Land-form Types and Vegetation of Eastern Papua

Comprising papers by D. H. Blake, K. Paijmans, J. R. McAlpine, and J. C. Saunders

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PART I. INTRODUCTION

By D. H. BLAKE*

I. GENERAL

This report gives an account of the climate, geology, geomorphology, vegetation, and forestry of mainland eastern Papua, and also includes some information on soils, drainage, and land use potential. The area involved is a mountainous tract of land, mostly bounded by sea, that is 650 km long and up to 190 km wide, extending from lat. 8°S. to 10°43′S. and from long. 145°48′E. to 150°58′E. It covers 60,900 km², made up of 23,300 km² surveyed in 1969, five previously surveyed parts totalling 27,200 km², and 10,400 km² mapped almost entirely from air photographs (Fig. 1).

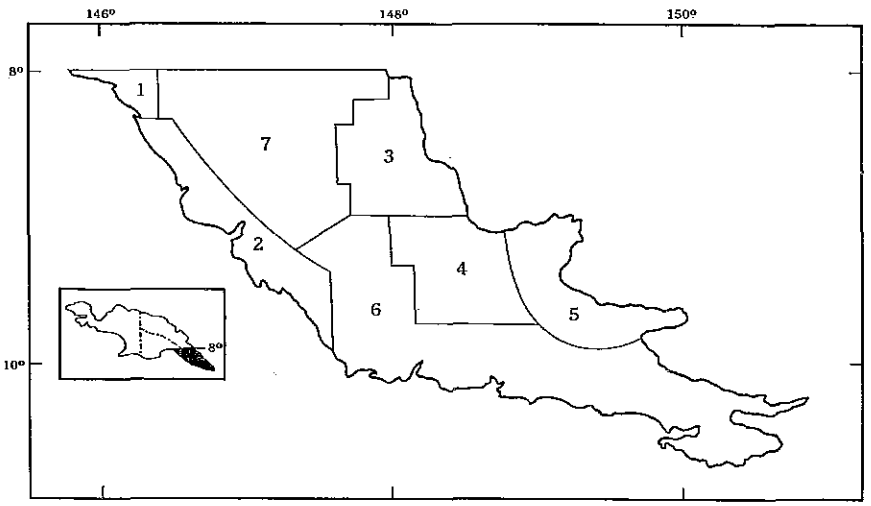

Fig. 1.—Eastern Papua survey area showing 1, Kerema–Vailala area (part); 2, Port Moresby–Kairuku area; 3, Buna–Kokoda area; 4, Safia–Pongani area; 5, Wanigela–Cape Vogel area; 6, area surveyed in 1969; 7, area mapped from air photographs.

The five previously surveyed parts are the Buna–Kokoda area surveyed in 1953 (Haantjens *et al.* 1964*b*), the Wanigela–Cape Vogel area surveyed in 1954 (Haantjens *et al.* 1964*a*), the Port Moresby–Kairuku area surveyed in 1962 (Mabbutt *et al.* 1965), the Safia–Pongani area surveyed in 1963 (Ruxton *et al.* 1967), and part of the Kerema–Vailala area surveyed in 1966 (Ruxton *et al.* 1969).

II. PHYSIOGRAPHY

Eastern Papua lies within the heavy precipitation belt of the humid tropics, and most of the area mapped has an average annual rainfall of over 2540 mm. However, lower-rainfall areas occur along the west and south coasts, in the Musa

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basin, and along the north-east coast near Cape Vogel. The rainfall generally has a seasonal distribution, which is most marked in the lower-rainfall areas.

The dominant topographic feature is the Owen Stanley Range, which runs the length of mainland eastern Papua. The range forms the main watershed between rivers flowing west and south to the Coral Sea and those flowing east and north to the Solomon Sea. Several peaks along the range rise to over 3000 m and the highest peak, Mt. Victoria, is 4035 m above sea level. Other generally lower mountain ranges occur on either side of the Owen Stanley Range. Two groups of large volcanoes are present on the north side of the main divide between long. 148°E. and 149°30'E.; two of the volcanoes, Mt. Lamington and Mt. Victory, have been active within the last hundred years. Ranges of hills occur along the south-west coast, on the Cape Vogel peninsula, and near Cape Ward Hunt and are interspersed with low-lying plains associated with the main rivers. The largest catchment is that of the Musa River. The most extensive plains are those of the Lakekamu, Biaru, Angabunga, Dilava, Vanapa, Brown, and Laloki Rivers, which flow into the Coral Sea, and of the Mambare, Kumusi, and Musa Rivers, which flow to the Solomon Sea.

The natural vegetation over most of eastern Papua is tropical rain forest. This forest becomes lower and poorer in species with increasing altitude. Savannah and grassland occur in areas with a strongly seasonal climate. Extensive areas of swamp vegetation are present on the low-lying plains. In many places, especially in the most densely populated areas and also on high mountain tops, the natural vegetation has been destroyed and replaced by forest regrowth and grassland.

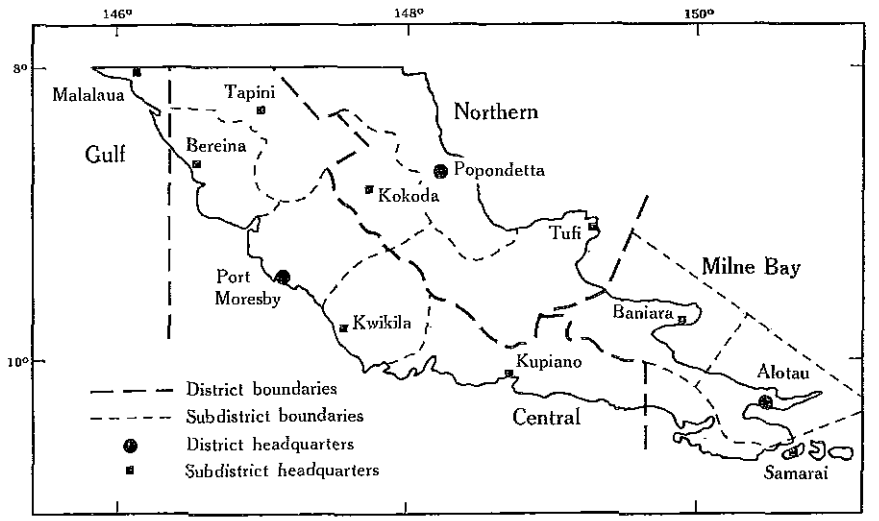

Fig. 2.—Administrative divisions.

III. Administration and Population

The districts, subdistricts, and administrative centres in the area covered are listed in Table 1, and their locations are shown in Figure 2.

The population is mainly concentrated along the coast and is densest near Port Moresby, between Cape Cupola and Yule Island, and in the vicinity of Popondetta and Milne Bay. Large parts of the interior, especially in the high mountain

ranges, are virtually uninhabited. Population figures by district and subdistrict are given in Table 1. The main town in the area is Port Moresby, the administrative centre of Papua New Guinea. Its population at 30 June 1966 was 41,848, of which 9865 were non-indigenes. The only other town with over 1000 inhabitants is Popondetta, which had a population of 2193, including 295 non-indigenes, in the 1966 census. The total population in the area is about 257,000 and the average population density is 4·2 persons per km².

TABLE 1

DISTRICTS, SUBDISTRICTS, INDIGENOUS POPULATION, AND ADMINISTRATIVE CENTRES AT 30 JUNE 1969

District	Subdistrict	Indigenous population	Administrative centre
Central			Port Moresby
	Abau	22,259	Kupiano
	Goilala	25,871	Tapini
	Kairuku	20,092	Bereina
	Port Moresby	19,777*	Port Moresby
	Rigo	27,060	Kwikila
	Total	115,059*	
Milne Bay			Alotau
	Baniara	18,083	Rabaraba
	Milne Bay	13,347	Alotau
	Part of Samarai	12,040†	Samarai
	Total	43,470†	
Northern			Popondetta
	Kokoda	6,701	Kokoda
	Popondetta	41,675	Popondetta
	Tufi	8,558	Tufi
	Total	56,934	
Gulf	Part of Kukipi	26,767†	Malalaua

* Excludes population of Port Moresby township.

† Includes population of part of subdistrict not in survey area.

IV. COMMUNICATIONS

Most of mainland eastern Papua is relatively readily accessible compared with other parts of Papua. There are over 1700 km of vehicular roads, most of which are all-weather roads, and over 40 aerodromes, many of which have regular scheduled air services. Most of the villages and plantations along the coast are served by small ships. Port Moresby and Popondetta are the main foci for both the road and air networks, and Port Moresby is both the main airport and the main seaport in the Territory.

V. SURVEY PROCEDURE

The objectives of the eastern Papua survey were: (1) to carry out a broad reconnaissance survey in 1969 of the part of mainland eastern Papua south of latitude 9°S. that had not been previously covered by land resource surveys; (2) to make an air-photo interpretation of the unsurveyed area between latitudes 8°S. and 9°S.; (3) to correlate these two areas with the previously surveyed parts of eastern

Papua; and (4) to produce an integrated report on the land resources of mainland eastern Papua.

The 1969 survey was carried out by a team consisting of D. H. Blake, geologist–geomorphologist and party leader; K. Paijmans, plant ecologist; J. C. Saunders, forest botanist; and R. M. Scott, pedologist. Prior to commencing field work, Blake and Paijmans completed an initial air-photo interpretation of the area. Field work was undertaken in June and July 1969, and 345 sample sites were investigated. A helicopter was used to transport the team between sites. During the field work the team was assisted by V. G. Dawson and P. Healy, transport officers, and 12 assistants from Madang under Gabi-Momo. On returning to Canberra, Blake and Paijmans carried out further air-photo interpretation in the light of the field work results, remapped the five previously surveyed areas, and photo-interpreted the unsurveyed part of eastern Papua. Because of, firstly, problems in correlating the previously surveyed parts with each other and with the newly surveyed parts and, secondly, the broad reconnaissance nature of the overall survey, the final mapping was accomplished using land-form types as the basic mapping unit instead of land systems which have been used before in mapping land resources in Papua New Guinea (see Part II). The land-form types were mapped by the geomorphologist and the vegetation was mapped separately but concurrently by the plant ecologist. Mutual problems that cropped up during the mapping were discussed together. The separate mapping of land-form types and vegetation enabled the air-photo interpretation to proceed more quickly than land system mapping normally does.

VI. Air Photos and Maps

Mainland eastern Papua is covered by air photographs taken by Adastra Airways Pty. Ltd. and QASCO between 1953 and 1969. These are mostly at scales of about 1 : 50,000 at sea level.

The base map used for this report was prepared at a scale of 1 : 500,000 by the Division of National Mapping, Department of National Development, Canberra.

VII. Acknowledgments

The photographs in Plates 1 to 19 are Crown Copyright and have been made available by courtesy of the Director of National Mapping, Department of National Development, Canberra.

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PART II. LAND-FORM TYPES OF EASTERN PAPUA AND THEIR ASSOCIATED CHARACTERISTICS

By D. H. BLAKE* and K. PAIJMANS†

I. INTRODUCTION

A land-form type is a mapping unit that is described in terms of land forms and rock types. For the eastern Papua survey land-form types are based firstly on land forms and relief classes that can be observed and interpreted on air photos at scales of 1 : 30,000 to 1 : 50,000, and secondly on available geological information. The mapping of the land-form types was therefore carried out by the geomorphologist, supplemented on plains by the mapping of the plant ecologist, who distinguished the different types of swampy, poorly drained, and well-drained terrain. Land-form types differ from land systems, which have been used in previous reports on land resource surveys by the Division of Land Research, in that a land system is defined as a recurring pattern of land forms, soils, and vegetation (Christian and Stewart 1953, 1968). As used in eastern Papua, land-form types are broader and more general mapping units than the previously mapped land systems and are considered by the authors to be more suitable for a rapid and broad reconnaissance survey of a large and complex area, such as eastern Papua, for which there is an overall scarcity of field data.

Eastern Papua has been mapped into 58 land-form types. The five previously surveyed parts of the area (Fig. 1) have been remapped and correlated with each other, with the part surveyed in 1969, and with the part mapped almost entirely from air-photo interpretation. It is pertinent to note that the remapping would have been necessary even if land systems had been used instead of land-form types. This is because the five previously surveyed areas were mapped by different survey teams in varying amounts of detail using different criteria. A total of 150 different land systems were distinguished in these five parts which together make up less than half of mainland eastern Papua, indicating that well over 200 such land systems would have been needed for the whole area covered. Such detailed mapping would not be justified because of the broad reconnaissance nature of the overall project.

As the land-form type mapping has been accomplished using different criteria again from those used previously, many land systems have been remapped into two or more land-form types. This is shown in Table 2, in which correlations between the land-form types mapped by the authors and the land systems mapped in the previously surveyed parts are given.

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TABLE 2

CORRELATIONS BETWEEN LAND SYSTEMS OF PREVIOUSLY SURVEYED PARTS OF EASTERN PAPUA AND LAND-FORM TYPES OF THIS REPORT

Land-form type symbol	Land systems				
	Buna–Kokoda area	Wanigela–Cape Vogel area	Safia–Pongani area	Port Moresby–Kairuku area	Kerema–Vailala area
LS	Killerton	Killerton	Bendorodo	Galley Reach, Lesewalai, Kido, Papa, Nipa	Alele, Nipa
LW	Buna	Buna	Pawara	Hisiu	Araimiri
AS	Ambasi, Ambi, Koena	Tortore	Tortore	Waigani, Engepa, Akaifu, Doura*	Murva, Ebala, Waigani, Movori, Karama, Melaleuca, Terapo*
APf	Hanau,* Sanananda, Deunia,* Warisota,* Sagere*	Monari,* Uiaku,* Dove	Imo, Dove, Ubo*	Inaukina,* Beipa,* Piunga,* Vanapa,* Biaru, Doura*	Malalaua,* Vailala,* Terapo,* Tauri, Hepea*
APr	—	Monari*	—	Boroko	—
AWs	Deunia,* Warisota,* Sagere*	Uiaku,* Ismari, Wakioka	Momoiogo, Gobera, Aiare, Nembadi, Safia,* Ubo,* Korala*	Inaukina,* Keviona, Pinu, Bebeo, Beipa,* Epo, Babiko, Vekabu, Piunga,* Vanapa*	Malalaua,* Vailala,* Hepea*
AWv	Popondetta,* Hanau,* Sagere*	Wanigela*	—	—	—
AWd	Amboga	Kopwei	—	—	—
AWu	—	—	—	—	—
FSa	—	—	—	—	—
FSn	Ilimo	—	Safia,* Liamu, Ubo*	—	—
FSu	—	—	Korala,* Boborobo,* Asaga*	Ward, Ouou	—
FSt	—	Tokinawara	—	—	—
VAv	Lamington	Victory	Manna	—	—
VBm	—	—	Uoive	—	—
VPd	Hamamutu, Higatura*	Kwin*	—	—	—
VPn	Higatura,* Awala, Bohu, Eundi, Popondetta,* Penderetta	Kwin,* Wanigela*	Iwuji	—	—

DSf	Komondo,* Kokoda*	Budi	Ibinambo,* Silimidi, Siviai,* Wowo, Bariji, Sibium	—	—
DSw	Kokoda*	Rakua, Uiaku*	Ibinambo,* Siviai,* Darumu	—	—
DSi	—	—	Asaga*	—	—
DSh	Komondo*	—	Kovio	—	—
EAv	Hydrographers	Trafalgar	Hydrographers, Sesaro	—	—
EAe	—	—	—	Rouna,* Uberi	—
EAf	—	Trafalgar*	Tahama, Gorabuna	Kanosia,* Mariboi, Rubberlands	—
EAw	—	Bekalama	Banderi	—	—
PBn	Iauga*	—	—	Sogeri, Subitana	—
PBy	Iauga*	—	—	Owers, Vouku	—
PMi	—	—	—	—	—
PMg	—	—	—	—	—
PMb	—	—	—	—	—
UHr	Ioma	—	—	—	—
USu	—	—	—	Nikura,* Tsiria, Kanosia,* Inaukina,* Piunga*	Olipai
UK	—	Tarakaruru	—	—	—
XHs	—	—	—	—	Hauta, Maipora
XHv	Mt. Green	—	—	Edebu*	—
XBp	—	—	—	—	—
XBu	—	—	—	—	—
XXu	—	Bewabewa*	Boborobo*	Fairfax, Diumana, Bomana Creek, Nikura,* Diulu	—
YSi	—	—	Avikaro	—	—
YHp	—	—	—	—	—
YHb	—	Bewabewa,* Koianaki*	Arumbai*	Kopu, Palipala,* Aropokina	—
YKc	—	—	—	—	—
YKr	—	Tarakaruru*	—	Hanuabada, Palipala,* Pokama, Kabuka	—
YMp	—	Maneau*	—	—	—

TABLE 2 (*Continued*)

Land-form type symbol	Land systems				
	Buna–Kokoda area	Wanigela–Cape Vogel area	Safia–Pongani area	Port Moresby–Kairuku area	Kerema–Vailala area
YXd	—	—	Fiobobo*	Edebu, Iawarere*	—
ZSv	—	Tama	Adau, Arumbai*	—	—
ZH	—	—	—	—	Kurai
ZKr	—	—	—	Tovobada	—
ZKv	—	—	—	—	—
ZP	—	—	Owalama	—	—
ZBb	Oivi,* Hegahorte,* Iauga*	Sesegara	Suwari,* Fiobobo*	Rouna,* Iawarere*	—
ZBm	—	—	Aimare	—	—
ZXb	—	Bewabewa,* Koianaki*	Arumbai*	Dubuna	Nabo*
ZXi	—	—	—	—	—
MBv	Hegahorte*	—	Foasi, Amora	Iawarere*	—
MUv	Botue, Oivi*	Didana	Suwari,* Avuru, Guaya, Didana	—	—
MMv	Misima	Maneau*	Misima	—	—
MMe	—	Maneau*	Suckling complex	—	—

* Partial correlation.

