly 5–6 ft. The estimated stocking rate is 4500 super ft per acre from up to 5 trees per acre. The forest is being actively exploited and cleared for indigenous agriculture.

(iii) *Mixed–Beech Forest* (550 sq miles).—The mixed–beech forest type is found throughout the lower montane zone.

It consists of a mixed forest, covering more than 50% of the area occupied by the forest, the remaining area occupied by beech in pure stand. The beech forest is confined to ridge tops, and the mixed forest to the side slopes and gullies. Thus the greater the ridge density, the greater is the proportion of beech forest. Each of the two components of this complex is similar to its counterpart described separately.

Because of the wide variation in the proportions of mixed to beech forest it is difficult to estimate a stocking rate for the type. However, assuming an average ratio of 75% mixed type to 25% beech type, the estimated stocking rate would be 9500 super ft per acre from 10 trees per acre.

The mixed–beech forest is cleared for native agriculture.

(iv) *Beech Forest* (80 sq miles).—Stands of beech forest are scattered throughout the lower montane zone. The extent of each stand is relatively small, generally not exceeding 5 sq miles, except for one area of about 20 sq miles on the southern side of Mt. Giluwe. It is found on all types of terrain, generally between 7000 ft and 9000 ft altitude.

Beech grows on a wide variety of sites from well-drained ridges to waterlogged bogs. On wetter sites, the trees become stunted. Small areas of stunted beech are found near Kandep and in the Tari basin.

Beech forest consists of a pure, or almost pure, stand of *Nothofagus* spp., 100–120 ft high. Two distinct air-photo patterns are recognizable. One species of *Nothofagus* with very small leaves is often found in monospecific stands at higher altitudes, particularly on the south-eastern slopes of Mt. Giluwe. This stand exhibits a dark smooth-textured pattern, the individual crowns being indistinguishable. Other stands, which are far more widespread in the area and may be multispecific, exhibit a pattern of compact, rounded, and more or less distinct crowns.

Girth of *Nothofagus* can be large. This is particularly so in the case of the small-leaf species, where girths recorded were generally between 8 and 13 ft, with one recorded at 18 ft. Other stands of *Nothofagus* spp. have a girth range of 5–13 ft, the 6–8-ft class being the most frequent.

The average stocking rate of the forest is approximately 11,000 super ft per acre from 11 trees per acre. This varies considerably, the largest figure recorded being 16,000 super ft per acre in a stand dominated by the small-leaf species. It is expected that many of the large-girth trees may have internal defects.

Beech forest is cleared for indigenous agriculture and is exploited for local use in centres of European population.

(v) *Degraded Beech Forest* (100 sq miles).—This type of forest is found in patches scattered throughout the area at elevations generally over 7000 ft. It is a low-density beech forest, this feature often being caused by patches of dead trees, presumably due to the dying off of even-aged stands of *Nothofagus.* Regrowth in the resulting open patches is dominated by *Nothofagus.* The air-photo pattern is particularly striking on the south-eastern slopes of Mt. Giluwe.

The estimated average stocking rate for this type is approximately 3000 super ft per acre, but it varies considerably. Some areas are cleared for indigenous agriculture.

(vi) *Beech–Mixed Forest* (690 sq miles).—This type is another complex forest found throughout the lower montane zone. In this type the beech forest covers more than 50% of the area, the remainder being covered by mixed forest. As with the mixed–beech forest, each component is similar to its counterpart already described.

Assuming a ratio of 75% beech to 25% mixed forest, the estimated stocking rate would be 10,500 super ft per acre from 11 trees per acre. The beech–mixed forest is mostly within the actively gardened range of altitude and is often cleared for indigenous agriculture.

(vii) *Stunted Beech–Mixed Forest* (250 sq miles).—This type is restricted to karst topography within the lower montane zone. The main occurrences are on steep and rugged limestone topography in the south-west of the area near the Wage and Kikori rivers and north-west of the Tari basin.

The forest is 60–80 ft high with pure stands of beech on the ridges and mixed forest on the slopes and gullies. Species composition is similar to the beech–mixed forest described above. The estimated stocking rate of this type is approximately 3000 super ft per acre from 11 trees per acre. In areas of high population density, notably along the Wage River and on the edge of the Tari basin, the forest is cleared for indigenous agriculture.

(viii) *Coniferous Forest* (<10 sq miles).—Coniferous forest is found mainly between 8500 ft and 10,000 ft and as a marginal forest to the grasslands of the intramontane basins where frosts appear to inhibit the growth of many broad-leaf species. It occurs as several small areas on the slopes of Mt. Giluwe, in the Sugarloaf and Yobobos grassland areas, and in the extreme north-west. The forest is generally 80–120 ft high. It is variable in species representation, and contains *Papuacedrus, Podocarpus, Dacrydium,* and *Phyllocladus,* with an occasional broad-leaf associate. *Papuacedrus,* when present, is usually about 20 ft higher than the other conifers.

Girths are generally small, between 5 and 8 ft but mostly 5–6 ft, and boles are long. The estimated stocking rate is approximately 7000 super ft per acre from 6 trees per acre. Coniferous forest is rarely, if ever, cleared for cropping.

(ix) *Coniferous–Mixed Forest* (210 sq miles).—This type is found on sites similar to those of the coniferous forest, but where the growth of broad-leaf trees has not been inhibited. It occurs throughout the higher mountain systems.

The forest consists of two elements, a broad-leaf element similar to the mixed forest type at the same altitude, and a coniferous element similar to the coniferous forest type. Species from each element combine to form a forest with a moderately open canopy 80–100 ft high. Some conifers, mainly *Papuacedrus,* are emergent.

Girths are generally small, most of the trees falling in the 5–6-ft class, with some up to 8 ft. The estimated stocking rate is approximately 6000 super ft per acre from 5 trees per acre. Like the coniferous forest, this type is rarely, if ever, cleared for indigenous agriculture.

(x) *Open Coniferous Forest* (< 10 sq miles).—This occurs in two small areas, one near Doma Peaks and one in the mountains to the north-west of Lake Iviva. It is a very open community of conifers 80 ft high, with an estimated stocking rate of approximately 3000 super ft per acre. It is not cleared for indigenous agriculture.