The land-form type map that accompanies this report is at a scale of 1 : 500,000. On it are superimposed lines that represent the boundaries of six major climatic zones. These zones are based on amount and seasonality of rainfall and on mean annual temperatures. The rainfall data are available from meteorological stations and vegetation indications, and the mean annual temperatures are estimated from heights above sea level obtained from published topographical maps. The climatic zones enable the land-form type map to be subdivided geographically into areas of similar climates. Within each of these geographic divisions any one land-form type has a restricted range of land forms, rock types, climate, and hence also natural vegetation, soils, and potential land use. The land-form types can therefore be described, like land systems, in terms of land forms, geology, climate, vegetation, forest resources, soils, and potential land use.

II. Grouping of Land-form Types and Explanations of Symbols

The land-form types have been arranged into 12 main groups, four of which are made up predominantly of constructional land forms, while the other eight groups consist mainly of erosional land forms. The characteristic and distinguishing features of the individual land-form types within the 12 groups are given on the land-form type map.

The four groups of constructional land-form types are littoral plains, alluvial plains, undissected non-volcanic fans, and well-preserved volcanic land forms. Littoral plains consist of mangrove flats subject to daily, monthly, or seasonal tidal flooding, well to imperfectly drained beach ridge complexes, and two dune fields near Hood Bay on the south coast. Alluvial plains are arbitrarily defined, for the purpose of land-form type mapping, as plains having general slopes less than 1° and a local relief less than 10 m. Undissected non-volcanic fans have characteristic slopes of 1–5°. Well-preserved constructional volcanic land forms are confined to late Pleistocene and Recent volcanoes. They include both steep-sided summit areas and gently sloping flanking fans.

In the remaining eight groups of land-form types the dominant geomorphic processes are erosional. The first three of these groups are dissected non-volcanic fans, deeply eroded but still recognizable volcanic terrain, and dissected plateaux and summit surfaces. The remaining land-form types are placed in the following arbitrary groups: undulating terrain of very low relief (relief 10–30 m), low hilly terrain (relief 30–100 m), moderately high hilly terrain (relief up to 200 m), high hilly terrain (relief up to 400 m), and mountainous terrain (relief over 400 m). Each of the groups is subdivided on dominant rock type or types and on topographic characteristics such as drainage and crestal patterns, steepness of slopes, and presence or absence of spurs.

In the group of dissected non-volcanic fans the original fan surfaces are either preserved on interfluves or indicated by accordant to subaccordant summit levels.

Deeply eroded volcanic land forms have been distinguished where possible from other types of terrain. The original volcanic land forms were of Pliocene and Pleistocene age and have been extensively eroded, so that now only the gross features can be identified, being indicated by remnant surfaces, summit profiles, and drainage patterns.

Dissected plateaux and summit surfaces consist of hilly terrain of various classes and are distinguished from other hilly terrain by their location in watershed areas and by their higher altitude and generally lower relief relative to the surrounding terrain.

Each land-form type has been given a symbol consisting of either two or three letters. The first letter of each symbol indicates the main group in which the land-

TABLE 3

EXPLANATION OF LAND-FORM TYPE SYMBOLS

Symbol	Explanation
First letter	
	Constructional land-form types
L	Littoral plains (relief <10 m, characteristic slopes <1°)
A	Alluvial plains (relief <10 m, characteristic slopes <1°)
F	Undissected non-volcanic fans (characteristic slopes >1°)
V	Well-preserved constructional volcanic land forms
	Erosional land-form types
D	Dissected non-volcanic fans
E	Deeply eroded volcanic terrain
P	Dissected plateaux and summit surfaces (relief 15–400 m)
U	Undulating and hilly terrain of very low relief (10–30 m)
X	Hilly terrain of low relief (30–100 m)
Y	Hilly terrain of moderate relief (100–200 m)
Z	Hilly terrain of high relief (200–400 m)
M	Mountainous terrain (relief over 400 m)
Second letter	
	Littoral and alluvial plains
S	Swampy
P	Poorly drained
W	Well to imperfectly drained
	Remaining land-form types
S	Unconsolidated and poorly consolidated (soft) sediments
H	Consolidated (hard) non-calcareous sedimentary rocks
K	Calcareous rocks
B	Mafic (mainly basaltic) volcanic and plutonic rocks
A	Intermediate (mainly andesitic) and acid consolidated volcanic and plutonic rocks
P	Unconsolidated pyroclastic rocks
U	Ultramafic igneous rocks
M	Foliated metamorphic rocks
X	Mixed sedimentary, igneous, and/or metamorphic rocks
Third letter	
	Littoral and alluvial plains
d	Unstable, liable to destructive flooding during future volcanic eruptions
f	Frequently flooded
r	Rarely flooded
s	Stable, not associated with recently active volcanoes
u	Unstable, not associated with recently active volcanoes
v	Stable, associated with recently active volcanoes

TABLE 3 (*Continued*)

Symbol	Explanation
	Remaining land-form types
a	>1500 m above sea level
b	Branching ridges
c	Cuestas
d	Dissected slopes
e	Extremely steep (precipitous) slopes and cliffs (slopes >45°)
f	Finely dissected
g	Glaciated
h	High relief (200–400 m)
i	Irregular
m	Moderate slopes (5–20°)
n	Negligible to very low relief (<30 m)
p	Parallel ridges
r	Rounded ridges
s	Steep slopes (20–30°)
t	Terraced
u	Undulating
v	Very steep slopes (30–45°)
w	Broadly (widely) dissected
y	Moderate relief (100–200 m)

form type has been placed. The second letter indicates the dominant drainage conditions in the land-form types of the littoral and alluvial plains groups but otherwise represents the main rock types present within the land-form types. The third letter represents a characteristic feature which serves to distinguish between otherwise similar land-form types. The symbols are explained in Table 3.

III. LAND-FORM TYPE DESCRIPTIONS

Each land-form type is described in note form under the headings below, and is illustrated by one or more photographs. The areas of the land-form types have been obtained by dot counts and are calculated to the nearest 5%.

(*a*) *Terrain Parameters*

The definitions of the terms altitude, relief, characteristic slope, and grain are based on those given in the report on the lands of Bougainville and Buka Islands (Speight 1967). *Altitude* is the range in height above sea level within the land-form type. *Relief* is the difference in height within the land-form type between ridge crest or summit and the nearest major valley. The *characteristic slopes* are the slopes that are typical for most of the land-form type. *Grain* is defined as half the distance between major stream beds in the land-form type, assessed from air photographs.

(*b*) *Climate*

The climate is indicated by means of zones, numbered I to VI, which are explained in Part III.

(*c*) *Geology*

The geological information is based on observations made in the field, air-photo interpretation, and published and unpublished reports mainly by geologists of the Commonwealth Bureau of Mineral Resources.

(*d*) *Land Forms*

In the descriptions of the land forms, each land-form type is subdivided into units numbered consecutively. The units, which are generally similar to the land units of land systems or to whole land systems, are also used in many cases for describing the associated soils, drainage, vegetation, forest resources, and land use potential. The percentages given in parentheses are the relative areas in the land-form type covered by the units, estimated from air photographs.

(*e*) *Stream Pattern*

The typical stream patterns of the land-form types, as seen on air photographs, are described in simple terms such as radial, subparallel, dendritic, etc.

(*f*) *Soils and Drainage*

Descriptions of the soils and drainage conditions are based on notes provided by R. M. Scott and the information given in the reports on the previously surveyed parts of the area. These reports contain more detailed soil descriptions than are given here. The general drainage is assessed from permeability of the soils, rate of run-off due to slope, effects of climate, incidence of flooding, and depth to water-table.

(*g*) *Vegetation*

The vegetation of each land-form type is placed in one or more structural groups, such as forest, woodland, savannah, etc. These groups and terms used to further describe the vegetation, such as height, crown size, and altitudinal zones, are defined in Part VI. Genera and species in brackets are the most common or characteristic ones for the particular vegetation category.

(*h*) *Forest Potential*

Data have been provided by J. C. Saunders. The forest potential is assessed in terms of stocking rate, accessibility, and forest productivity. These terms are defined in Part VII.

(*i*) *Land Use Potential*

Eight capability classes are used to assess the suitability of land for agricultural production. These classes are based on specific hazards that limit agricultural land use (Haantjens *et al.* 1964*a*, 1964*b*; Ruxton *et al.* 1967). Briefly, land in classes I to III is suitable for cultivation with no major limitations. Class I land has no limiting hazards, and class II and class III lands have minor and moderate limiting factors respectively. Class IV land is marginally suitable for agriculture because of major limiting factors. Class V and class VI lands are suitable for improved pastures,

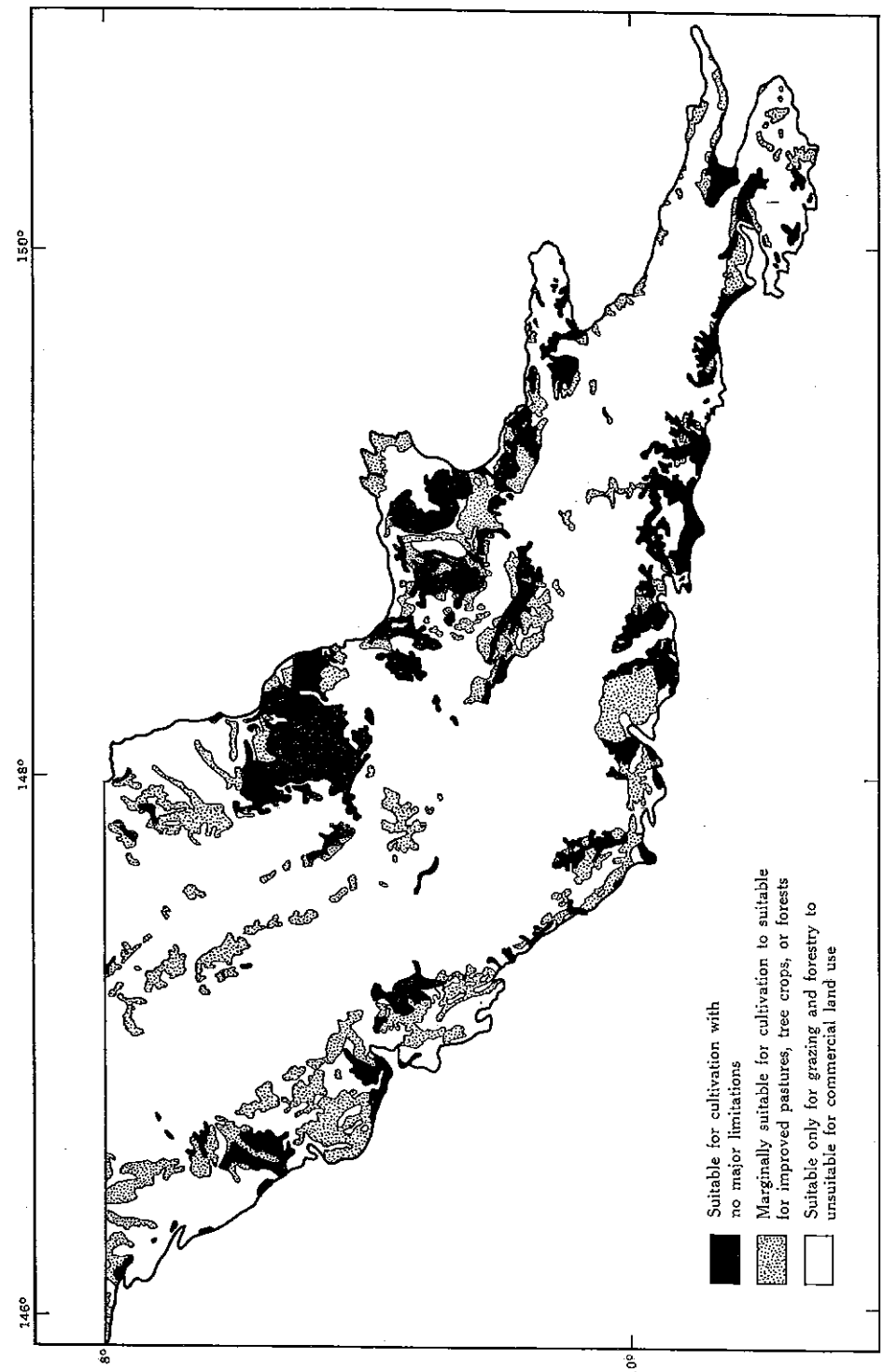

Fig. 3.—Land capability.

tree crops, or forests, although class VI land has moderate limitations for pastures and tree crops. In class VII limitations are so severe that land use is restricted to grazing and forestry, and in class VIII the land is unsuited for any type of commercial land use.

Figure 3 shows the land-form types classified into three groups: land predominantly in classes I to III covering 12% of the total area, land mainly in classes IV to VI covering 13% of the total area, and classes VII and VIII land covering 75% of the area.

(j) *Correlations*

Under this heading a list is given of previously mapped land systems that occur in the land-form type being described. The land systems are those mapped in the Buna–Kokoda, Safia–Pongani, Wanigela–Cape Vogel, Port Moresby–Kairuku, and Kerema–Vailala areas.

(k) *Relationships*

Comments are given on the type of boundaries mapped between the land-form type being described and adjacent land-form types. A list is also given, if appropriate, of commonly associated land-form types and of features that serve to distinguish the land-form type from other closely comparable land-form types.

IV. Land Use Potential

The potential of eastern Papua for agricultural land use is generally low. The best land, that is land which is suitable for cultivation without major limitations (Fig. 3), is restricted to well-drained volcanic and non-volcanic fans and plains, and beach ridges and flats. The largest areas of such land occur on the middle and lower slopes of Mt. Lamington and Mt. Victory, on the coastal plains south of Dyke Ackland and Collingwood Bays and along the south and west coasts, and inland in the Musa basin, in the upper Mambare River valley, and between the Sibium and Hydrographers Ranges.

The forest potential of eastern Papua as a whole is classed as moderate, mainly because most forest occurs on steep and inaccessible terrain. However, areas of largely unbroken and relatively easily accessible forest of moderate to high stocking rate (30–70 m^3/ha) occur on alluvial plains and fans on the lower slopes of Mt. Lamington and Mt. Victory, on the Musa coastal plain, on the fans and plains north of the Goropu Mountains, and along the major rivers flowing to the south coast. The most common useful trees in these forests are *Pometia* and *Octomeles*. About 45% of eastern Papua is covered by hill forest, which generally has a low to moderate stocking rate (20–50 m^3/ha). One of the largest areas of unbroken hill forest with a moderate to high stocking rate occurs south of Mt. Lamington between the headwaters of the Kumusi River and the Hydrographers Range. Common and valuable trees in hill forest are *Pometia* and the dipterocarps *Hopea* and *Anisoptera*. Rare stands of dense *Araucaria* locally have a timber volume over 300 m^3/ha. High-altitude forests generally carry timber of higher quality than the hill forests below, mainly due to the presence of *Nothofagus* and various conifers, but they generally pose major access problems.

The extensive grasslands of eastern Papua are little used at present but many have a potential for cattle-raising. Large areas of grassland occur on and to the west and south-west of Cape Vogel peninsula, near Hood Lagoon on the south coast, and inland in the Musa basin and south of Woitape. At present the few cattle in the area are grazed mainly on unimproved pastures. The natural pastures have a low productivity but this could be improved by measures such as introduction of legumes for grazing and browsing, and fire protection.

The tourist potential of eastern Papua has been little exploited to date, mainly because of a general lack of accommodation outside Port Moresby, and also because eastern Papua is off the main air routes to Lae and the Highlands. However, sights in and around Port Moresby are becoming increasingly popular with tourists, and many places outside the Port Moresby area could be developed as tourist attractions providing accommodation facilities are made available and access is improved.

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LS Land-form Type (1250 km²)

Swampy littoral plains subject to salt and brackish water flooding (Plates 1, 3, 4, 19).

Terrain Parameters.—Altitude: 0–2 m. Relief: <2 m. Characteristic slopes: 0°–0°4′.

Climate.—Zones I–IV.

Geology.—Unconsolidated littoral and estuarine clay, silt, and sand, locally as thin veneer on dead coral reefs; Recent.

Land Forms.—Tidal flats; channelled or hummocky microrelief up to 1 m generally present, locally consisting of beach ridges and swales; crab mounds up to 2 m high and 4 m across common, in places forming raised rims bordering tidal channels. Four units recognized.
(1) *Flats subject to daily salt water flooding* (60%).
(2) *Flats subject to monthly salt water flooding* (20%).
(3) *Flats subject to seasonal salt water flooding* (10%): mainly restricted to climatic zones I and II.
(4) *Estuarine areas subject to frequent to daily brackish water flooding* (10%).

Stream Pattern.—Reticulate, irregular; channels highly sinuous or with straight reaches and sharp elbow bends; entrances to channels commonly funnel-shaped.

Soils.—Strongly alkaline clay to sand, and peat.
(1), (2) Stratified grey and brown sand to clay and fibrous peat, pH 8·0–9·0.
(3) Black to very dark grey or brown sticky clay, pH 8·5–9·0.
(4) Dark grey to dark greyish brown mottled silty clay loam to silty clay, pH 8·5–9·0.

Drainage.—Swampy, as subject to daily, monthly, or seasonal flooding; permeability variable but mainly slow; water-table close to surface.

Vegetation.—Predominantly low to mid-height forest, woodland, and scrub of various mangrove species.
(1) Small-crowned, low to mid-height forest (*Rhizophora, Bruguiera*) without ground cover.
(2) Small-crowned mid-height forest (*Bruguiera, Rhizophora, Heritiera*) with ground cover (*Acrostichum, Acanthus*) in climatic zones III and IV; small-crowned low forest (*Avicennia, Ceriops, Excoecaria, Lumnitzera, Hibiscus*) with ground cover (*Sesuvium*) in climatic zones I and II.
(3) Salt flats with bare centres, inner rims of mixed herbaceous vegetation (*Sesuvium, Tecticornia*) and outer rims of mangrove scrub (*Avicennia, Ceriops, Excoecaria*).
(4) Palm vegetation (*Nypa*); small-crowned mid-height forest (*Bruguiera, Heritiera, Xylocarpus, Rhizophora*); small-crowned low seral forest (*Sonneratia*).

Forest Potential.—Forest resources nil (FRI*–0); most mangroves suitable for minor forest produce only, although small local stands attain millable size. Access very poor (AI*–8) because of frequency of flooding; access category S0W3. Forest productivity nil to very low.

Land Use Potential.—Class VIII. Unsuitable for commercial land use because of flooding and alkaline soil hazards.

Correlations.—Includes Killerton land system of the Buna–Kokoda and Wanigela–Cape Vogel areas; Bendorodo land system of the Safia–Pongani area; Galley Reach, Lesewalai, Kido, Papa, and Nipa land systems of the Port Moresby–Kairuku area; and Alele and Nipa land systems of the Kerema–Vailala area.

Relationships.—Boundaries generally sharp but locally gradational with LW, APf, and AS land-form types; minor unmapped inclusions of other land-form types present locally. Many areas of LS too small to be shown on map.

* FRI, forest resources index; AI, access index.

LW Land-form Type (500 km²)

Littoral plains consisting of well to imperfectly drained beach ridges and flats separated by commonly swampy swales (Plate 1; Plate 17, Fig. 2; Plate 19, Fig. 2).

Terrain Parameters.—Altitude: mainly 0–3 m. Relief: mainly <2 m. Characteristic slopes: <1°.

Climate.—Zones I–IV.

Geology.—Unconsolidated littoral sand, silt, and clay overlain in many places, especially inland from the coast, by thin layers of alluvial clay and silt; also minor aeolian sand; Recent.

Land Forms.—Plains up to 6 km wide consisting of the following units.
(1) *Linear beach ridges and flats* (75%): up to 100 m wide, ridges up to 2 m high with slopes up to 10°, highest close to coast and becoming less pronounced inland, commonly merging into slightly undulating flats with slopes generally less than 1°; irregular sand dunes up to 3 m high locally present on outermost beach ridge.
(2) *Swales* (20%): linear depressions mostly 5–70 m wide situated between adjacent ridges and flats of (1).
(3) *Present beaches and offshore bars* (<5%).
(4) *Dunes* (5%): present in two small areas near Hood Bay, in climatic zones I and II; up to 30 m high, with side slopes up to 30°.

(Areas of predominantly swampy beach ridges, flats, and swales are not included as these have been mapped as LS and AS land-form types.)

Stream Pattern.—Generally few surface streams; those present mainly follow swales.

Soils.—Mainly unconsolidated sands with little or no profile development.
(1) Mainly black friable sandy loam, 25–40 cm, pH 5·0–6·0, over dark brown speckled sand, pH 6·0; minor loose sand, black to dark brown over greyish to olive-brown, pH 6·0–8·5; permeability rapid to very rapid.
(2) Stratified dark grey, brown, or black silty loams to clays, mottled at depth, variable pH, moderate to low permeability.
(3) No soil development.
(4) Black to dark brown over greyish to olive-brown loose sand, pH 6·0–8·5, permeability very rapid.

Drainage.—(1) Well to imperfectly drained; soils rapidly permeable; water-table variable, commonly over 1 m deep; flooding infrequent or rare.
(2), (3) Poorly drained to swampy because of frequent flooding and generally shallow water-table.
(4) Well to excessively drained because of rapidly permeable soils, deep water-table, steep slopes, and no flooding.

Vegetation.—Dominant natural vegetation types, where preserved, are medium-crowned mid-height forest in climatic zones III and IV, and more or less deciduous woodland in climatic zones I and II.

(1*a*) Climatic zones III and IV: medium-crowned mid-height forest with understorey rich in palms, *Planchonia* in canopy and sago palm in understorey in poorly drained areas, locally mid-height to tall grassland (*Imperata cylindrica, Saccharum spontaneum, Ophiuros tongcalingii*).

(1*b*) Climatic zones I and II: more or less deciduous woodland (*Gyrocarpus, Harpullia*), scrub (*Hibiscus, Clerodendrum, Desmodium*), forest with *Melaleuca* in canopy in poorly drained areas, large areas of mid-height and tall grassland (*Themeda australis, Ophiuros tongcalingii, Imperata cylindrica, Saccharum spontaneum*); extensive areas of gardens, coconut plantations, and woody regrowth present throughout.

(2) Swamp woodland with sago palm and *Pandanus;* locally swamp savannah (*Melaleuca* with ground layer of *Phragmites karka*); minor tall grassland (*Phragmites karka*) and mixed herbaceous aquatic and swamp vegetation (*Nymphaea/Azolla, Leersia/Hanguana*); mangrove and nypa palm along tidal creeks.

(3) Above HWM (and on outermost beach ridge) mixed herbaceous vegetation (*Ipomoea, Canavalia, Spinifex*), woodland (*Calophyllum inophyllum, Terminalia catappa, Pandanus tinctorius*), minor *Casuarina equisetifolia* forest; secondary woody vegetation.

(4) Savannah (*Eucalyptus–Themeda australis, Imperata cylindrica*), mid-height grassland (*Imperata cylindrica, Themeda australis*).

Forest Potential.—Forest resources very low (FRI–11); forests of moderate and low stocking rates cover about 20 and 5% of the land-form type respectively. Poles of *Melaleuca* (1*b*) could be used for wharf piles. Access generally good (AI–73) except on poorly drained parts; access category S0W1. Forest productivity low.

Land Use Potential.—Classes II–IV.
(1) Suitable for cultivation; minor limitations are local slight flooding and seasonal soil moisture stress,
(2), (3) Unsuitable for commercial land use because of swampiness and tidal flooding.
(4) Unsuitable for commercial land use; severe erosion hazard because of steep slopes on unconsolidated sand.

Correlations.—Includes Buna land system of the Buna–Kokoda and Wanigela–Cape Vogel areas; Pawara land system of the Safia–Pongani area; Hisiu land system of the Port Moresby–Kairuku area; and Araimiri land system of the Kerema–Vailala area.

Relationships.—Boundaries generally well defined, but in places gradational with LS, AS, and APf land-form types, all of which occur locally as unmapped inclusions in LW. In many places areas of LW are too small to be shown on map and form unmapped inclusions in other land-form types.

AS Land-form Type (3900 km²)

Alluvial plains consisting of permanent, semi-permanent, and seasonal fresh-water swamps (Plates 2, 3; Plate 17, Fig. 2).

Terrain Parameters.—Altitude: 0–40 m. Relief: <3 m. Characteristic slopes: 0°–0°10′.

Climate.—Zones I–IV.

Geology.—Unconsolidated alluvial clay with minor silt, sand, and peat; Recent.

Land Forms.—Plains covered by standing fresh water for at least 3 months a year; local hummocky microrelief; slopes generally less than 0°10′ but may be steeper at margins; beach ridge pattern discernible in some coastal areas.
(1) *Permanent swamps* (60%).
(2) *Semi-permanent swamps* (15%): flooded for at least 6 months a year.
(3) *Seasonal swamps* (25%): flooded for 3–6 months a year.

Stream Pattern.—Generally few surface channels except for outlet streams; patches of open water traversing active and abandoned meandering river channels present locally.

Soils.—(1) Stratified layers of various textures in areas of active sedimentation; elsewhere very dark brown moderately decomposed peat, 1–2 m, generally over olive-grey to grey sticky clay, pH 4·5–6·0.
(2) Greyish stratified layers of various textures, pH 6·0–7·0, generally mottled below 1·5–4 m in areas of active sedimentation; elsewhere dark to very dark sticky clay, pH 6·0–7·0, generally mottled below 2–4 m.
(3) Similar to (2) but pH 7·0–8·5.

Drainage.—Swampy, due to permanent, semi-permanent, or long seasonal flooding.

Vegetation.—(1) Swamp forest and woodland, mixed or pure stands (*Campnosperma, Syzygium, Mitragyne*), commonly with sago palm and pandans, and ground layer of *Hanguana* and *Thoracostachyum;* tall grassland (*Phragmites karka, Saccharum robustum*); mixed herbaceous vegetation (*Leersia, Hanguana, Thoracostachyum*); aquatic vegetation (*Azolla, Nymphaea, Lemna*).
(2) Swamp forest (*Bischofia, Planchonia, Terminalia, Palaquium, Neonauclea*), commonly with sago palm and pandans; tall grassland (*Phragmites karka*).
(3) Swamp savannah (*Melaleuca* with ground layer of *Phragmites karka*, locally sago palm); small-crowned, mid-height forest (*Melaleuca, Nauclea*).

Forest Potential.—Forest resources nil (FRI–<1). Access very poor (AI–19) due to swampy conditions; access category S0W3. Forest productivity nil.

Land Use Potential.—Class VIII.
(1) Unsuitable for commercial land use because of permanent flooding.
(2) Unsuitable for cultivation because of semi-permanent flooding.
(3) Suitable for cultivation, but has seasonal flooding limitation.

Correlations.—Includes Ambi, Koena, and most of Ambasi land systems of the Buna–Kokoda area; Tortore land system of the Wanigela–Cape Vogel and Safia–Pongani areas; Waigani, Engepa, Akaifu, and part of Doura land systems of the Port Moresby–Kairuku area; and Murva, Ebala, Waigani, Movori, Karama, Melaleuca, and part of Terapo land systems of the Kerema–Vailala area.

Relationships.—Commonly merges into LW, LS, and APf land-form types but otherwise has well-defined boundaries. Occurs as minor unmapped inclusions in other land-form types.

APf Land-form Type (2350 km²)

Poorly drained alluvial plains subject to common flooding (Plate 2).

Terrain Parameters.—Altitude: 0–300 m but mostly <70 m. Relief: generally <3 m, maximum 8 m. Characteristic slopes: 0°04′–0°10′.

Climate.—Zones I–IV.

Geology.—Unconsolidated alluvial clay, silt, sand, and minor gravel; Recent.

Land Forms.—Poorly drained plains consisting of three major units.
(1) *River tracts subject to fresh-water flooding* (15%): mainly meander scrolls consisting of arcuate ridges and swales with up to 1 m microrelief; also local levees up to 8 m but generally less than 3 m high; unit includes active and swampy prior river channels.
(2) *Back plains subject to fresh-water flooding* (75%): generally flank unit 1; smooth to hummocky or channelled surfaces with microrelief up to 1 m common. Most of unit is being actively aggraded, as it is flooded by sediment-laden river water, but some parts appear to receive little or no sediment as they are flooded only by rain water and relatively clear run-on water from adjacent low hills.
(3) *Plains subject to slightly brackish water flooding* (10%): smooth to hummocky or channelled surfaces with up to 1 m local relief; include local low levees bordering river channels.

Stream Pattern.—Generally either single traversing major stream with few tributaries or widely spaced minor streams.

Soils.—(1) Stratified layers of various textures, mostly dark grey, pH 6·0–6·5, permeability generally slow.
(2) Where being aggraded, dark grey to brown silty clay, up to 45 cm thick, pH 6·0–7·0, over olive-grey to grey mottled silty clay, pH 6·5–7·5, permeability slow. Where not being aggraded, black to dark brown or grey very plastic heavy clay, pH 6·0–7·0, mottled below 10–30 cm, very slowly permeable.
(3) As (2) but pH 8·5–9·0.

Drainage.—Poorly drained because soils slowly permeable, water-table generally close to surface, and flooding common.

Vegetation.—(1), (2) Mainly open forest with very irregular canopy (*Octomeles, Artocarpus, Pometia, Alstonia, Pterocarpus, Terminalia, Laportea;* on wettest sites *Planchonia, Bischofia, Nauclea, Dillenia, Palaquium*); also medium-crowned mid-height forest (*Melaleuca, Nauclea*) in climatic zones I and II; tall grassland (on youngest scrolls *Saccharum robustum, Phragmites karka;* on plains *Saccharum spontaneum–Imperata cylindrica–Phragmites karka*) particularly common in climatic zones I and II.
(3) In climatic zones III and IV, small- to medium-crowned, low to mid-height forest (stilt-rooted *Myristica, Diospyros ferrea, Brownlowia, Xylocarpus*); in climatic zones I and II, scrub (*Pluchea, Hibiscus*), woodland, and small-crowned low to mid-height forest (*Hibiscus, Excoecaria, Melaleuca*).

Forest Potential.—Forest resources moderate (FRI-41); forests of moderate to locally very high (*Octomeles*) stocking rate cover about 65% mainly on (1) and (2) in climatic zones III and IV, and forests of low stocking rate, including a *Melaleuca*-dominated variant in climatic zones I and II, cover about 20% of the area. Access moderate (AI–19); poor drainage and common flooding hazards; access category S0W1F. Forest productivity moderate.

Land Use Potential.—Classes V–VIII. Largely unsuitable for cultivation because of frequent flooding and poor drainage.