TABLE 13

CORRELATION BETWEEN FOREST TYPES AND VEGETATION COMMUNITIES

Forest Type	Vegetation Community
Lowland	
Alluvium forest	Alluvium forest
Alluvium forest	Dense *Campnosperma*–sago palm forest
Hill forest	Lowland hill forest
Beech–hill forest	Lowland hill forest
Lower montane	
Mixed forest	Mixed forest
Mixed forest	Oak forest
Beech forest	Beech forest
Coniferous forest	Coniferous forest
Montane	
Montane forest	Montane rain forest
Other areas	Bog forest and all other communities

(c) *Montane Zone*

Montane forest covers an area of 120 sq miles and is restricted to elevations above 10,000 ft. Only one type has been recognized.

(i) *Montane Forest* (120 sq miles).—The main occurrences are on the Maramuni Divide, the McNicoll Mountains, Doma Peaks, Mt. Kerewa, Mt. Giluwe, the Sugarloaf, and Mt. Wamburi. The canopy is dense and fine-textured in pattern and is generally 30–40 ft high. At the upper boundary, where the forest borders on alpine grassland, there is an alpine shrubbery or thicket up to 15 ft high. This has been included with montane forest as a mapping unit. Species of Myrtaceae are common, and often dominant. Occasional conifer emergents, *Papuacedrus* and *Phyllocladus*, are present in certain areas. The trees are of small girth and twisted bole form.

Although montane forest is of no commercial interest it has a valuable function as a protection forest. The forest is above the altitudinal limit for indigenous agriculture and is therefore rarely cleared. However, on both the eastern and western slopes of Mt. Giluwe the forest shows a discontinuous distribution pattern consistent with clearing.

IV. Correlation with Vegetation Communities

The correlation between forest types and the forest communities described in Part VII is outlined in Table 13. Generally the two are closely correlated but some overlap occurs. The alluvium forest type includes denser stands of the *Campnosperma*–sago palm forest. Because of the complexity of types described in the lower montane zone, correlation can best be shown by using the major types, mixed, beech, and coniferous. As bog forest occupies a very small area and the trees do not attain 5-ft girth, it has not been classified as a forest type. It and all other vegetation communities have been included in "other areas".

V. Acknowledgments

Acknowledgment is made to the Department of Forests, Territory of Papua–New Guinea, for its cooperation; to the Division of Forest Products, CSIRO, for its assistance in the identification of wood samples; and to the staff of the Herbarium Australiense, for their plant specimen determinations. The author would also like to acknowledge the cooperation and assistance of the other survey team members, particularly the ecologists.

PART IX. POPULATION AND LAND USE OF THE WABAG–TARI AREA

By J. R. McAlpine*

I. Introduction

This Part aims to give some indication of present forms of land use, their intensity, and the population distribution of the area surveyed, particularly in relation to the land systems previously described.

II. Method

Land use information in this Part and on the accompanying map has been obtained from limited field observations used in conjunction with an analysis of air-photograph cultivation patterns. As 99% of the land use in the area is based on a chiefly monocultural agriculture system, only one type of land use can be mapped. This has been mapped in three classes to provide a land use intensity map. The classes are:

(1) Intense—over 50% of the land normally used for cultivation.

(2) Moderate—between 10% and 50% of the land normally used for cultivation.

(3) Low—less than 10% of the land normally used for cultivation.

It must be emphasized that the areas given of these classes are of "land normally used for cultivation" and *not* "areas of cultivated land". Areas of these classes have been determined by use of a dot grid overlay of 1 dot to the square kilometre.

Population data have been obtained from the 1959–60 census of the area. Where these census data include population estimates, the distribution and numbers involved have been checked against air-photo evidence and found to be sufficiently reliable for the purposes of this Part.

III. Population

The area surveyed has an indigenous population of 191,000 and includes some of the most densely settled areas in Papua and New Guinea. Actual densities within some tribal groups near Wabag rise to over 400 persons per sq mile. The heaviest population densities are found in the broader, lower valley floors, the better-drained volcanic plains, and the lower limestone valley depressions. Census figures indicate a rising population over the area as a whole.

The non-indigenous population of the area is estimated to be less than 500 persons and is virtually wholly engaged in government and mission activities. The sociology and anthropology of the area are outside the scope of this report. References (Meggitt 1956, 1957, 1958) at the end of this Part cover these aspects for the Western Highlands District.

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

IV. Land Use

The land use map indicates a similarity in cultivation intensity to other parts of the New Guinea highlands. This is in direct contrast to the lower cultivation intensities found in the lowland regions, even in those lowland areas of high population density.

A total of 1760 sq miles or 29% of the area surveyed is used for cultivation. Of the area cultivated, 3% is cultivated intensely, 11% moderately, and 86% lightly.

Three types of land use occur in the area: (1) root crop (subsistence) cultivation; (2) sago gathering; (3) alienated and cash crop land. Types (2) and (3) account for less than 1% of the land use.

(1) Root crop (subsistence) cultivation is based mainly on the sweet potato (*Ipomoea batatas*), which supports 99·5% of the region's population. The system of cultivation cannot be classed as "shifting agriculture", but varies from a "long fallow cultivation" of 25 years and more in the least densely occupied sections, to the intensive, almost permanent short-fallow cultivation found in the densely populated regions. (The general limitations of these terms are discussed by Brookfield and Brown (1963).) Within the garden the cultivation method is intensive and similar for all areas.

Garden preparation involves complete tillage and the subsequent heaping of the tilled soil into mounds usually 9 ft in diameter, 2 ft high, and 3–5 ft apart (Plate 8, Fig. 1). The vegetation collected in clearing the ground is laid in the centre of each mound for composting. Occasionally grass roots and stubble are burnt in the mounds, resulting in a higher mineral nutrient level. The mounds are then planted either wholly with sweet potato or with lesser amounts of other crops (e.g. tomatoes, peanuts) in addition.

Sweet potato is usually harvested between 5 and 7 months in the lower altitudes but only after a considerably longer period at higher altitudes. Normally any one garden will have various sections of its mounds at different stages of development from initial clearing to final harvesting (Plate 8, Fig. 2). The poorer produce of the final harvest before the mounds are destroyed is usually fed to the pigs.