Correlations.—Includes all or parts of the following land systems: Warisota, Hanau, Sanananda, Deunia, and Sagere of the Buna–Kokoda area; Imo, Dove, and Ubo of the Safia–Pongani area; Monari, Uiaku, and Dove of the Wanigela–Cape Vogel area; Inaukina, Beipa, Piunga, Vanapa, Biaru, and Doura of the Port Moresby–Kairuku area; and Malalaua, Vailala, Terapo, Tauri, and Hepea of the Kerema–Vailala area.

Relationships.—Commonly merges into AS and AWs land-form types but is otherwise generally sharply bounded; unmapped inclusions of AS and AWs land-form types common.

APr Land-form Type (130 km²)

Rarely flooded but poorly drained alluvial plains of small rivers in monsoonal areas, characterized by dark cracking clay soils (Plate 4).

Terrain Parameters.—Altitude: 0–70 m. Relief: <10 m. Characteristic slopes: 0°35′–1°.

Climate.—Zones I, II.

Geology.—Unconsolidated alluvial and colluvial clay and silt; Recent. Local reef limestone on seaward margins.

Land Forms.—Plains occupying valley floors mostly less than 2 km wide. Main streams perennial, with highly sinuous channels incised 1–5 m; minor streams ephemeral and mostly ill defined.
(1) *Back plains* (90%): plains with concave cross profiles, smooth to gently undulating, slopes generally less than 1° but increasing to 5° at margins where bordered by colluvial foot slopes of adjacent hills; low terraces locally present.
(2) *Narrow flood-plains* (10%): flank main stream channels; slopes less than 0°35′.

Stream Pattern.—Single major streams with widely spaced tributaries.

Soils.—Black or very dark neutral to alkaline clays.
(1) Black to very dark grey very firm sandy to heavy clay, pH 6·5–8·5, calcareous concretions common at depth; very slowly permeable, water-table over 3 m; very rarely or never subject to river flooding.
(2) Black to very dark grey very firm sandy to heavy clay, brown and mottled at depth, pH 7·0–8·5, calcareous concretions and/or gravel layers commonly present; very slowly permeable; water-table generally less than 3 m deep; subject to occasional river flooding.

Drainage.—Poorly drained due to very slowly permeable soils and to slow run-off of rain water because of low slopes and relief; local ponding common.

Vegetation.—(1) Large- to medium-crowned, tall, slightly deciduous forest (*Terminalia* spp., *Pterocarpus, Alstonia brassii, A. scholaris, Planchonia, Bischofia*), mostly secondary or disturbed; tall grassland (*Saccharum spontaneum–Imperata cylindrica, Ophiuros tongcalingii*) with scattered pandans, *Nauclea, Albizia procera;* in west also savannah (*Eucalyptus* with ground layer of *Themeda australis, Ophiuros tongcalingii*).
(2) As (1) but no savannah; also tall grassland (*Saccharum robustum, Phragmites karka*).

Forest Potential.—Forest resources nil (FRI–3); less than 5% of land-form type has forest with moderate stocking rate. Access moderate (AI–57); poor drainage hazards; access category S0W2. Forest productivity very low.

Land Use Potential.—Class III. Suitable for cultivation but limitations due to erosion on slight slopes, temporary ponding in depressions, and seasonal soil moisture stress.

Correlations.—Includes part of Monari land system of the Wanigela–Cape Vogel area and most of Boroko land system of the Port Moresby–Kairuku area.

Relationships.—Restricted to narrow valleys bordered by hills, hence boundaries generally well defined. Includes small local unmapped swamps of AS land-form type.

AWs Land-form Type (4250 km²)

Well to imperfectly drained stable alluvial plains of rivers that are not associated with recently active strato-volcanoes (Plates 1, 2, 10; Plate 14, Fig. 1; Plate 17, Fig. 2; Plate 19).

Terrain Parameters.—Altitude: 0–500 m. Relief: up to 10 m. Characteristic slopes: 0°04′–0°10′.

Climate.—Zones I–IV.

Geology.—Unconsolidated alluvial clay, silt, sand, and gravel; Recent.

Land Forms.—Plains sloping at less than 1° consisting of present and prior river tracts and lower and upper back plains.
(1) *Tracts with present and prior river channels* (10%): up to 3 km wide, consist mainly of meander scrolls formed of arcuate ridges and swales with up to 1·5 m local relief; also includes minor levees up to 5 m high and 300 m wide and, in the south between Marshall Lagoon and Amazon Bay, narrow slightly incised flood-plains of braided rivers; prior channels up to 5 m deep present locally, usually permanently flooded or swampy.
(2) *Lower back plains* (25%): less than 3 m above mean river levels, smooth to slightly undulating, locally channelled with up to 1·5 m microrelief; low terraces present in places; also includes local breakthrough splays.
(3) *Upper back plains* (65%): 3–10 m above mean river levels, smooth to slightly undulating, up to 1 m microrelief; locally incised by small streams; includes some alluviated beach ridges in north-west.

Stream Pattern.—Mainly highly sinuous, meandering, present and/or prior major streams with few tributaries; some braided streams present locally.

Soils.—Variety of alluvial soils present, many with thick dark topsoils; commonly stratified; mainly silt, clay, and loam, less commonly sand, some gravel horizons locally present; mostly weakly acid to neutral but range from acid to alkaline; permeability generally slow to moderate.

Drainage.—(1) Meander scrolls are imperfectly to poorly drained because of very common flooding and shallow water-table; levees are well drained as they are rapidly permeable, rarely flooded, and have relatively deep water-tables.
(2) Mostly imperfectly drained because of common flooding and shallow water-table.
(3) Well drained, as water-table relatively deep and flooding very rare.

Vegetation.—Three main vegetation types present: large- to medium-crowned tall forest; tall to locally mid-height grassland, most common in climatic zones I and II; and savannah, virtually confined to climatic zones I and II.
(1) Youngest scrolls have succession from tall grassland (*Saccharum robustum*, locally *Phragmites karka*) to *Artocarpus–Octomeles* forest; higher parts of levees have large-crowned, tall to very tall forest in climatic zones III and IV, and medium-crowned, mid-height to low forest in climatic zones I and II; parts subject to frequent short-lived flooding have mainly large-crowned, very irregular forest with *Octomeles* and *Kleinhovia* very common trees.
(2) Large- to medium-crowned tall forest, less tall in climatic zones I and II and on poorly drained sites (common trees *Pometia, Terminalia, Alstonia, Octomeles, Pterocarpus;* where poorly drained, *Planchonia* common generally and *Melaleuca* and *Nauclea* common in climatic zones I and II); also large areas of tall grassland.
(3) Mainly large-crowned forest; also large areas of grassland, mostly tall (*Saccharum spontaneum–Imperata cylindrica*), locally mid-height (*Themeda australis, Imperata cylindrica, Ophiuros tongcalingii);* minor savannah (*Eucalyptus*, locally *Melaleuca, Timonius, Nauclea, Antidesma*) with ground layer of mid-height grasses (*Themeda australis, Sorghum nitidum, Themeda novoguineensis*).

Forest Potential.—Forest resources moderate (FRI–42); forest of high to locally very high (*Octomeles*) stocking rate covers about 55%, and forest of moderate and low stocking rates about 10% of the area. Access generally very good (AI–81), especially on (3); access category S0W1F. Forest productivity high.

Land Use Potential.—Classes I–IV.
(1) Mostly unsuitable for commercial land use.
(2) Marginally suitable for cultivation; flooding limitation.
(3) Suitable for cultivation.

Correlations.—Includes parts of Deunia, Warisota, and Sagere land systems of the Buna–Kokoda area; Ismari, part of Uiaku, and most of Wakioka land systems of the Wanigela–Cape Vogel area; Momoiogo, Gobera, Aiare, and parts of Nembadi, Safia, Ubo, and Korala land systems of the Safia–Pongani area; Keviona, Pinu, Bebeo, Epo, Babiko, Vekabu, and parts of Inaukina, Beipa, Piunga, and Vanapa land systems of the Port Moresby–Kairuku area; and parts of Hepea, Vailala, and Malalaua land systems of the Kerema–Vailala area.

Relationships.—Commonly merges into APf land-form type but is otherwise generally sharply bounded. Includes small unmapped areas of AS and APf land-form types.

AWv Land-form Type (750 km²)

Mostly well-drained and generally stable alluvial plains of rivers draining Mt. Lamington and Mt. Victory volcanoes (Plate 5).

Terrain Parameters.—Altitude: 0–200 m. Relief: <10 m. Characteristic slopes: 0°10′–0°35′.

Climate.—Zones III, IV.

Geology.—Unconsolidated recent alluvial sand, gravel, and minor silt and clay, with volcanic ash derived locally from recently active andesitic strato-volcanoes.

Land Forms.—(1) *Smooth to slightly undulating upper plains* (80%): slopes less than 1°, locally with one or two terraces; streams incised to 7 m.
(2) *Narrow flood-plains of major streams* (20%): incised into (1).

Stream Pattern.—Sinuous major streams with few tributaries; channels locally braided.

Soils.—(1) Mainly little-weathered to unweathered grey loamy sand to sandy loam, neutral, with weakly alkaline black topsoils about 30 cm thick; permeability rapid.
(2) Mainly stratified loam to clay over sandy clay loam to sand, weakly acid to acid; permeability rapid to slow.

Drainage.—(1) Well to locally excessively drained, as rapidly permeable soils, deep water-table, and very rare flooding.
(2) Imperfectly to poorly drained because of generally shallow water-table and seasonal flooding.

Vegetation.—Natural vegetation is large- to medium-crowned tall forest, but has largely been destroyed and replaced with grassland, regrowth, and secondary forest.

(1) Tall grassland (*Saccharum spontaneum/Imperata cylindrica*) with remnants and regrowth stages of large-crowned tall forest (*Anisoptera, Pometia*).
(2) Large- to medium-crowned tall forest (*Pometia, Octomeles, Alstonia*) and tall grassland as in (1).

Forest Potential.—Forest resources low (FRI–22); forest of high to locally very high (*Octomeles*) stocking rate covers 30%, and scattered stands of low stocking rate cover 5% of the area. Access good (AI–77), especially on (1); access category S0F. Forest productivity moderate.

Land Use Potential.—Classes I–II.
(1) Suitable for cultivation, with only minor limitations.
(2) Marginally suitable for cultivation because of flooding hazards.

Correlations.—Comprises parts of Popondetta, Hanau, and Sagere and small part of Bohu land systems of the Buna–Kokoda area, and part of Wanigela land system of the Wanigela–Cape Vogel area.

Relationships.—Has gradational boundaries with AWs and APf land-form types but is otherwise sharply defined.

AWd Land-form Type (160 km²)

Mainly well-drained but unstable alluvial plains and fans associated with braided rivers draining the recently active Mt. Victory and Mt. Trafalgar volcanoes (Plates 3, 5).

Terrain Parameters.—Altitude: 0–300 m. Relief: <4 m. Characteristic slopes: 0°35′–1°.

Climate.—Zones III, IV.

Geology.—Unconsolidated volcanic debris, mainly alluvial gravel, sand, and silt of andesitic composition; Recent.

Land Forms.—Broad flood-plains with slopes up to 1° merging upslope with terraced fans and narrow incised flood-plains.
(1) *Broad flood-plains* (60%): smooth to gently undulating, crossed by many unstable stream channels less than 2 m deep.
(2) *Terraced fans* (25%): smooth to slightly undulating, slopes up to 2°, commonly with channelled microrelief.
(3) *Flood-plains of present and prior highly unstable braided rivers* (15%): incised 2–3 m into terraced fans, up to 2 m local relief of stream channels, bars, and low terraces.
(1) and (3) are subject to periodic destructive flooding and all units are liable to volcanic damage.

Stream Pattern.—Braided major rivers with few tributaries; subradial pattern of distributary channels on (1) below Mt. Victory.

Soils.—(1) Probably dark grey stratified sands and clays.
(2) Very dark brown to dark greyish brown loamy sand to sandy loam, pH 6·0–7·0, over loose grey sand, gravelly at depth.
(3) Bouldery loose sand and gravel.
Rapidly permeable throughout.

Drainage.—(1) Poorly drained to locally swampy as frequent flooding and water-table close to surface.
(2) Well to excessively drained as soils rapidly permeable, water-table over 2 m deep, and no flooding.
(3) Imperfectly drained because of frequent short-lived flooding and shallow water-table.

Vegetation.—Predominantly seral communities.
(1) Large-crowned, tall, open and irregular forest (*Pometia, Planchonia*), locally with sago palm understorey and small patches of sago palm vegetation; some tall grassland (*Saccharum spontaneum/Imperata cylindrica*).
(2) Scrub and woodland (*Trema orientalis, Pipturus argenteus, Ficus* spp.), small-crowned low forest with large-crowned emergents (*Albizia, Octomeles*), tall grassland (*Saccharum spontaneum/Imperata cylindrica*).
(3) Stream-bed successions dominated by tall grasses (*Saccharum spontaneum, Pennisetum macrostachyum*, on poorly drained sites *Phragmites karka*) with scattered shrubs and low trees; bare ground.

Forest Potential.—Forest resources nil (FRI–4); 10% of land-form type covered by forest with moderate stocking rate. Access generally poor (AI–38) because of poor drainage and flooding hazards; access category S0W2F, Forest productivity very low due to access difficulties within forest.

Land Use Potential.—Classes IV–VIII.
(1) Mostly unsuitable for commercial land use because of frequent flooding.
(2) Marginally suitable for cultivation, main limitation is likely soil moisture stress.
(3) Unsuitable for commercial land use because of frequent flooding and stony soils.

Correlations.—Comprises Amboga land system of the Buna–Kokoda area and Kopwei land system of the Wanigela–Cape Vogel area.

Relationships.—Locally merges into VPn, AWs, and APf land-form types; otherwise boundaries well defined.

AWu Land-form Type (46 km²)

Unstable mainly imperfectly drained alluvial plains associated with braided rivers draining the Owen Stanley Range (Plate 6; Plate 20, Fig. 1).

Terrain Parameters.—Altitude: 100–300 m. Relief: <4 m. Characteristic slopes: 0°10′–1°.

Climate.—Zone IV.

Geology.—Unconsolidated alluvium, predominantly sand and gravel; Recent.

Land Forms.—Plains up to 2 km wide made up of central braided river tracts flanked by back plains.
(1) *Central tracts* (30%): consist of anastomosing stream channels separated by elongate subparallel bars up to 1 m high and 20 m wide.
(2) *Back plains* (70%): slopes generally less than 1°, channelled microrelief present; some local cross-cutting flood-water channels.

Stream Pattern.—Braided major rivers with widely spaced tributary streams.

Soils.—Young to very young grey stratified gravel, sand, and silt; neutral; rapidly permeable.

Drainage.—(1) Poorly drained because of very frequent flooding and generally shallow water-table.
(2) Mainly imperfectly drained because of frequent short-lived flooding and fluctuating water-table.

Vegetation.—(1) Variable cover of grasses (*Paspalum* spp., *Saccharum spontaneum*), shrubs (*Ficus*, *Cassia alata*), and dense *Casuarina cunninghamiana* forest up to 40 m high; locally bare.
(2) Large- to medium-crowned irregular forest with *Pometia* very common, undergrowth of palms, gingers, and ferns.

Forest Potential.—Forest resources high (FRI–62); over 90% of land-form type forested; forest of high to locally very high (*Octomeles*) stocking rate covers most of (2); *Casuarina cunninghamiana* forest of (1), covering about 20% of area, has generally low but locally moderate to high stocking rate. Access moderate to good (AI–62); flooding and drainage hazards; access category S0W1F. Forest productivity moderate to high.

Land Use Potential.—Classes V–VIII.
(1) Unsuitable for commercial land use because of frequent flooding.
(2) Unsuitable for cultivation because of flooding hazard; moderately suitable for tree crops.

Correlations.—Not mapped in previously surveyed areas but present as minor inclusions in Ubo, Safia, Aiara, and Gobera land systems of the Safia–Pongani area.

Relationships.—Merges downstream into AWs land-form type, otherwise sharply bounded.

FSa Land-form Type (45 km²)

Undissected fans of intermontane basins mainly over 2000 m, formed of unconsolidated sediments (Plate 7; Plate 16, Fig. 2).

Terrain Parameters.—Altitude: 1500–3000 m. Relief: <20 m. Characteristic slopes: 0°35′–1°45′.

Climate.—Zone V.

Geology.—Unconsolidated alluvial and colluvial sand, silt, clay, and gravel; Recent.

Land Forms.—Intermontane basins up to 2·5 km wide, with concave cross profiles.
(1) *Fans* (80%): locally terraced, slopes up to 5° but generally less than 2°; hummocky microrelief up to 0·5 m common on lower parts; fans descend to (2).
(2) *Flood-plains* (20%): slopes less than 0°35′; commonly swampy, with sinuous meandering streams; hummocky microrelief up to 0·5 m common.

Stream Pattern.—Open dendritic, with highly sinuous meandering main streams and widely spaced tributaries.

Soils.—Sandy loam to sandy clay loam, very humic, commonly with thick dark topsoil, weakly acid; also peat.

Drainage.—Imperfectly drained to swampy.

Vegetation.—(1) Low to mid-height (to 75 cm) tussock grassland (*Deschampsia klossii*, *Anthoxanthum angustum*) with sedges and ferns (*Gleichenia* spp.) common; low shrubs (*Styphelia*, *Hypericum*) locally dense. Minor lower montane forest (*Nothofagus*) and coniferous lower montane forest (*Dacrycarpus*, *Phyllocladus*, *Papuacedrus*, *Araucaria*).
(2) Open low tussock grassland with carpet of low herbs (*Potentilla*, *Plantago*, *Eriocaulon*, *Astelia*) and mosses (locally *Sphagnum*) in between tussocks; locally ferns (*Gleichenia vulcanica*) dominant; sedges very common generally, and dominant in the most swampy parts and locally in pools of standing water (*Scirpus mucronatus*) and in streams (*Scirpus crassiusculus*).

Forest Potential.—Forest resources nil (FRI–3); moderate stocking rate forest (*Nothofagus*) covers 5%, and low stocking rate forest (conifers) 4%, of the land on (1). Access within land-form type poor (AI–30) due to poor drainage and swampiness; access category S0W2. Forest productivity nil to very low, mainly due to inaccessibility of surrounding land.

Land Use Potential.—Classes V–VI. Unsuitable for cultivation because of drainage and frost hazards.

Correlations.—Not present in previously mapped areas.

Relationships.—Sharply bounded by adjacent hill and mountain land-form types.

FSn Land-form Type (320 km²)

Undissected alluvial fans associated with swiftly flowing braided rivers, formed of unconsolidated sediments (Plate 8; Plate 16, Fig. 1).

Terrain Parameters.—Altitude: 100–1000 m. Relief: <10 m. Characteristic slopes: 1–5°.

Climate.—Zones II–IV.

Geology.—Unconsolidated alluvial gravel, sand, silt, and clay; minor colluvial material; Recent. Veneer of andesitic volcanic ash present locally near Mt. Lamington.

Land Forms.—Alluvial fans crossed by shallowly incised braided rivers.
(1) *Fan surfaces* (95%): smooth to slightly undulating, slopes 1–5°; discontinuous low terraces, prior channels, bouldery surfaces, and channelled microrelief locally present.
(2) *Flood-plains of braided rivers* (5%): incised 2–10 m into (1); microrelief of channels separated by bouldery and gravelly rises.

Stream Pattern.—Generally subparallel to subradial, with braided major rivers.

Soils.—(1) Mainly black to very dark greyish brown friable loam to clay, pH 6·5–7·0, over olive-brown to dark brown friable silty loam, and clay, pH 6·0–7·5; moderately permeable.
(2) Grey to brown loose sand over gravel, stones, and boulders, pH 6·0–7·0; rapidly permeable.

Drainage.—(1) Well drained because soils moderately permeable, water-table generally over 2 m deep, and flooding rare.
(2) Imperfectly to poorly drained because of shallow water-table and frequent short-lived flooding.

Vegetation.—*Originally mainly large-crowned tall forest, slightly* deciduous in climatic zones II and III, but now widely replaced by gardens, garden regrowth, secondary forest, and, in climatic zone II, tall grassland and savannah.
(1) Large-crowned tall forest (*Pometia, Octomeles, Alstonia scholaris;* where slightly deciduous *Terminalia* spp., *Anisoptera, Intsia*); tall grassland (*Saccharum spontaneum*/*Imperata cylindrica*); minor savannah (*Eucalyptus tereticornis* with *Nauclea–Antidesma* in slight depressions, ground layer of *Imperata cylindrica, Themeda australis, Alloteropsis semialata*).
(2) Bare ground; stands of *Saccharum spontaneum*, lines of *Casuarina cunnighamiana* at east end of Musa basin.

Forest Potential.—Forest resources low (FRI–33); high stocking rate forest covers 45% and low stocking rate forest covers 10% of the land mainly on (1); *Casuarina cunnighamiana* forest of very variable stocking rate occurs on (2). Access very good (AI–84) except on (2); access category S0. Forest productivity moderate.

Land Use Potential.—Classes I–II.
(1) Mostly suitable for cultivation with only minor limiting factors.
(2) Unsuitable for commercial land use because of frequent flooding hazard.

Correlations.—Includes Ilimo land system of the Buna–Kokoda area and Liamu and parts of Ubo and Safia land systems of the Safia–Pongani area.

Relationships.—Locally grades into dissected fans and alluvial plains but is generally sharply bounded by other land-form types.

FSu Land-form Type (400 km²)

Undissected alluvial and colluvial fans with gently undulating surfaces and no traversing major rivers; formed of unconsolidated sediments (Plates 4, 10; Plate 17, Fig. 2).

Terrain Parameters.—Altitude: 0–500 m. Relief: <15 m across fan slopes but up to 50 m along slope. Characteristic slopes: 1–3°. Grain: 250–500 m.

Climate.—Zones I–III.

Geology.—Unconsolidated alluvial and colluvial clay, silt, sand, and gravel; Pleistocene and Recent. Sediments overlie various types of bed-rock and increase in thickness downslope.

Land Forms.—Undissected slightly concave fans consisting of interfluves separated by drainage depressions. No traversing major rivers; existing streams perennial, intermittent, or ephemeral.
(1) *Interfluves* (80%): crests up to 15 m above adjacent drainage depressions, smooth to gently undulating; slopes generally 0°35′–3° but range from 0° to 10°; channelled microrelief common.
(2) *Drainage depressions* (20%): generally less than 200 m wide, *slopes up to 3°, hummocky and channelled microrelief and* incised stream channels common.

Stream Pattern.—Parallel to subparallel transverse minor streams.

Soils.—Predominantly texture-contrast, commonly with varying amounts of concretions and stony gravel.
(1) Friable sandy loam to sandy clay loam, black to dark brown over grey to brown and generally mottled, pH 6·0–7·0, abruptly overlying grey and brown mottled sandy to heavy clay, pH 5·5–7·5; very slowly permeable.
(2) Where only occasionally flooded, black firm clay to heavy clay, pH 6·0–8·5; where more frequently flooded, dark brown firm sandy to heavy clay, pH 6·0–8·5, locally with calcareous concretions; very slowly permeable.

Drainage.—(1) Imperfect to poor because of very slowly permeable soils, although unit is not subject to river flooding; water-table deep.
(2) Poor because of very slowly permeable soils, generally shallow water-table, and occasional to common short and irregular flooding.

Vegetation.—Main types are eucalypt savannah, which is dominant in climatic zones I and II, and small-crowned forest, mid-height grassland, and tea-tree savannah.
(1) Savannah (*Eucalyptus* spp. or *Melaleuca cajuputi*, with ground layer of *Themeda australis, Ophiuros tongcalingii, Imperata cylindrica, Themeda novoguineensis*); mid-height grassland (*Themeda australis, Imperata cylindrica, Heteropogon contortus*); small-crowned, low forest with *Casuarina*.
(2) Savannah as in (1); tall grassland (*Saccharum spontaneum, Imperata cylindrica, Ophiuros tongcalingii*); medium-crowned mid-height forest (*Anisoptera, Intsia, Pterocarpus, Pometia, Planchonia, Nauclea*); minor swamp woodland with sago palm and pandans in lowest parts.

Forest Potential.—Forest resources very low (FRI–10); high stocking rate forest covers 10%, and low stocking rate forest 15%, mainly on (2). Access generally moderate (AI–70) due to poor drainage hazards throughout and common flooding on (2); access category S0W1. Forest productivity low.

Land Use Potential.—Classes IV–VI. (1) Marginally suitable to unsuitable for cultivation; potential high run-off and severe erosion because of very slowly permeable subsoils. (2) Marginally suitable for cultivation because of flooding hazard.

Correlations.—Includes parts of Korala, Boborobo, and Asaga land systems of the Safia–Pongani area and Ward and Ouou land systems of the Port Moresby–Kairuku area.

Relationships.—Sharply bounded by adjacent hill land-form types; boundaries with alluvial plains land-form types gradational over short distances.

FSt Land-form Type (90 km²)

Undissected terraced fans formed of unconsolidated sediments (Plate 13, Fig. 1; Plate 20, Fig. 2).

Terrain Parameters.—Altitude: 0–500 m. Relief: 5–30 m. Characteristic slopes: 0°35′–3°. Grain: 250–500 m.

Climate.—Mainly zone II, small part in zone III.

Geology.—Unconsolidated alluvial gravel and sand, minor silt and clay; Recent and probably late Pleistocene.

Land Forms.—(1) *Terraces* (90%): 3–30 m above flood-plains of traversing streams; surfaces flat to gently undulating, 0°35′–3°, commonly bouldery, locally channelled; successive terraces separated by extremely short moderate to steep slopes; precipitous slopes and cliffs present adjacent to incised streams.
(2) *Flood-plains* (10%): slopes less than 1°, channelled to hummocky microrelief, streams commonly braided.

Stream Pattern.—Generally subparallel traversing streams with few tributaries.

Soils.—Young stratified gravel, sand, and sandy loam, less commonly clay; neutral; stones, boulders, and layers of gravel common.

Drainage.—(1) Excessively to well drained, as rapidly permeable and deep water-table.
(2) Mostly well drained; rapidly permeable but subject to frequent short-lived flooding.

Vegetation.—Mainly mid-height to tall grassland; also woodland, along incised streams and in scattered patches, and remnant patches of large- to medium-crowned, tall, slightly deciduous forest (*Pterocarpus, Anisoptera, Terminalia, Buchanania, Alstonia brassii, Dracaena*). In grassland, *Themeda australis, Heteropogon contortus*, and *Eulalia leptostachys* dominant or co-dominant on gravelly soils, and *Saccharum spontaneum, Ophiuros tongcalingii, Sorghum nitidum, Imperata cylindrica*, and occasionally *Coelorachis rottboellioides* more prominent on finer-textured and more moist soils; grasses usually accompanied by scattered to fairly dense shrubs and low trees of *Albizia procera, Nauclea* (particularly in tall grassland), *Antidesma*, and *Semecarpus*.

Forest Potential.—Forest resources very low (FRI–9); high stocking rate forest covers 15% and low stocking rate forest less than 5% of land-form type. Access very good (AI–87) except for local steep to precipitous slopes on (1) and frequent flooding hazard on (2); access category S0. Forest productivity low to very low.

Land Use Potential.—Classes VI–VII.
(1) Not suitable for cultivation because of stoniness.
(2) Not suitable for cultivation because of stoniness and frequent flooding.

Correlations.—Includes Tokinawara and small part of Wakioka land systems of the Wanigela–Cape Vogel area.

Relationships.—Generally abruptly bounded; mainly associated with ZSv land-form type.

VAv Land-form Type (180 km²)

Steep to very steep flanks and summit areas of little-eroded mainly andesitic volcanoes (Plate 5; Plate 19, Fig. 2; Plate 21, Fig. 2).

Terrain Parameters.—Altitude: 100–2000 m. Relief: 200–400 m. Characteristic slopes: 30–45°. Grain: 1000–2000 m.

Climate.—Mainly zones III and IV; small part on the summit of Mt. Victory in zone V.

Geology.—Lava and fragmental material consisting of agglomerate, scoria, ash, and scree, mostly of andesitic composition but also including basaltic andesites, shoshonites, and rhyodacites; late Pleistocene to Recent.

Land Forms.—(1) *Lava flows* (65%): sinuous, up to 7 km long and 2 km wide, with axial slopes 10–30°; very steep side slopes; upper slopes with irregular relief up to 35 m.
(2) *Lava domes* (10%): up to 300 m high; very steep to precipitous convex sides, locally deeply gullied.
(3) *Scoria cones and mounds* (5%): up to 100 m high; side slopes 20–35°, commonly gullied.
(4) *Debris slopes* (15%): main unit on Waiowa volcano; concave slopes of 30–5°, gullied; locally incised to 30 m by major streams.
(5) *Craters* (5%): more or less flat floors, some with crater lakes, bounded by irregular steep to cliffed crater walls up to 300 m high.

Stream Pattern.—Radial to subradial; incised bouldery streams with rapids and waterfalls.

Soils.—Mainly shallow and stony loam to sandy loam (ash soils); also bare rock.

Drainage.—Well to excessively drained.

Vegetation.—Seral communities present on the recently active Lamington and Waiowa volcanoes, mainly forest elsewhere; also minor man-induced secondary forest and grassland near population centres.
(1) Bare rock; herbaceous seral vegetation (*Gleichenia, Lycopodium, Saccharum spontaneum*); woodland (*Trema, Rhus, Casuarina*); *Casuarina cunninghamiana* forest; mixed small- and medium-crowned forest; large-crowned tall forest (*Pometia, Octomeles, Tristiropsis, Anisoptera*). (2), (3) Herbaceous seral vegetation, tall grassland, woodland, and small-crowned forest. (4) Tall grassland (*Saccharum spontaneum*); woodland and forest with *Casuarina cunninghamiana* predominating.
(5) Bare, herbaceous seral vegetation, or open water on crater floors; bare or as (2) and (3) on crater walls.

Forest Potential.—Forest resources moderate (FRI–46); 90% of land-form type forested; forests of high and moderate stocking rate on (1) cover 25% and 35% of area respectively; forest of low stocking rate, including local stands of *Casuarina* and *Octomeles*, covers 30%. Access very poor (AI–10) due to prevailing very steep slopes; access category S3. Forest productivity very low due to inaccessibility of main forested areas.

Land Use Potential.—Classes VII–VIII. Unsuitable for commercial land use.

Correlations.—Includes most of Lamington land system of the Buna–Kokoda area, most of Victory land system of the Wanigela–Cape Vogel area, and Manna land system of the Safia–Pongani area.

Relationships.—Passes downslope to VPd and VPn land-form types, with which it generally has sharp boundaries.

VBm Land-form Type (220 km²)

Moderately steep flanks of little-eroded basaltic volcanoes (Plate 9).

Terrain Parameters.—Altitude: 10–1500 m. Relief: mostly 30–200 m. Characteristic slopes: 5–10°. Grain: very variable, mainly 500–2000 m.

Climate.—Mainly zones III, IV, small part in zone II.

Geology.—Mainly basaltic and andesitic massive and brecciated lava; also scoria, agglomerate, and minor derived sediments; Recent. A thin veneer of volcanic ash is commonly present on surfaces not being actively eroded.

Land Forms.—(1) *Upper surfaces of lava flows* (85%): gently undulating, slopes 0–10°, locally incised up to 70 m.
(2) *Short steep slopes* (10%): on margins of lava flows and on sides of incised valleys; irregular and commonly blocky slopes up to 200 m long, mainly 25–35°.
(3) *Scoria cones and mounds* (5%): mostly 100–200 m high, side slopes generally about 30°; small craters, commonly breached, present on summits of cones.
(4) *Craters* (<5%): up to 200 m deep and 400 m across; floors generally flat, some with lakes; walls very steep to precipitous.

Stream Pattern.—Radial to subradial.

Soils.—(1) Moderately deep to deep, dark-coloured, weakly acid to acid clay and moderately deep to deep sandy loam to sandy clay volcanic ash soils.
(2), (3), (4) Shallow to moderately deep clay to sandy clay loam, and stony land.

Drainage.—Well drained.

Vegetation.—(1) Mainly gardens, garden regrowth, and secondary forest; scattered areas of tall grassland (*Saccharum spontaneum*/*Imperata cylindrica*, *Ophiuros tongcalingii*); large-crowned tall forest (*Pometia*, *Alstonia*, *Sloanea*, *Tristiropsis*, *Anisoptera*); small-crowned low *Rhus taitensis* forest on blocky lava flows.
(2) Medium-crowned forest.
(3) Medium- to small-crowned forest; minor mid-height grassland and savannah (*Eucalyptus tereticornis*).
(4) Forest, swamp woodland, and open water.