Land selected for gardening is generally under *Miscanthus* grassland. Only occasional clearing of the forest margins occurs, and then mostly following population movements. The upper gardening limit and hence the forest–grassland margin tend to occur at an altitude of 8500 ft, but locally may occur higher. Colder conditions above this limit do not encourage root crop cultivation.

Periodic frosts tend to damage crops and for this reason hollows susceptible to frosts are avoided even at lower altitudes. In addition to the greater chance of frost damage with increasing altitude, crop returns per acre are diminished, crop quality is adversely affected, and growing season is lengthened. A number of crops common in the lower areas (particularly bananas) will not grow above 7000 ft.

Some of the higher-altitude gardening areas are adjacent to large swamps (Kandep land system), and irregular flooding of some of these gardens occurs following heavy rains. Soil compaction following tillage may also reduce the garden level, causing greater likelihood of flooding.

Most gardens are enclosed by fences of cordylines and casuarinas, particularly in the more densely populated areas and at Tari. This results in a distinctive air-photo pattern which greatly facilitates land use mapping.

The main crops planted are listed here, but the list is not exhaustive: sweet potato (*Ipomoea batatas*), banana (*Musa sapientum*), taro (*Colocasia antiquarium*), yam (*Dioscorea* sp.), wing beans (*Psophocarpus tetragonolobus*), sugar-cane (*Saccharum officinarium*), papaw (*Carica papaya*), peanuts (*Arachis hypogaea*), edible pit-pit (*Saccharum edule*), pandanus (*Pandanus julianetti* and *P. brosimos*), cassava (*Manihot* sp.), coconut (*Cocos nucifera*).

Sago (*Metroxylon sagu*) is collected and processed in the lower-altitude swamps. European vegetables, particularly potatoes, cabbages, and tomatoes, have been introduced and are found throughout the area.

(2) Sago gathering is restricted to a small area below 3500 ft above sea level in the Lake Kutubu–Mubi River region, where 1100 people (0·5% of the total population) use less than 1 sq mile of land for low-intensity cultivation (i.e. less than 64 acres in use). They subsist on sago (*Metroxylon sagu*) collection and processing, supplemented by sweet potato cultivated in the normal "shifting agriculture" manner of the lowlands and not by "mounding".

(3) Alienated and cash crop land comprises very little of the survey area, and that land which is alienated is mostly restricted to government and mission use. There is only one small commercial coffee plantation (*Coffea arabica*) and it is owned by a mission.

Cash cropping by the indigenous population is limited to the sale of garden produce to government and mission stations and to the planting of small coffee blocks under government guidance. Trial pyrethrum (*Chrysanthemum cinerariaefolium*) plantings were commenced in 1960–61. Only with coffee is specific land set aside for cash cropping.

Large numbers of pigs and some poultry are raised for both ceremonial and dietary needs. Hunting and bush collection provide little of the food consumed in the area.

V. Population–Land Use Data in Relation to Land Systems

Table 14 lists the population and the area of land use intensity of each land system. The data have been extended to provide overall land system population densities (i.e. the quotient of total population on the land system to the total land system area) and a more refined land system population density based on land used (i.e. the quotient of total population on the land system to the area of land system used for cultivation).

In the table the land systems have been arranged in groups relating to the degree of land use present on each land system.

The actual cultivation pattern within the land systems can be obtained from a comparison of the land system and land use intensity maps. The intensity of land use within the land systems can be found by reference to Table 14.

TABLE 14

POPULATION AND LAND USE WITHIN LAND SYSTEMS

Land System	Population			Total Area of Land System (sq miles)	Land Use			
	Population in Land System	Population Density (per sq mile)			Total Area used for Cultivation (sq miles)	Area used for Cultivation on Land System (sq miles)		
		Overall	On Land Used			Intense	Medium	Low
No use of land system								
Andabare	—	—	—	100	—	—	—	—
Dibibi	—	—	—	25	—	—	—	—
Digumu	—	—	—	190	3	—	—	3
Duma	—	—	—	30	2	—	—	2
Giluwe	—	—	—	65	—	—	—	—
Hariu	—	—	—	65	—	—	—	—
Ialibu	—	—	—	100	1	—	—	1
Lai	—	—	—	15	4	—	—	4
Lava	—	—	—	10	—	—	—	—
Nop	—	—	—	80	—	—	—	—
Nose	—	—	—	100	11	—	<1	11
Pinnacle	—	—	—	7	—	—	—	—
Sugarloaf	—	—	—	95	—	—	—	—
Tage	—	—	—	40	—	—	—	<1
Tou	—	—	—	10	2	—	—	2
Tsang	—	—	—	35	—	—	—	—
Low use of land system								
Doma	1600	5	59	330	27	—	3	24
Kandep	350	3	39	100	9	—	3	6
Kaijende	1800	2	24	720	76	1	4	71
Nemarep	8600	13	60	650	142	—	10	132
Tibinini	2900	22	85	130	33	<1	3	30

Low to moderate use of land system								
Ambum	53,100	34	100	1550	526	5	44	477
Birap	1400	47	140	30	10	2	<1	8
Laiagam	6000	63	133	95	45	2	7	36
Nembi	10,300	33	110	310	93	2	10	81
Silim	1600	32	100	50	16	—	—	16
Suma	7300	24	88	300	83	—	8	75
Yalis	1200	48	109	25	11	—	2	9
Moderate use of land system								
Kwandi	3700	49	61	75	60	—	3	57
Poroma	2400	80	86	30	28	—	2	26
Wongum	32,700	99	123	330	266	11	36	219
Tari	18,900	90	132	210	143	2	16	125
High use of land system								
Kagua	3400	136	136	25	25	—	6	19
Kaugel	800	114	114	7	7	—	2	5
Ko	10,700	178	178	60	60	2	14	44
Tambul	4500	225	225	20	20	1	5	14
Wabag	16,000	266	266	60	60	15	22	23
Other land systems								
Kutubu	1000	29	*	35	1	—	<1	1
Winjaka	300	75	†	4	4	—	<1	4

* Figure meaningless as Kutubu land system is used for sago gathering.