Forest Potential.—Forest resources moderate (FRI–41); high stocking rate forest on (1) covers 15%, and medium and low stocking rate forests on (1) to (3) cover 45% and 20% respectively. Access good (AI–61), mainly due to large size of (1), although local deep drainage incisions inhibit lateral movement; steep to precipitous slopes on (2) to (4) should be avoided; access category S1. Forest productivity moderate.

Land Use Potential.—Classes II–III.
(1) Suitable for cultivation but erosion hazard.
(2), (3), (4) Unsuitable for commercial land use because of stoniness and erosion hazard.

Correlations.—Includes small part of Victory land system of the Wanigela–Cape Vogel area and most of Uoive land system of the Safia–Pongani area.

Relationships.—Generally abruptly bounded by other land-form types.

VPd Land-form Type (500 km²)

Dissected gently sloping lower flanks of little-eroded andesitic strato-volcanoes (Plates 3, 5).

Terrain Parameters.—Altitude: 30–1000 m. Relief: 15–100 m. Characteristic slopes: 20–35%. Grain: variable, mainly 100–250 m.

Climate.—Zones III, IV.

Geology.—Andesitic ash and probably some agglomerate and lava; Recent.

Land Forms.—Dissected gently sloping foot slopes of recently active strato-volcanoes.
(1) *Accordant summit surfaces and ridge crests* (40%): up to 200 but mostly less than 50 m wide, 15–100 m above adjacent valley bottoms, smooth to gently undulating, axial slopes mainly 1–6°; microrelief up to 1 m.
(2) *Steep slopes* (60%): side slopes of ridges, also bordering incised streams; 50–300 m long; mainly 20–35° but locally precipitous; small slumps common.
(3) *Flood-plains* (<5%): less than 300 m wide, slopes up to 2°, *frequently flooded*; generally unstable, with braided streams.

Stream Pattern.—Subparallel to radial.

Soils.—(1), (2) Dark friable loam over lighter-coloured sandy loam; deep to moderately deep; weakly acid; very thin topsoils on steep slopes.
(3) Recent alluvial deposits.

Drainage.—Generally well drained but (3) is subject to frequent short periods of flooding.

Vegetation.—(1), (2) Large-crowned tall forest (*Pometia*, *Alstonia*, *Anisoptera*); medium-crowned forest above 500 m (*Castanopsis*, *Lithocarpus*, *Elaeocarpus*); woody seral communities (*Euroschinus papuanus*) in blast area of Mt. Lamington; also gardens, garden regrowth, grassland, and secondary forest.
(3) *Mainly herbaceous seral vegetation* (*Saccharum spontaneum*).

Forest Potential.—Forest resources moderate (FRI–41); high and moderate stocking rate forests cover 35% and 10% respectively on (1) and (2), whilst low stocking rate forest covers another 15%; (3) is virtually non-forested. Access poor (AI–32) due to high proportion of steep slopes on (2); access category S2. Forest productivity low due mainly to steep slopes on (2) and resultant difficult access to (1).

Land Use Potential.—Classes I–III, VII.
(1) Suitable for cultivation but slight erosion hazard.
(2) Unsuitable for commercial land use because of erosion hazard.
(3) Unsuitable for commercial land use because of frequent flooding.

Correlations.—Comprises Hamamutu, part of Higatura, and small part of Awala land systems of the Buna–Kokoda area and part of Kwin land system of the Wanigela–Cape Vogel area.

Relationships.—Sharply bounded by VAv and VBm land-form types but commonly merges into VPn land-form type.

VPn LAND-FORM TYPE (900 km²)

Undissected to slightly dissected gently sloping lower flanks of little-eroded mainly andesitic volcanoes (Plates 3, 5).

Terrain Parameters.—Altitude: 0–300 m. Relief: <15 m. Characteristic slopes: 1–5°. Grain: variable, mostly 250–500 m.

Climate.—Zones III, IV.

Geology.—Andesitic and minor basaltic ash, fanglomerate, and probably some lava and agglomerate; also minor alluvial sediments; Recent.

Land Forms.—Gently sloping foot slopes of volcanoes incised less than 15 m by major rivers in narrow flood-plains.
(1) *Gentle slopes* (95%): 1–5°, very long, slightly undulating, with incised narrow rounded gullies up to 15 m deep.
(2) *Flood-plains* (5%): slopes generally less than 1°; locally bordered by low terraces.

Stream Pattern.—Subparallel to radial.

Soils.—(1) Weathered brown ash soils and unweathered sandy volcanic soils.
(2) Recent alluvial deposits.

Drainage.—(1) Mostly well drained; locally poorly drained due to a slowly permeable layer in subsoil.
(2) Imperfectly to poorly drained.

Vegetation.—(1) Large-crowned tall forest (*Pometia, Anisoptera*) and its regrowth stages; also tall grassland (*Saccharum spontaneum*/*Imperata cylindrica*); seral communities (*Euroschinus papuanus, Saccharum spontaneum*) in blast area of Mt. Lamington; tall grassland regenerating to forest south-west of Mt. Victory; tall savannah of *Eucalyptus tereticornis* with ground layer of mainly *Saccharum spontaneum, Imperata cylindrica*, and *Coelorachis rottboellioides* south of Pongani.
(2) Remnants and regrowth stages of large-crowned tall forest (*Pometia, Alstonia, Octomeles*, locally *Tetrameles*).

Forest Potential.—Forest resources low (FRI–28); high to locally very high (*Octomeles* on (2)) stocking rate forest covers 35%, and moderate and low stocking rate forests each cover 5%. Access good (AI–79) but local poor drainage hazard on (2); access category S0. Forest productivity high.

Land Use Potential.—Classes I–III.
(1) Suitable for cultivation; slight hazards are erosion, and local poor drainage and soils with low moisture-holding capacities.
(2) Not suitable for cultivation because of poor drainage and flooding hazards.

Correlations.—Comprises Penderetta, Eundi, most of Awala and Bohu, and parts of Higatura and Popondetta land systems of the Buna–Kokoda area; parts of Kwin and Wanigela land systems of the Wanigela–Cape Vogel area; and Iwuji land system of the Safia–Pongani area.

Relationships.—Generally passes upslope into VPd and downslope into AWv land-form types. Locally contains unmapped inclusions of VPd and VAv land-form types.

DSf LAND-FORM TYPE (450 km²)

Closely dissected alluvial, colluvial, and mudflow fans of low to moderate relief formed on mainly coarse unconsolidated sediments (Plate 8).

Terrain Parameters.—Altitude: 100–1100 m. Relief: 10–200 m. Characteristic slopes: 25–45°. Grain: mainly <250 m.

Climate.—Zones III, IV.

Geology.—Unconsolidated to poorly consolidated alluvial and colluvial gravel, sand, silt, and clay; also local layers of ultramafic breccia; Pleistocene and Recent. Patchy veneer of Recent andesitic volcanic ash near Mt. Lamington.

Land Forms.—Closely dissected fans flanking mountain ranges. The fans consist of parallel to subparallel accordant ridges up to 200 m high separated by narrow V-shaped valleys; also include a corrugated surface in the eastern part of the Musa basin.
(1) *Ridge crests* (20%): up to 200 m wide, even to rounded and undulating, with slopes up to 20°; they slope down away from adjacent mountains and represent original fan surfaces.
(2) *Side slopes of ridges* (60%): straight or irregular, mainly 25–45° but steeper locally, with precipitous slopes and cliffs adjacent to some incised streams.
(3) *Corrugated surfaces* (20%): undulating, 0–20°, with small swampy patches in local level areas.

Stream Pattern.—Dense parallel to subparallel.

Soils.—Brown acid clay loam to clay over brown to reddish brown clay, moderately deep to deep but shallow and gravelly or stony on steep slopes; volcanic ash soils locally on crests.

Drainage.—Well drained, steepest slopes excessively drained.

Vegetation.—Mainly medium-crowned forest, locally with *Araucaria;* also small-crowned forest, locally with *Casuarina*, and large-crowned forest on gentle slopes. *Castanopsis* is predominant in forest above 500 m where ridges very closely spaced. Minor eucalypt savannah, mid-height grassland, and slightly deciduous forest with *Terminalia* and *Anisoptera* present in lowest parts in climatic zone III. Open forest, scrub, and low grassland occur on very steep and precipitous slopes. Gardens, regrowth, and secondary forest are widespread.

Forest Potential.—Forest resources moderate (FRI–42); high, moderate, and low stocking rate forests cover 15%, 40%, and 25% of the area; *Araucaria* moderately common, mainly scattered but locally in dense stands with very high stocking rate. Access poor (AI–27) mainly due to steep to locally precipitous slopes on (2); access category S2. Forest productivity low.

Land Use Potential.—Classes I–III, VI–VIII.
(1), (3) Suitable for cultivation, but hazards due to erosion.
(2) Unsuitable for commercial land use because of erosion hazard and stony soils.

Correlations.—Includes parts of Komondo and Kokoda land systems of the Buna–Kokoda area; Budi land system of the Wanigela–Cape Vogel area; and Wowo, Silimidi, Bariji, Sibium, and parts of Ibinambo and Siviai land systems of the Safia–Pongani area.

Relationships.—Generally sharply bounded but locally grades into and contains inclusions of DSw, FSn, and AWs land-form types.

DSw Land-form Type (440 km²)

Broadly dissected alluvial and mudflow fans of low to moderate relief, formed on unconsolidated sediments (Plate 8).

Terrain Parameters.—Altitude: 0–1000 m. Relief: 10–200 m. Characteristic slopes: 0°35′–5°. Grain: 250–500 m.

Climate.—Zones II–IV.

Geology.—Alluvial fan and mudflow deposits consisting mainly of unconsolidated gravel, sand, silt, and clay, with local layers of ultramafic breccia in the Musa basin; Pleistocene to Recent. Local veneer of Recent volcanic ash in vicinity of Mt. Lamington.

Land Forms.—Broadly dissected fans.
(1) *Fan surfaces* (90%): mainly flat to gently undulating, slopes up to 5°; commonly terraced, locally uneven, gullied; also hummocky and irregularly undulating surfaces with slopes up to 25°.
(2) *Very short steep slopes* (10%): adjacent to incised streams, mainly 30–50° but locally precipitous and cliffed; straight, concave, or irregular; landslips common.

Stream Pattern.—Subparallel traversing streams.

Soils.—Brown clay loam to clay over brown to reddish brown clay, moderately deep to shallow and locally stony.

Drainage.—Well to excessively drained.

Vegetation.—(1) Mainly large-crowned tall forest (*Pometia, Alstonia scholaris*, Lauraceae) in climatic zones III and IV; also medium-crowned forest and extensive areas of garden regrowth, secondary forest, plantation, and grassland; small-crowned forest in climatic zone II, with scattered to locally dense *Araucaria* and *Casuarina;* also eucalypt savannah.
(2) Small-crowned open forest, in climatic zone II mixed with scrub, savannah, and low grassland.

Forest Potential.—Forest resources moderate (FRI–42); high and moderate stocking rate forests on (1) cover 35% and 20% respectively, and low stocking rate forest on (1) and (2) covers 20%; *Araucaria* forest of variable stocking rate locally on (1). Access good (AI–73) except for steep to precipitous slopes on (2); access category S0. Forest productivity high.

Land Use Potential.—Classes II–III.
(1) Suitable for cultivation but local stoniness and erosion hazards.
(2) Unsuitable for cultivation because of erosion and stoniness hazards.

Correlations.—Includes part of Kokoda land system of the Buna–Kokoda area; Rakua and part of Uiaku land systems of the Wanigela–Cape Vogel area; and Darumu and parts of *Siviai* and *Ibinambo* land systems of the Safia–Pongani area.

Relationships.—Generally sharply bounded but locally grades into and contains unmapped inclusions of DSf, FSn, and AWs land-form types.

DSi Land-form Type (140 km²)

Irregularly dissected stepped fan surfaces and low cuestas; formed on poorly consolidated sediments (Plate 10).

Terrain Parameters.—Altitude: 180–700 m. Relief: up to 70 m. Characteristic slopes: 0°35′–5°. Grain: very variable because of irregular dissection.

Climate.—Zones II, III.

Geology.—Fanglomerate, mudstone, siltstone, sandstone, and conglomerate, mostly poorly consolidated; Plio–Pleistocene (Domara River Beds).

Land Forms.—(1) *Long gentle slopes* (85%): fan surfaces and dip slopes of cuestas; smooth to gently undulating and irregularly hummocky; slopes mainly 0–5°, locally up to 20°; small poorly drained to swampy flats present locally; includes some narrow to broad ridge crests.
(2) *Short straight steep slopes* (15%): form scarps, steps, and sides of incised valleys; slopes mainly 20–35° but locally steeper adjacent to incised streams.

Stream Pattern.—Subparallel to dendritic.

Soils.—(1) Moderately deep to deep sandy to gravelly clay loam over heavy clay.
(2) Shallow gravelly clay commonly with thick dark topsoil.

Drainage.—Generally well to excessively drained, but some local temporary waterlogging and poor drainage.
(2) Excessively drained.

Vegetation.—(1) Mainly *Eucalyptus alba* savannah, with minor medium-crowned slightly deciduous forest; poorly drained flats have *Nauclea–Antidesma* savannah with ground layer of tussocky mid-height grasses.
(2) Mainly medium-crowned slightly deciduous forest (*Anisoptera* common throughout), commonly with scrambling bamboo; also *Eucalyptus alba* savannah.

Forest Potential.—Forest resources very low (FRI–8); moderate and low stocking rate forests cover 15% and 5% respectively. Access good (AI–66); minor poor drainage hazard on (1); access category S1. Forest productivity low.

Land Use Potential.—Class VI.
(1) Unsuitable for cultivation because of poor physical soil conditions.
(2) Unsuitable for cultivation because of gravelly soils and erosion hazard.

Correlations.—Comprises part of Asaga land system of the Safia–Pongani area.

Relationships.—Generally abruptly bounded, but has minor inclusions of and locally grades into YHb, YSi, and AWs land-form types.

DSh Land-form Type (70 km²)

Hill and mountain ridges representing dissected alluvial and colluvial fans; formed on poorly consolidated sediments (Plate 11).

Terrain Parameters.—Altitude: 200–1200 m. Relief: 200–500 m. Characteristic slopes: 30–45°. Grain: 500–1500 m.

Climate.—Zone IV.

Geology.—Poorly consolidated colluvial and alluvial gravel, sand, silt, and clay; Pleistocene. Many surfaces with mantle of Recent andesitic volcanic ash.

Land Forms.—Hill and mountain ridges of deeply dissected fans.
(1) *Ridge crests* (20%): more or less accordant, rounded to undulating, up to 300 m wide, slopes 0–20°; broad crests represent original fan surfaces.
(2) *Side slopes* (80%): mainly 25–45°, upper slopes generally straight, lower slopes irregular, with precipitous slopes and cliffs along incised streams; gullies and slumps common.

Soils.—(1) Volcanic ash soils consisting of acid to weakly acid yellow-brown friable sandy loam to sandy clay with generally thick dark topsoils; also brown to yellow-red heavy clay.
(2) Acid clay with or without ash admixture, thin topsoils.

Drainage.—Well drained.

Stream Pattern.—Subparallel, open.

Vegetation.—Medium-crowned forest, largely secondary.

Forest Potential.—Forest resources low (FRI–28); moderate and low stocking rate forests cover 55% and 10% respectively. Access very poor (AI–10) due to steep to precipitous slopes on (2); access category S3. Forest productivity very low.

Land Use Potential.—Classes VII–VIII.
(1) Suitable for cultivation where not too steep; erosion main hazard.
(2) Unsuitable for commercial land use because of erosion hazard.

Correlations.—Includes part of Komondo land system of the Buna–Kokoda area and Kovio land system of the Safia–Pongani area.

Relationships.—Boundaries generally sharply defined.

EAv Land-form Type (2650 km²)

Very steep-sided mountain ridges and spurs of deeply eroded andesitic and basaltic strato-volcanoes (Plate 5).

Terrain Parameters.—Altitude: 0–3000 m. Relief: generally >400 m. Characteristic slopes: 30–45°. Grain: generally 500–1000 m.