† Inclusion of part of land system of Goroka–Mt. Hagen area.

(a) *No Use of Land System*

This group includes all land systems with minimal or no land use. The land use which does occur on some of these land systems is small in area, light in intensity, and impermanent. It is marginal and generally results from heavy "land pressure" on adjoining land systems.

(b) *Low Use of Land System*

This group comprises land systems containing only small restricted areas of land use and relatively low population densities.

Doma—land use restricted to the lower valley floors of the Benaria census division of Tari subdistrict.

Kandep—land use restricted to small levees and small flood-plains.

Kaijende—land use restricted to small valley floors, cliff tops and bases.

Nemarep—land use restricted to areas under 8500 ft.

Tibinini—land use restricted to areas under 8500 ft where populated.

(c) *Low to Moderate Use of Land System*

This group includes all land systems with between 30% and 50% of their areas used and with moderate population densities.

Ambum—land use restricted chiefly to the larger, lower, less rugged valleys.

Birap—land use restricted to areas under 8500 ft.

Laiagam—land use restricted to areas under 8500 ft.

Nembi—land use restricted to the doline and valley floors east of the Wage River.

Silim—land use restricted to areas under 8500 ft.

Suma—land use restricted to less rugged areas under 8500 ft.

Yalis—land use restricted to the lower terraces and plateaux.

(d) *Moderate Use of Land System*

This group includes land systems with over 80% of their areas used with moderately high population densities. The only exception is Tari land system. Although only 68% of this land system is used, its high population density warrants its inclusion in this group.

(e) *High Use of Land System*

This group includes all land systems with high population densities and use of the whole area.

VI. Present Land Use and Land Use Capability

In comparing the present land use and land use capability (Part X) of each land system it is found that land systems of groups (a), (b), and (c) (i.e. unused to moderately used land systems) fall into the very low to low land use capability classes, with four exceptions. These are:

Tage land system, which is of moderate land use capability but has no land use due to the lack of nearby population.

Laiagam and Nemarep land systems although of moderate land use capability are in the low-to-moderate use groups. This is due to the presence of large high-altitude areas which are unsuitable for gardening.

Tibinini land system, which is of high to moderately high land use capability but has low use. This is because sections of the land system are in higher altitudes and the remainder is distant from populated areas.

Land systems of groups (*d*) and (*e*) (i.e. moderate to high use of land system) fall into the moderate to high land use capability classes with no exceptions.

Two land systems are omitted from this classification. Kutubu land system is excluded because it supports a sago-gathering population and hence is wholly outside the classification used. Winjaka land system is excluded because it is only a minor occurrence of a land system found in the Goroka–Mt. Hagen survey area (Haantjens, Reiner, and Robbins, unpublished data).

Generally those land systems of higher land use capability are those most intensively used, and those with lower capability are less intensively used. There are no land systems with low to very low land use capability accompanied by moderate or high present land use. Some land systems of moderate to high land use capability (Tibinini, Tage, Nemarep) are little used at present.

VII. References

BROOKFIELD, H. C., and BROWN, PAULA (1963).—"The Struggle for Land." pp. 162–3. (Oxford Univ. Press.)

MEGGITT, M. J. (1956).—The valleys of the Upper Wage and Lai Rivers, Western Highlands, New Guinea. *Oceania* **27**: 90–135.

MEGGITT, M. J. (1957).—The Ipili of the Porgera valley, Western Highlands District, Territory of New Guinea. *Oceania* **28**: 31–55.

MEGGITT, M. J. (1958).—The Enga of the New Guinea Highlands: some preliminary observations. *Oceania* **28**: 253–329.

PART X. LAND USE CAPABILITY OF THE WABAG–TARI AREA

By G. K. Rutherford* and R. A. Perry†

I. Introduction

Owing to the reconnaissance nature of the survey and the lack of agricultural experience in the area, the potential land use can only be considered broadly.

In Part IX the present land use has been described. It is almost entirely a monoculture of sweet potatoes. Cultivation consists of shallow digging and mounding and the operations can be performed on steep slopes, among stones and outcrop, and in small isolated patches that need only be accessible by foot. Although present agriculture supports only a subsistence economy and high yields are not important, in most areas relatively long fallow periods are necessary to maintain productivity. The only domestic animals are pigs and so grazing is unimportant. There is virtually no forest exploitation.

II. Factors Limiting More Intensive Land Use

Apart from watershed management, the possible forms of land use are cropping (including tree crops), grazing, and forestry. The broad suitability of a particular piece of land for any of these forms of land use can be assessed by considering the limitations of the site for the operations necessary for production.

(a) *Slope*

In contrast to the present subsistence agriculture, any form of land use requiring the operation of machinery must be limited to fairly gentle, stone-free slopes in relatively large areas which are easily accessible for implements. Steepness of slope is also important from the viewpoint of erosion hazard; although in the Wabag–Tari area the even distribution of the rainfall and the high infiltration capacity and structural stability of the soils would appear to allow permanent cultivation on considerably steeper slopes than would be considered prudent in most parts of the world.

Perennial tree cropping, forest exploitation, and grazing are possible on steeper slopes than annual row cropping, but access and erodability are still factors to be considered. The establishment and maintenance of improved pastures and certain tree crops in a weed-free condition may, however, require the operation of machinery, and this would be difficult on steep slopes.

(b) *Climate*

Because of the high, evenly distributed rainfall, relatively low temperatures, and high cloud cover, the climate has been likened to the moist maritime climates

* Formerly Division of Land Research and Regional Survey, CSIRO, Canberra, A.C.T. Present address: Department of Geography, Queen's University, Kingston, Ontario, Canada.

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

of higher latitudes (Part IV). However, because of the proximity of the area to the Equator there is little variation in day length, with the result that some higher-latitude crops might not be grown successfully.

Rainfall is such that it is unlikely that plants would at any time be subjected to moisture stress, but the lack of dry sunny periods would seriously limit maturing and harvesting of many commercial crops. The constantly wet conditions adversely affect the fleece of sheep, but are suitable for cattle.

Frosts occur with increasing frequency and severity from about 5000 ft above sea level upwards, and are a regular feature above about 9000 ft and in valleys (frost pockets) a thousand feet or so lower. For most annual crops, any practice that allows for maturation during the period of greatest frost risk would also necessitate the completion of seed-bed preparation and cultivation during the rainiest part of the year. The general low temperatures and frost hazard at high altitudes, in combination with the small variation in day length throughout the year, are likely to limit cropping to areas below 9000 ft above sea level.

An indirect effect of climate is that the rapid growth of native plants would present problems of weed control in crops and improved pastures.

(*c*) *Drainage*

In many sites, particularly on the gentler slopes and plains most suitable for mechanical agriculture, poor drainage would be a severe limitation to crop production. Many such areas have waterlogged soils or a high water-table, or are subject to flooding.

(*d*) *Soils*

Most of the soils of the area are infertile and would require the application of fertilizers for crop or improved pasture production. Some soils are shallow and some are very slowly permeable.

(*e*) *Other Factors*

Social factors, communications, and markets all affect the development of more intensive land use but are outside the scope of this report.

III. System of Assessment of Land Capability

The land use capability of all units of the land systems has been assessed (Part III) in terms of eight land classes adapted (Haantjens 1963) from the standard land classification system of the United States Soil Conservation Service (United States Department of Agriculture 1954).

The land classes, denoted by Roman numerals, indicate the level of suitability of land for crop production. Land classes I–IV are all suitable for cultivation but in decreasing order, class IV being marginal for this form of land use. Land classes V–VIII are not suitable for cultivation but V–VII are suited to grazing and forestry. The level of suitability is determined by the nature and intensity of the limiting factors, of which soil fertility is only a relatively minor one. These land classes should therefore not be considered as productivity or fertility classes in a narrow sense.

Land is placed in a particular class where it is reasonable to assume that individual cultivators or groups of cultivators might be able to modify factors that at present limit a particular form of land use, given adequate guidance. This should be kept in mind particularly where poor drainage or flooding is the limiting factor. Large-scale projects would be necessary in some areas which cannot be properly drained or safeguarded against floods by the individual cultivators and which therefore rank low in the classification.

Except for class I, the land classes are subdivided into subclasses, denoted by letter symbols indicating the nature of the limiting factors that affect the suitability of the land for various agricultural purposes.

The letter symbols used are:

e, erodability	s2, shallow soils
st, stoniness	s3, slowly permeable soils
d, poor drainage	f, flooding
s1, low chemical fertility	a, altitude

When the land use potential is limited by two or more factors the most important is given first, but the capability class is determined by the combined effect of all factors listed. Thus land with such a degree of erodability as to make it unsuitable for cultivation would not be ranked still lower because of a limited degree of stoniness.

The land capability classes and subclasses are described in Appendix I.

IV. Regional Potential Land Use

The assessment of the potential land use, based on the system outlined above and applied to the land systems and units in Part III, expresses the limit of generalization in land classification to be expected from this type of broad survey.

To present a simple picture of the potential land use within the survey area, the land systems have been grouped into a number of broad land use groups (Table 15).

(*a*) *Land with High or Moderately High Potential Land Use*

(i) *Plains.*—These have a large proportion of very good land, although they are generally broken by numerous stream-beds of varying width and depth. This land is suitable for many types of agricultural production. The Wabag land system is one of the most densely populated in the survey area and is one of the most promising areas for more intensive development.

(*b*) *Land with Moderate Use Capabilities*

(i) *Plains.*—Although topographically eminently suited for agriculture, the potential for arable crops is limited by poor drainage and flood risk. The poor drainage is due mainly to impermeability and high water-table and cannot be easily improved, so that choice of crops would be limited. Considerable areas are suited to improved pastures.

(ii) *Hills and Long Gentle Slopes*.—Much of the land in these land systems consists of hill and valley side slopes which would be suited to tree crops and pasture. Much of the country is at present gardened, with only minor forest stands. There are considerable areas of gentle slopes which could support arable crops.

(*c*) *Land with Low Use Capabilities*

(i) *Hills*.—Nembi, Diguma, and Suma land systems consist of karst topography commonly with dolines and sink-holes, and the general ruggedness makes them unattractive for tree crops. Extensive stands of forest are present but access is usually

TABLE 15

LAND USE CAPABILITY GROUPS AND THEIR CONSTITUENT LAND SYSTEMS

Land Use Groups		Land Systems	Principal Land Classes
Agricultural Potential	Terrain		
High to moderately high	Plains	Tibinini, Poroma, Tambul, Wabag	I–III or complex of I and IV
Moderate	Plains	Kagua, Tari, Ko, Kaugel	IV–V or complex of I–III and VI–VII
	Hills and long gentle slopes	Wongum, Laiagam, Tage, Kwandi, Nemarep	
Low	Hills	Nembi, Digumu, Suma, Andabare, Hariu, Silim, Dibibi, Birap, Winjaka	V–VII or complex of IV with VI–VIII, or of VII–VIII with smaller areas of II and III
	Mountains and plateaux	Nop, Ambum, Yalis, Nose, Sugarloaf, Lava	
Very low to nil	Plains	Kandep, Kutubu	VII–VIII
	Mountains and cliffs	Kaijende, Duma, Pinnacle, Tou, Tsang, Giluwe, Ialibu, Doma, Lai	

difficult. Andabare and Dibibi land systems consist of hill slopes in lower montane grasslands. High altitude and infertile soils make this land suitable only for extensive grazing. Tree crops would be liable to frost and hail damage over much of the area. The potential use of Silim, Birap, and Winjaka land systems is limited by steep slopes.

(ii) *Mountains*.—The land systems in this group consist of densely and strongly dissected mountain and mountain summit areas. The slopes are too steep for cultivation and the general ruggedness makes them rather unattractive for tree crops, although these could possibly be introduced on a small scale. The most natural use appears to be forest exploitation. However, difficulty of access is a limiting factor. The cold wet climate and the relatively shallow, infertile, and wet soils render Sugarloaf and Lava land systems almost useless for agricultural settlement. Frequent frosts are a hazard for tree crops.