Climate.—Zones III–V.

Geology.—Andesitic and basaltic lava, agglomerate, and tuff, gently dipping; Pleistocene.

Land Forms.—Mountain ridges and spurs and narrow V-shaped valleys.
(1) *Ridge and spur crests* (10%): mostly less than 50 m wide, uneven to very uneven, slopes up to 30°.
(2) *Gentle to moderate upper slopes* (5%): 5–20°, commonly undulating and incised by small streams.
(3) *Very steep side slopes* (85%): mainly 30–45°, straight, gullied; also local precipitous slopes and cliffs with rock faces.
(4) *Concave foot slopes* (<5%): 5–25°, bouldery surfaces.

Stream Pattern.—Dendritic to subparallel or radial.

Soils.—Acid red and brown clay, shallow and stony on steep slopes; locally ash soils on crests.

Drainage.—Well drained.

Vegetation.—Mainly medium-crowned forest below 1400 m, lower montane forest above; also small-crowned forest, grassland, and minor eucalypt savannah (in climatic zone III) and seral forest near the summits of Mt. Lamington and Mt. Victory.
(1), (2) Medium-crowned forest below 1400 m, in many places with *Castanopsis* predominant above 500 m; lower montane forest, locally with *Nothofagus*, above 1400 m.
(3) Medium- and small-crowned forest; lower montane forest; some grassland on steepest slopes.
(4) Medium- and small-crowned forest; mid-height grassland; minor eucalypt savannah in climatic zone III.

Forest Potential.—Forest resources moderate (FRI–42); forests of moderate stocking rate cover 70% of area including local stands of high stocking rate *Nothofagus;* low stocking rate forests cover 25%, with *Castanopsis* often dominant on (1). Access very poor (AI–7); slope hazard throughout but mainly on (3); access category S3. Forest productivity very low to nil due to slope hazard.

Land Use Potential.—Classes VII–VIII. Mainly unsuitable for commercial land use because of severe erosion hazard.

Correlations.—Includes most of Hydrographers and small part of Lamington land systems of the Buna–Kokoda area; most of Trafalgar and small part of Bekalama land systems of the Wanigela–Cape Vogel area; and Hydrographers and most of Sesaro land systems of the Safia–Pongani area.

Relationships.—Locally merges into EAe, EAf, and EAw land-form types.

EAe Land-form Type (1000 km²)

Very steep and precipitous slopes and cliffs of deeply eroded volcanic terrain formed on andesitic and basaltic rocks (Plate 13, Fig. 2).

Terrain Parameters.—Altitude: 200–3000 m. Relief: generally >400 m. Characteristic slopes: 40–50°. Grain: mainly 250–1000 m.

Climate.—Zones II–V.

Geology.—Andesitic and basaltic agglomerate, lava, and tuff on upper slopes; Pliocene and Pleistocene. Mainly Recent volcanic debris on lower slopes.

Land Forms.—Very steep and precipitous slopes and cliffs forming scarps and knife-edged ridges, locally with short steep spurs; some very minor valley floors up to 50 m wide with slopes up to 5°. Streams mainly ephemeral or intermittent, especially in climatic zones II and III.
(1) *Upper slopes* (30%): 50–90°, mostly over 300 m long; rock faces with joint-controlled clefts and buttresses very common.
(2) *Lower slopes* (70%): 20–50°; over 500 m long, straight to weakly concave and commonly uneven to very uneven with bouldery microrelief; minor local narrow benches with slopes less than 10°.

Stream Pattern.—Subparallel.

Soils.—Strongly acid red to brown friable clay; shallow brown stony clay over weathered rock.

Drainage.—Well drained.

Vegetation.—Medium- and small-crowned forest, lower montane forest, minor eucalypt savannah; some gardens, garden regrowth, and secondary forest near perennial streams.
(1) Small-crowned forest below 1400 m, locally with *Casuarina* and *Castanopsis* predominant on crests, also minor savannah (*Eucalyptus tereticornis*) in climatic zones II and III; lower montane forest above 1400 m.
(2) Medium-crowned forest, slightly deciduous in climatic zones II and III.

Forest Potential.—Forest resources moderate (FRI–41); forests of moderate and low stocking rate cover 65% and 30% respectively; *Castanopsis* locally dominant on ridge crests. Access nil (AI–0); slope hazards throughout; access category S3. Forest productivity nil due to slope hazard and relief.

Land Use Potential.—Classes VII–VIII. Unsuitable for commercial land use because of severe erosion and stoniness hazards.

Correlations.—Includes most of Uberi and part of Rouna land systems of the Port Moresby–Kairuku area.

Relationships.—Locally merges into and contains small unmapped inclusions of EAv land-form type.

EAf Land-form Type (1250 km²)

Closely dissected lower flanks of eroded andesitic volcanoes (Plate 5).

Terrain Parameters.—Altitude: 0–1000 m. Relief: 20–150 m, but mainly <75 m. Characteristic slopes: 20–35°. Grain: 100–250 m.

Climate.—Zones II–IV.

Geology.—Andesitic and basaltic ash, tuff, agglomerate, fanglomerate, and lava; Pleistocene. Many surfaces in vicinity of Mt. Lamington have veneer of Recent andesitic ash.

Land Forms.—Long parallel accordant hill ridges and steep-sided V-shaped valleys on the lower flanks of deeply eroded strato-volcanoes.
(1) *Ridge crests* (15%): 5–200 m wide, commonly slightly undulating axial slopes 1–5°.
(2) *Steep hill slopes* (80%): mostly 20–35°, locally precipitous; 100–300 m long, straight or uneven, with slumps and bouldery surfaces common.
(3) *Moderate to gentle foot slopes* (<5%): slopes up to 15°.
(4) *Flood-plains* (<5%): less than 400 m wide, axial slopes up to 2°.

Stream Pattern.—Subparallel to radial.

Soils.—Acid friable clay loam, commonly with volcanic ash admixture; also acid red to brown clay.

Drainage.—Well drained.

Vegetation.—(1), (2) In climatic zones III and IV, large-crowned tall forest (*Pometia, Alstonia, Anisoptera*) with medium-crowned forest (*Castanopsis, Lithocarpus, Elaeocarpus*) above 500 m; in climatic zone II, small-crowned slightly deciduous forest (*Intsia, Albizia*); extensive areas of plantation, garden, garden regrowth, and secondary forest.
(3) In climatic zones III and IV, large-crowned tall forest; in climatic zone II, small-crowned slightly deciduous forest, mid-height grassland (*Themeda australis*), woodland (*Eucalyptus, Acacia*). and eucalypt savannah.
(4) Large-crowned tall forest (*Pometia, Alstonia, Octomeles, Artocarpus*) and tall grassland (*Saccharum spontaneum/Imperata cylindrica*).

Forest Potential.—Forest resources low (FRI–30); high stocking rate forest (10%) on (3) and (4); moderate stocking rate forest (30%) mainly in climatic zones III and IV; low stocking rate forest (30%) throughout all zones, often dominated by *Castanopsis* on (1). Access very poor (AI–21); slope hazard on (2), drainage and minor flooding hazards on (4); access category S2. Forest productivity very low due to steep slopes on (2).

Land Use Potential.—Classes VII–VIII, III, VI.
(1), (2) Suitable for cultivation but some erosion hazards.
(3) Unsuitable for commercial land use because of erosion hazard.
(4) Unsuitable for cultivation because of flooding and drainage hazards.

Correlations.—Includes small part of Hydrographers land system of the Buna–Kokoda area; part of Trafalgar land system of the Wanigela–Cape Vogel area; Tahama, part of Gorabuna, and small part of Uoive land systems of the Safia–Pongani area; and part of Kanosia and most of Mariboi and Rubberlands land systems of the Port Moresby–Kairuku area.

Relationships.—Boundaries generally abrupt but locally gradational with EAw and EAv land-form types.

EAw Land-form Type (900 km²)

Broadly dissected lower flanks of deeply eroded andesitic and basaltic strato-volcanoes (Plate 19, Fig. 2).

Terrain Parameters.—Altitude: 0–700 m. Relief: 100–250 m. Characteristic slopes: 20–40°. Grain: generally 250–500 m.

Climate.—Mainly zones III, IV, small part in zone II.

Geology.—Andesitic and basaltic agglomerate, tuff, lava, breccia, and fanglomerate; Pliocene and Pleistocene. Mantle of Recent andesitic ash on many surfaces near Mt. Lamington and Mt. Victory.

Land Forms.—Very long parallel to subparallel ridges, with accordant crests descending at 2–6° from deeply eroded volcanic centres; narrow U- and V-shaped valleys up to 250 m deep.
(1) *Summit surfaces* (25%): range from rounded ridge crests less than 50 m wide to plateau-like planezes up to 1000 m wide; undulating to hilly, with 10–50 m local relief and slopes up to 20°.
(2) *Valley sides* (75%): slopes mainly 20–40°, locally precipitous and cliffed; short spurs with crestal slopes up to 35° commonly present.

Stream Pattern.—Subparallel to radial.

Soils.—Acid friable red and brown clay on undulating terrain; strongly acid yellow-brown silty clay loam to silty clay, commonly shallow and stony, on steep slopes; volcanic ash soils locally on crests.

Drainage.—Well to excessively drained.

Vegetation.—West and south of Owen Stanley Range: small- and medium-crowned forest, slightly deciduous in climatic zone II generally and zone III on summit surfaces, *Castanopsis*, *Lithocarpus*, and *Elaeocarpus* very common genera above 500 m. North-east of Owen Stanley Range: grassland mainly on summit surfaces and secondary forest mainly on valley sides. Minor areas of eucalypt savannah on lowest slopes in climatic zones II and III.

Forest Potential.—Forest resources low (FRI–28); moderate and low stocking rate forests cover 45% and 30% respectively. Access very poor (AI–14) due mainly to steep to locally precipitous valley sides in (2); access category S3. Forest productivity very low.

Land Use Potential.—Classes VI–VIII. Mostly unsuitable for cultivation because of severe erosion hazard on steep slopes; flat areas suitable for cultivation.

Correlations.—Includes small part of Hydrographers land system of the Buna–Kokoda area; most of Bekalama land system of the Wanigela–Cape Vogel area; Banderi land system of the Safia–Pongani area; and small parts of Rubberlands and Mariboi land systems of the Port Moresby–Kairuku area.

Relationships.—Locally merges into EAv and EAf land-form types and in places contains small unmapped inclusions of EAv, EAf, and AWs land-form types.

PBn Land-form Type (220 km²)

Dissected plateaux of very low relief on basaltic volcanic rocks (Plate 13, Fig. 2).

Terrain Parameters.—Altitude: 0–700 m. Relief: mainly 15–30 m. Characteristic slopes: 15–20°. Grain: 100–250 m.

Climate.—Zones II–IV.

Geology.—Basaltic and minor andesitic tuff, lava, dyke rocks, agglomerate, and fanglomerate; some limestone in north; Tertiary.

Land Forms.—Dissected plateaux consisting of parallel and branching accordant ridges and spurs up to 30 m high, with some undulating terrain and flat valley floors.
(1) *Ridge crests* (15%): rounded, up to 100 m wide, gently undulating, slopes mainly less than 5°.
(2) *Hill slopes* (60%): up to 450 m long; slopes mainly 15–20°, locally steepening to 30°.
(3) *Undulating terrain* (15%): up to 15 m relief, slopes up to 6°.
(4) *Valley floors* (10%): up to 100 m wide, slopes up to 5°, with alluvial terraces up to 5 m above mean river level.

Stream Pattern.—Dense dendritic.

Soils.—Mainly strongly acid, friable red and brown clay, rapidly permeable; acid brown clay on valley floors.

Drainage.—Mainly well drained, but valley floors imperfectly to poorly drained.

Vegetation.—Sogeri plateau: in the south-west, savannah of *Eucalyptus tereticornis* with ground layer of mainly *Ophiuros tongcalingii;* in higher and wetter north-east, rubber plantations, gardens, locally mid-height grassland (*Ophiuros tongcalingii*/*Imperata cylindrica*), and mainly small-crowned, locally medium-crowned, forest with *Castanopsis* and *Elaeocarpus*. North-east coast: small-crowned forest (*Anisoptera*, *Eucalyptopsis*), regrowth, and gardens. Minor medium- to large-crowned forest, in many places disturbed, on alluvial terraces and along creeks.

Forest Potential.—Forest resources very low (FRI–6); forests of high and moderate stocking rate cover 5% mainly on (4) and (3) and forests of low stocking rate cover 10% of the area. Access moderate (AI–47); slope hazard on (2), drainage and minor flooding hazards on (4); access category S1. Forest productivity very low to nil.

Land Use Potential.—Classes VII, II.
(1), (3) Suitable for cultivation (minor erosion hazard).
(2) Not suitable for cultivation (erosion hazard).
(4) Not suitable for cultivation (poor drainage and flooding hazards).

Correlations.—Comprises part of Iauga land system of the Buna–Kokoda area and Sogeri and Subitana land systems of the Port Moresby–Kairuku area.

Relationships.—Grades into and has minor inclusions of PBy land-form type; otherwise sharply bounded.

PBy Land-form Type (650 km²)

Dissected plateau surfaces of moderate relief on basaltic volcanic rocks (Plate 13, Fig. 2).

Terrain Parameters.—Altitude: 0–1500 m. Relief: 30–200 m. Characteristic slopes: 20–30°. Grain: generally 50–250 m.

Climate.—Mainly zones III and IV, small part in zone II.

Geology.—Basaltic lava, agglomerate, tuff, and dyke rocks; minor limestone in north-west and south-east; Tertiary (probably mainly Pliocene).

Land Forms.—Finely dissected plateau surfaces consisting of mainly accordant ridges with prominent spurs.

(1) *Ridge crests* (10%): rounded, up to 50 m wide, even to gently undulating.
(2) *Hill slopes* (85%): mainly 150–300 m long, 20–30°; slumps and terracettes common.
(3) *Valley floors* (5%): up to 300 m wide, slopes 0–5°.

Stream Pattern.—Dense dendritic.

Soils.—Strongly acid friable red and brown clay, rapidly permeable; also local lithosols: slightly acid friable clay; on valley floors, acid brown clay.

Drainage.—Well drained except for valley floors which are imperfectly drained.

Vegetation.—Mainly small-crowned forest, above 500 m with *Castanopsis* very common, locally with *Casuarina*, and in the east with *Hopea* predominant. Minor *Eucalyptus tereticornis* savannah in climatic zone II. Large-crowned forest on valley floors. Very little regrowth and secondary forest except in north near Douglas Harbour.

Forest Potential.—Forest resources low (FRI–21); forests of high stocking rate (1%) on (3) and moderate stocking rate (10%), the latter locally dominated by *Hopea* in east; remaining 60% low stocking rate forest with *Castanopsis* very common. Access poor (AI–29); slope hazard on (2) and drainage hazard on (3); access category S1. Forest productivity low to moderate.

Land Use Potential.—Class VII. Mostly unsuitable for commercial land use because of erosion hazard due to steep slopes, also locally shallow stony soils.

Correlations.—Includes part of Iauga land system of the Buna–Kokoda area, and Vouku and Owers land systems of the Port Moresby–Kairuku area.

Relationships.—Locally grades into PBn, BAv, MBv, and ZBb land-form types, all of which, with AWs land-form type, occur locally as minor unmapped inclusions.

PMi Land-form Type (650 km²)

Irregular summit surfaces on mainly foliated metamorphic rocks (Plate 7; Plate 21, Fig. 1).

Terrain Parameters.—Altitude: 2000–3500 m. Relief: generally 200–400 m. Characteristic slopes: 20–30°. Grain: variable, mainly in range of 250–1000 m.

Climate.—Zones V–VI.

Geology.—Schist and phyllite (Owen Stanley Metamorphics), minor granite; Tertiary and Mesozoic.

Land Forms.—Irregular summit surfaces consisting of branching ridges and spurs mainly less than 300 m high, with narrow V-shaped valleys, undulating shallowly dissected remnant surfaces mainly forming watershed areas, and flat valley floors.
(1) *Ridge and spur crests* (10%): mainly 0–50 m wide, rounded, slopes generally less than 10°.
(2) *Side slopes* (60%): variable length, straight or irregular, generally 15–30°, but locally steeper; gullied.
(3) *Remnant undulating surfaces* (20%): up to 200 m local relief, slopes generally less than 20°; shallow basins locally present on broad summit areas.
(4) *Valley floors* (10%): locally over 300 m wide, represent inclusions of FSa land-form type.