(*d*) *Land with Very Low or No Use Capabilities*

(i) *Plains*.—The possibilities of reclaiming the swamp lands are remote and the peat soils are very infertile. Parts of the Kandep land system could be used for timber extraction and parts of the Kutubu land system for sago palm exploitation.

(ii) *Mountains*.—This land is generally so rugged as to be virtually useless for agricultural development. Forest exploitation may be possible in some foothill areas, notably in Doma and Ialibu land systems. The maintenance of a protective forest cover is important as this group constitutes major catchments in the area.

V. References

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

United States Department of Agriculture (1954).—A manual on conservation of soil and water. U.S.D.A. Agric. Handb. No. 61.

APPENDIX I

DESCRIPTION OF LAND CAPABILITY CLASSES AND SUBCLASSES

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 is not subject to damaging floods. It is suited to most types of land use.

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 other forms of land use, but tree crops require special measures where drainage is imperfect.

Subclass IIe.—Simple measures to control the degree of erodability are required when the land is cultivated. These may be contour planting, strip cropping, short rotations with legumes or cover crops, mulching, simple terracing, etc.

Subclass IIs3.—This land has imperfectly drained soils due to slow permeability in relation to rainfall rather than to a high water-table. It is suitable for arable crops and pastures, but less so for tree crops. Deep drainage trenches could prove beneficial.

Subclass IId.—This land has imperfectly drained soils due to insufficient surface drainage or a high water-table. Drainage improvement can be effected by simple means and would make the land suitable for most types of agricultural production.

Subclass IIe.s1.—This land has slight erosion hazards (see IIe) as well as soils with very low chemical fertility. Although it can be used for many types of agricultural production, it appears to be most suitable for tree crops.

Subclass IIe.s3.—This land combines the limitations of subclasses IIe and IIs3. Although usable for a variety of types of agricultural production, it is probably most suited to pastures and least suited to tree crops.

Class III land is moderately good land requiring intensive special measures to improve and maintain its productivity when cultivated. It can generally be used without special limitations for other forms of land use, but when the land is imperfectly drained intensive measures are required for tree crops. Some areas are suitable for paddy rice growing.

Subclass IIIe.—The erosion hazards are such that intensive erosion-control measures are necessary when the land is cultivated. Crops under which land is liable to erode should not be grown; frequent rotations with grasses or legumes or terracing are necessary.

Subclass IIIs3.—This land has poorly drained soils due to slow permeability in relation to rainfall. Although some beneficial effect can be expected from deep drainage, this land is inherently most suitable for pastures, only moderately suitable for arable crops, and poor for tree crops.

Subclass IIId.—This land has poorly drained soils due to insufficient surface drainage and/or high water-tables. Intensive measures to improve the drainage are required that would make this land well suited for arable crops and pastures, but probably less so for tree crops.

Subclass IIIe.st.—This land requires simple or intensive erosion-control measures when cultivated. Stones interfere with operations but can be removed easily.

Subclass IIIe.s3.—This land requires intensive erosion-control measures for arable crops (see IIIe) and has also imperfectly drained, relatively impermeable soils (see IIs3). Although suitable for cultivation it is most suited for pastures.

Class IV land is fairly good land that is best maintained in perennial vegetation, but it can be cultivated occasionally or in a limited way if handled with great care.

Subclass IVs3.—This land is poorly drained because of very slow soil permeability that makes drainage very difficult. The choice of crops is therefore limited. It is unsuitable for tree crops, the best-adapted types of land use being pastures and forestry. These soils may be stony locally.

Subclass IVa.—This land has no other limitations than those imposed by its position above 9000 ft. In the absence of any experience of land use under the prevailing conditions, little can be said about the potential use of this land. Certainly it appears unsuitable for forestry or tree crops. The main potential would be for grazing, but a few arable crops may be introduced or developed.

Subclass IVe.s3.—This land has poorly drained impermeable soils (see IVs3) as well as slight to moderate erosion hazards (see II-IIIe). With careful drainage measures it may carry a limited range of arable crops, but it is most suited for pastures and forestry. It is poor land for tree crops.

Subclass IVs3.a.—This is land above 9000 ft (see IVa) with imperfectly drained, relatively slowly permeable soils which require drainage improvement (see IIs3), particularly if used for arable crops.

Subclass IVe.a.—This is land above 9000 ft (see IVa) that would require erosion-control measures (see IIe and IIIe) if used for arable crops.

Subclass IVe.s3.a.—This is land above 9000 ft (see IVa), with imperfectly drained, relatively slowly permeable soils (see IIs3) and slight erosion hazards (see IIe), requiring special management if used for arable crops.

Subclass IVd.a.—This is land above 9000 ft (see IVa) with imperfectly to poorly drained soils (see II-IIId). Improvement of surface drainage can be made quite simply, and is required for productive use of this land for grazing and particularly for arable crops.

Subclass IVd.f.—This is imperfectly or poorly drained land (see II-IIId) with moderate flood risks that tend to make drainage improvement more difficult. It is suitable for pastures and forestry, but the choice of arable crops is limited and their cultivation is subject to flood risks.

Subclass IVs3.f.—This is land with poorly drained, very slowly permeable soils; it is also subject to moderate flood risks. The land is most suited for grazing, whilst the choice of arable crops is severely limited and crop production is subject to slight flood risks.

Class V land is nearly level, not subject to erosion, and has productive soils, but other factors render it unsuitable for cultivation. It is productive grazing or forestry land, and may be suitable for tree crops.

Subclass Vd.—This land is too poorly drained for arable and tree crops and the drainage cannot feasibly be improved because of low topographic position, strong seepage, or regular flooding in the wet season. This land is suitable only for pastures.

Subclass Vst.—This is level land with so many stones on the surface that normal cultivation is impossible. It is suitable for pastures and forestry and could be used for tree crops.

Class VI land is subject to moderate limitations for pastures or forestry. Some subclasses are also moderately suitable for tree crops.

Subclass VIe.—The seriousness of the erosion hazard on this land requires controlled grazing if the land is used for pastures and simple erosion-control measures if it is used for tree crops. This land is suitable for forestry.

Subclass VId.—This is poorly drained land that can only be used for rather extensive grazing or forestry. It is difficult to reclaim, but would in many cases yield productive land for arable crops and pastures.

Subclass VIe.st.—This is land with serious erosion hazards (see VIe). Many stones on the surface (see Vst) tend to make the management of tree crops more difficult. Thus, this land is primarily suited for grazing and forestry.

Subclass VIe.s1.—This is land with serious erosion hazards (see VIe) and soils of very low chemical fertility (see IIs1). It is probably most suitable for tree crops and forestry, and to a lesser degree for grazing.

Subclass VIe.s2.—This is steep land with serious erosion hazards and very shallow soils. It has a moderate potential for grazing or forestry but appears to be unsuitable for tree crops.

Subclass VIe.s3.—This is land with serious erosion hazards (see VIe) and imperfectly to poorly drained, relatively slowly permeable soils (see II-IVs3). It is moderately suitable for grazing and forestry, but little suited or unsuited for tree crops.

Subclass VId.f.—This is poorly drained land (see II-IIId) with serious flood hazards. Thus potential land use is virtually restricted to grazing or forestry.

Subclass VIe.a.—This is land above 9000 ft (see IVa) with serious erosion hazards (see VIe). It could only be used for grazing.

Subclass VIs3.a.—This is land above 9000 ft (see IVa) with poorly drained, very slowly permeable soils (see IVs3). It could only be used for grazing, and improvement of the drainage would be very difficult.

Subclass VIe.s3.a.—This is land above 9000 ft (IVa) with moderate to strong erosion hazards (see IIIe and VIe), and also poorly drained slowly permeable soils (see IIIa–IVa). It could only be used for grazing.

Subclass VId.a.—This is land above 9000 ft (see IVa) with very poorly drained soils (see Vd). It could only be used for grazing.

Class VII land is subject to severe limitations for pastures or forestry. Some areas could be used for tree crops.

Subclass VIIe.—The limitations of this subclass are similar in nature but more severe than those of subclass VIe. It is very difficult land to manage, even for forestry.

Subclass VIId.—This is very poorly drained land which is virtually unusable, or only suitable for periodical, extensive grazing. It could be reclaimed with difficulty, in which case it would yield productive land mainly suitable for arable crops and pasture.

Subclass VIIe.st.—This is very steep land with very serious erosion hazards (see VIIe) and it is also very stony (see Vst). Its very low potential appears to be virtually restricted to forestry and extensive grazing.

Subclass VIIe.s1.—This land has very severe erosion hazards for pastures and tree crops, and infertile leached soils (see IIs1). It is probably best suited for forestry, but even in this case it is difficult land to manage.

Subclass VIIe.s2.—This is very steep land with very serious erosion hazards (see VIIe) and very shallow soils. Its very low potential appears to be restricted to forestry or extensive grazing.

Subclass VIIe.s3.—This is very steep land with very serious erosion hazards (see VIIe) and imperfectly to poorly drained, slowly permeable soils (see IIs3–IVs3). Its very low potential appears to be restricted to extensive grazing and forestry.

Subclass VIId.f.—This is very poorly drained land (see Vd) subject to serious flooding. Its very low potential is restricted to periodical grazing or forestry. Its land is virtually unreclaimable.

Subclass VIIe.a.—This is land occurring above 9000 ft (see IVa) with very serious erosion hazards. Its very low potential would be restricted to extensive grazing. In some areas it is very stony.

Subclass VIId.a.—This is land occurring above 9000 ft (see IVa) in very poorly drained flat areas and depressions (see VId). Whilst some improvement of the surface drainage appears possible, this land would at best be usable for extensive grazing only.

Class VIII land is of such unfavourable character as to be unsuited to cultivation, tree crops, grazing, and forestry. In many cases it is important for watershed protection. Much of it is covered by tall forest, but its exploitation would be very difficult. Class VIII land has not been subdivided into subclasses, as these are merely of academic interest.

INDEX TO LAND SYSTEMS, SOIL FAMILIES, VEGETATION COMMUNITIES, AND FOREST TYPES

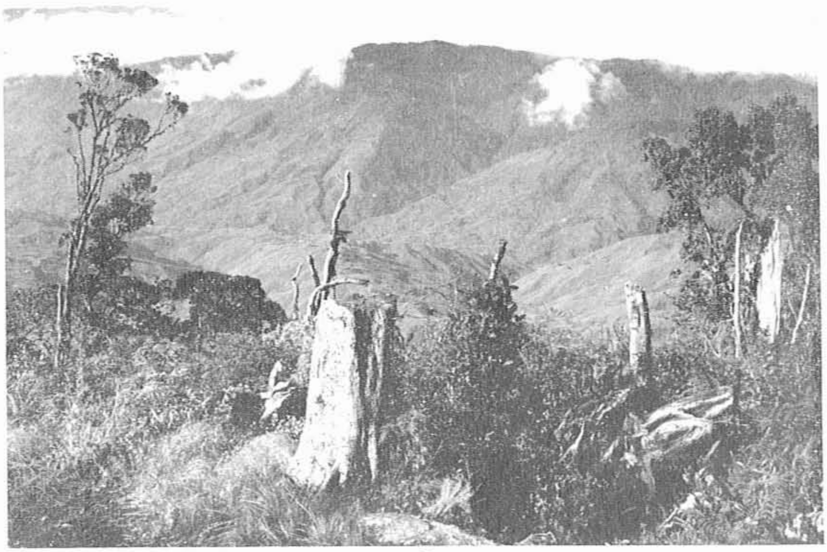


Fig. 1.—The area is part of the central highland belt of New Guinea. It is mostly between 5000 and 10,000 ft above sea level and is characterized by rugged mountainous topography. The lands have been mapped and described in 39 land systems, mainly differentiated by rock type and topography.

Fig. 2.—Mountainous topography on limestones (Kaijende and Duma land systems), characterized by very steep slopes, occur mostly in the south-western half of the area.

Fig. 1.—Karst lands, with little organized surface drainage, are extensive on the south-western half of the area. They consist mostly of fields of enclosed depressions varying from 50 yd to more than a mile in diameter, and from 50 to 500 ft deep. Smaller areas of tower and pinnacle karst also occur.

Fig. 2.—Most of the north-eastern half of the area consists of mountains on mainly non-calcareous, unresistant sedimentary rocks. They are characterized by north-west–south-east trending strike ranges with steep slopes.

Fig. 1.—Smaller areas developed on mainly non-calcareous, unresistant sedimentary rocks have less relief and consist of hills and benchlands.

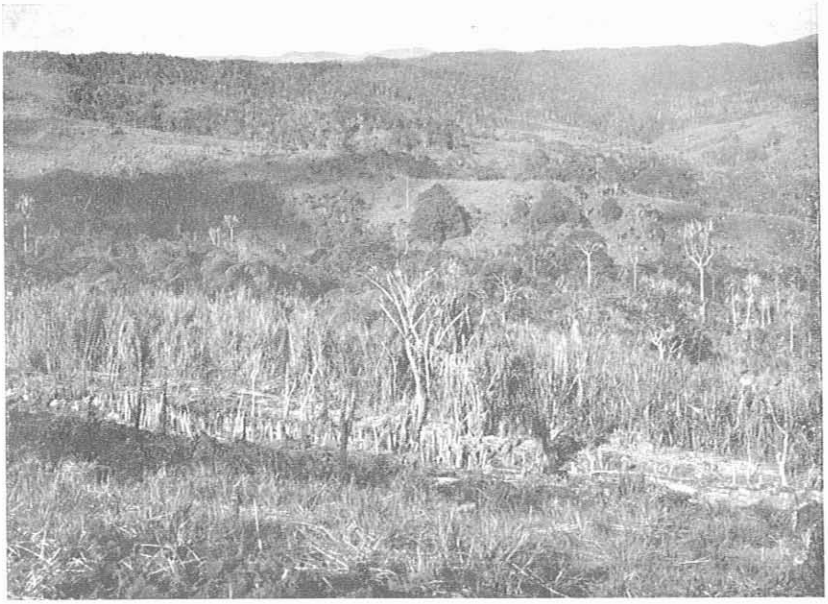


Fig. 2.—In the north-east there are several areas developed on basic intrusive rocks. Silim land system (illustrated) consists of rounded hills and ridges, and Nose land system consists of closely and strongly dissected mountains.

Fig. 1.—Rugged mountains on volcanic materials comprise the upper zone of the large volcanoes (Mt. Giluwe, Mt. Ialibu, Mt. Hagen, and Doma Peaks). Local relief is up to 2000 ft in Giluwe (illustrated) and 1500 ft in Ialibu land systems, but is less in Doma land system.

Fig. 2.—The Sugarloaf area and small areas on Mt. Giluwe and Doma Peaks comprise plateaux and upland basins on volcanic materials. Because of high altitude and cold-air drainage much of this country carries alpine or lower montane grassland.

Fig. 1.—The long gentle piedmont slopes of the volcanoes are formed of lava flows, scoria, and laharic and ash accumulations and comprise Nemarep land system. The summit of Mt. Giluwe (illustrated) is 13,660 ft above sea level. The piedmont slopes are 4 to 6 miles long and fall from about 10,000 ft to the plain in the foreground at about 7000 ft above sea level.

Fig. 2.—The outermost zone of the large volcanoes consists of gently undulating to strongly rolling ash plains, in part poorly drained, and forms Tari land system.

Fig. 1.—Gorges up to 1000 ft deep, cut mainly in volcanic ash and agglomerate, comprise Lai land system.

Fig. 2.—In the Pleistocene period disruption of drainage by volcanic activity resulted in the formation of alluvial valley fills and colluvial aprons which have since been variously dissected. Wabag land system (illustrated) consists of terraced valley fills and associated fans, deeply dissected by a moderately dense pattern of narrow streams.

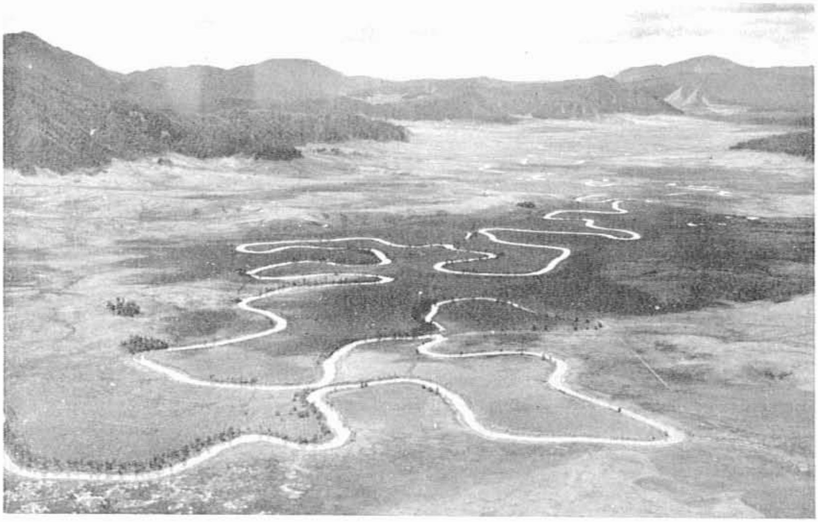


Fig. 1.—Lake and river plains contain the youngest alluvial deposits. Kandep land system consists of medium-altitude swampy plains and stream flats, in part peat-covered, traversed by meandering channels. In the illustration it is flanked by mountains, the grassy lower slopes of which comprise Andabare land system and the forested steeper slopes Kaijende and Suma land systems.

Fig. 2.—Timber is an important resource, particularly in the lower montane forests, but lack of a suitable outlet restricts present utilization to local requirements.

Fig. 1.—Sweet potato, the basic crop of the region, is cultivated in mounds of earth containing compost. In the illustration three Wabag men stand beside one mound. Note the *Casuarina–Cordyline* boundary of the garden.

Fig. 2.—Every garden has groups of mounds at different stages of maturity. At the right centre new mounds are being prepared and those in the right foreground have been composted. In the centre, mounds a month old can be seen and in the centre background are mounds two months old. Sugar-cane, corn, and planted *Casuarina* are also present.