Stream Pattern.—Generally dendritic, but irregular.

Soils.—Mainly humic brown clay, shallow to moderately deep; with peaty soils on valley floors.

Drainage.—Generally well drained but valley floors permanently waterlogged.

Vegetation.—Mainly coniferous lower montane forest (*Dacrycarpus, Phyllocladus, Papuacedrus, Syzygium,* Cunoniaceae; *Araucaria* near Mt. Orian). Forest becomes smaller crowned and conifers more prominent with increasing altitude. Tree height decreases towards crests and on highest crests the forest commonly degenerates to scrub. Low to mid-height tussock grassland (*Danthonia archboldii, Agrostis reinwardtii*) with more or less dense low shrubs (*Hypericum, Styphelia*) mainly in valleys but locally also on crests. Tree ferns (*Cyathea* spp.) common in grassland near forest edge. Flat valley floors have a mixed vegetation of low grasses, sedges, ferns, and many herbs.

Forest Potential.—Forest resources low (FRI–22); forests of moderate and low stocking rate cover 10% and 40% respectively mainly on (1) and (2) and locally on (3); locally high stocking rate stands of *Araucaria* totalling 3%. Access poor (AI–30); slope hazard on (2), drainage hazard on (4); access category S2. Forest productivity very low to nil due to altitude and poor access of surrounding land.

Land Use Potential.—Classes V–VII.
(1), (3) Unsuitable or only marginally suitable for cultivation because of erosion hazard and frost hazard above 2600 m.
(2) Not suitable for cultivation because of erosion hazard.
(4) Not suitable for cultivation because of poor drainage.

Correlations.—Not present in previously mapped areas.

Relationships.—Boundaries mostly well defined but locally gradational with PMb land-form type, which also occurs as unmapped inclusions in PMi.

PMg Land-form Type (220 km²)

Glaciated mountain summits on foliated metamorphic rocks (Plate 7).

Terrain Parameters.—Altitude: >3500 m. Relief: generally <400 m, locally up to 700 m. Characteristic slopes: 5–10°. Grain: very variable, generally >1000 m.

Climate.—Zone VI.

Geology.—Mainly schist (Owen Stanley Metamorphics); Tertiary and Mesozoic. Patchy veneer of late Pleistocene glacial and fluvioglacial deposits and Recent peat.

Land Forms.—Glaciated terrain with rocky crags, cirques, rock basins, and moraine ridges. Numerous lakes and swamps occur in rock basins and on cirque floors. Slopes are generally less than 10°, but range from 30° to nearly vertical on the sides of summit ridges and U-shaped valleys, on crags, and on cirque back walls. Main units are
(1) *Irregularly undulating plateau surfaces* (75%).
(2) *Steep to very steep-sided summit ridges* (20%).
(3) *Flat-bottomed U-shaped valleys* (5%).

Stream Pattern.—Dendritic, open and irregular.

Soils.—Shallow peat; rock outcrop.

Drainage.—Poorly drained to permanently waterlogged or swampy.

Vegetation.—Undulating plateau surfaces have mainly low and rather open tussock grassland (*Deschampsia klossii, Dichelachne, Deyeuxia, Danthonia vestita*) with mosses and low herbs (*Plantago,*

Potentilla, Ranunculus, Tetramolopium) between tussocks; also very scattered shrubs (Ericaceae, *Hypericum, Styphelia, Coprosma*) and occasional tree ferns; swampy parts have mainly sedges such as *Oreobolus;* lakes have aquatic vegetation (*Isoetes, Callitriche*) or open water. Summit ridge crests are bare or have low open grassland with mosses, ferns (*Gleichenia vulcania*), herbs, and very low shrubs. Remnants of montane forest persist on steep slopes, especially on plateau edges; conifers (*Dacrycarpus compactus, Papuacedrus papuana*) form canopy up to 20 m high. Dense shrubbery of *Pittosporum, Coprosma*, Ericaceae, Myrsinaceae, and seedlings and saplings of *Dacrycarpus* and *Papuacedrus* form a transition zone between forest and grassland.

Forest Potential.—Forest resources nil (FRI–2); low stocking rate coniferous forest covers 5% mainly on (2). Access very poor (AI–26); slope hazard on (2), drainage hazard on (1) and (3); access category S0W2. Forest productivity nil due to low stocking rate, small forest area, altitude, and surrounding inaccessible land.

Land Use Potential.—Class VIII. Unsuitable for commercial land use because of poor soils, poor drainage, frost hazard, and also inaccessibility.

Correlations.—Not present in previously surveyed areas.

Relationships.—Boundary is lower limit of Pleistocene glaciation as indicated by glacial land forms identified on air photographs.

PMb Land-form Type (290 km²)

Deeply dissected plateaux on mainly foliated metamorphic rocks (Plate 18, Fig. 1).

Terrain Parameters.—Altitude: 200–3000 m; Relief: mainly 200–400 m. Characteristic slopes: 30–45°. Grain: 250–500 m.

Climate.—Mainly zones III–V, small part in zone VI.

Geology.—Phyllite and schist (Owen Stanley Metamorphics), also local basaltic volcanics; Tertiary and Mesozoic.

Land Forms.—Branching ridges and spurs of ridge-and-ravine type.
(1) *Ridge and spur crests* (10%): 5–50 m wide, even to uneven, with slopes up to 30°.
(2) *Side slopes* (90%): 30–45°, mainly 200–500 m long, gullies, landslides, and slumps very common.
(3) *Foot slopes* (<5%): locally present, 0–35°, irregular, hummocky.
(4) *Valley floors* (<5%): generally less than 300 m wide, slopes less than 5°, terraces commonly present.

Stream Pattern.—Dense dendritic.

Soils.—Acid yellow-brown friable clay, humic above 2000 m.

Drainage.—Well drained.

Vegetation.—Small-crowned forest with *Castanopsis* predominant in climatic zones III and IV, elsewhere as in PMi land-form type.

Forest Potential.—Forest resources low (FRI–23); forests of moderate and low stocking rate cover 10% and 70% respectively; variable (low to very high) stocking rate *Araucaria* forest covers 2%. Access nil to very poor (AI–5); slope hazard; access category S3. Forest productivity nil to very low due to poor access of surrounding land.

Land Use Potential.—Class VIII. Largely unsuitable for commercial land use because of erosion hazard.

Correlations.—Not present in previously mapped areas.

Relationships.—Boundaries generally well defined, but PMb locally grades into PMi, MBv, and ZBb land-form types.

UHr Land-form Type (380 km²)

Dissected plains consisting of very low rounded ridges and gently undulating terrain on mainly coarse-grained variably consolidated sediments (Plate 12).

Terrain Parameters.—Altitude: 5–130 m. Relief: 10–30 m. Characteristic slopes: 10–20°. Grain: generally <100 m.

Climate.—Zone IV.

Geology.—Largely piedmont deposits consisting of variably consolidated sand and gravel of mainly basaltic composition.

Land Forms.—Intricate pattern of very low ridges and narrow valleys, with gently undulating terrain and minor terraces. Gorges locally over 30 m deep occur along the incised Mambare River and its tributaries.
(1) *Ridges* (60%): 10–30 m high, with narrow rounded accordant crests and very short side slopes of 5–30° but mostly 10–20°.
(2) *Gently undulating terrain* (35%): slopes up to 5°, relief less than 10 m.
(3) *Terraces* (5%): slopes less than 1°, situated along Gira River.

Stream Pattern.—Intricate dendritic.

Soils.—Friable red acid clay.

Drainage.—Well drained.

Vegetation.—Small-crowned forest with uneven canopy and local groups of large-crowned trees; minor secondary forest and garden regrowth.

Forest Potential.—Forest resources moderate (FRI–53); moderate and low stocking rate forests cover 80% and 10% respectively. Access moderate (AI–53); hazards are some steep slopes on (1) and local gorges along the Mambare River and its tributaries; access category S1. Forest productivity moderate.

Land Use Potential.—Classes VI, II–III.
(1) Not suitable for cultivation because of erosion hazard.
(2) Suitable for cultivation, but slight erosion hazard and low fertility as soils strongly weathered.
(3) Suitable for cultivation.

Correlations.—Includes Ioma land system of the Buna–Kokoda area.

Relationships.—Locally merges with XHv land-form type and contains minor unmapped inclusions of XHv and AS land-form types. Boundary with AS land-form type is very intricate in detail and is much generalized on the land-form type map.

USu Land-form Type (950 km²)

Gently to very gently undulating terrain of very low relief on unconsolidated and consolidated sedimentary rocks (Plate 2; Plate 14, Fig. 1).

Terrain Parameters.—Altitude: 0–100 m. Relief: 10–30 m. Characteristic slopes: 1–5°. Grain: very variable, mostly 250–1000 m.

Climate.—Zones I–IV.

Geology.—Unconsolidated flat-lying alluvial clay, silt, sand, gravel, and coralline limestone; Pleistocene and Recent; also consolidated moderately to steeply dipping mudstone, sandstone, siltstone, and conglomerate, with basaltic volcanics, and minor gabbro; Tertiary.

Land Forms.—(1) *Interfluves* (90%): flat or very gently undulating crests; sides generally less than 5°, with mainly convex upper slopes and concave lower slopes; minor steeper slopes, 5–30°, border some incised streams, valley floors, and hill and swamp inclusions; bouldery surfaces present locally and channelled and hummocky microrelief common.
(2) *Valley floors* (10%): up to 800 m wide, slopes mostly less than 0°30′, often poorly drained or swampy; low terraces present locally; streams generally incised up to 3 m; channelled and hummocky microrelief up to 1 m common.

Stream Pattern.—Dendritic, open.

Soils.—(1) Mainly texture-contrast soils with coarser-textured surface horizon passing abruptly into a fine-textured subsurface horizon. Friable to firm sandy loam to sandy clay loam to clay over firm sandy clay to heavy clay, subsoil commonly mottled, with iron and manganese concretions and quartzite gravel often present; also red and brown clay, mostly acid; flat parts have acid brown clay or neutral olive-grey silty clay with gilgai locally present.
(2) Dark cracking heavy clay; acid brown or grey clay; grey sticky clay in swamps.

Drainage.—(1) Generally poorly drained; waterlogged in wet season as soils slowly permeable; perched water-table commonly present.
(2) Imperfectly to poorly drained.

Vegetation.—Climatic zones I and II: mainly eucalypt savannah and monsoonal woodland; also small-crowned, slightly to strongly deciduous forest.
Climatic zone III: mainly forest; also thin-stemmed low savannah of *Melaleuca* or *Melaleuca–Eucalyptus* with ground layer commonly of *Themeda novoguineensis;* the forest is a mixture of small-crowned dense forest on slopes and in depressions lacking through-going streams, and medium-crowned forest usually along rivers; *Hopea* common to locally predominant east from Marshall Lagoon.
Climatic zone IV: small-crowned, rather tall, slender, dense forest with *Hopea* common throughout and *Vatica* normally present; minor pandan savannah with ground layer of tall fern. Also much secondary forest and mid-height and tall grassland near population centres.

Forest Potential.—Forest resources moderate (FRI–43); *c.* 65% forested, mainly in climatic zones III and IV; forests generally rather thin-stemmed and stocking rates moderate, but *Hopea* common to predominant in many localities. Low relief facilitates access, but poor drainage is a hazard (AI–67); access category S0W1. Forest productivity moderate.

Land Use Potential.—Classes III–IV, VI.
(1) Suitable to marginally suitable for cultivation because of erosion, water stress, and waterlogging hazards; flat parts not suitable for cultivation because of poor drainage.
(2) Marginally suitable for cultivation (drainage, water stress, *not easily worked) to not suitable for cultivation because of poor* drainage, flooding hazard.

Correlations.—Includes Tsiria and parts of Nikura, Kanosia, Piunga, and Inaukina land systems of the Port Moresby–Kairuku area, and Olipai land system of the Kerema–Vailala area.

Relationships.—Locally merges with and has inclusions of AS, AWs, APf, XXu, XHs, and YHp land-form types. Boundaries with AS land-form type commonly have the highly indented outlines of drowned valleys.

UK Land-form Type (55 km²)

Raised reefs of coralline limestone forming gently undulating terrain of very low relief (Plate 18, Fig. 2).

Terrain Parameters.—Altitude: 0–50 m. Relief: generally <15 m. Grain: generally >1000 m. Characteristic slopes: 0°35′–5°.

Climate.—Zone II.

Geology.—Coralline limestone; Pleistocene to Recent.

Land Forms.—*Smooth to gently undulating terrain, slopes 0–5°* with minor benches and steep to very steep slopes adjacent to sinuous incised streams. Rock outcrops up to 1 m high common.

Stream Pattern.—Very open dendritic.

Soils.—Dark-coloured friable heavy clay, shallow to moderately deep; rock outcrop common.

Drainage.—Well to excessively drained.

Vegetation.—Mid-height grassland (*Eulalia leptostachys, Imperata cylindrica, Heteropogon contortus*) and medium- and small-crowned slightly deciduous forest (*Rhus, Terminalia, Gmelina, Endospermum, Semecarpus, Canarium*).

Forest Potential.—Forest resources very low (FRI–6); low stocking rate forest covers 25%. Access generally very good (AI–95); access category S0. Forest productivity nil to very low.

Land Use Potential.—Classes VI–VIII. Not suitable for cultivation because of shallow stony soils, erosion hazard.

Correlations.—Includes most of Tarakaruru land system of the Wanigela–Cape Vogel area.

Relationships.—Sharply bounded by adjacent land-form types.

XHs Land-form Type (160 km²)

Intricate pattern of accordant low hill ridges with steep to moderate slopes on consolidated sedimentary rocks (Plate 15, Fig. 2).

Terrain Parameters.—Altitude: 0–200 m. Relief: up to 80 m. Grain: 50–250 m. Characteristic slopes: 15–30°.

Climate.—Zones II, III.

Geology.—Mudstone, siltstone, greywacke, sandstone, and subordinate limestone; Tertiary (Upper Miocene and Pliocene).

Land Forms.—Branching low hill ridges and narrow V-shaped valleys.
(1) *Ridge crests* (5%): rounded, mainly 5–50 m wide, slopes up to 10°.
(2) *Steep side slopes* (85%): generally 15–30° but locally steeper; less than 150 m long.
(3) *Gentle to moderate slopes* (10%): mainly foot slopes, 2–15°.
(4) *Valley floors* (<5%): generally less than 30 m wide; locally swampy.

Stream Pattern.—Dense dendritic.

Soils.—Reddish brown, yellowish brown, and olive-brown clay loam to clay; also sandy soils, commonly gravelly; mottling in subsoil and slight texture contrast common, thick dark topsoils present locally, mainly acid to strongly acid.

Drainage.—Well drained.

Vegetation.—Small-crowned forest, locally very small-crowned with patches of *Melaleuca* savannah and grassland. Also medium-crowned forest. Open forest with irregular canopy and local sago palm on valley floors.

Forest Potential.—Forest resources very low (FRI–15); moderate and low stocking rate forests cover 5% and 50% of the area respectively. Access poor (AI–29); slope hazards on (2); access category S2. Forest productivity very low.

Land Use Potential.—Classes IV–VII. Generally unsuitable for cultivation because of erosion, moisture stress.

Correlations.—Comprises Hauta and Maipora land systems of the Kerema–Vailala area.

Relationships.—Merges with and contains minor inclusions of USu land-form type.

XHv Land-form Type (600 km²)

Intricate pattern of low hills and ridges with very steep slopes on consolidated sedimentary rocks (Plate 12).

Terrain Parameters.—Altitude: 0–300 m. Relief: generally 30–100 m. Characteristic slopes: 25–40°. Grain: 50–250 m.

Climate.—Zones III, IV.

Geology.—Sandstone, siltstone, conglomerate, limestone, tuff, basaltic and intermediate lava, and pyroclastics; Tertiary and Upper Cretaceous.

Land Forms.—Intricately dissected low hills and ridges with minor local undulating terrain; summits roughly accordant.
(1) *Hill and ridge crests* (10%): generally less than 15 m wide; very uneven, slopes up to 30°, summits commonly pyramidal; local bouldery microrelief.
(2) *Side slopes* (70%): mostly straight, less than 150 m long; generally 25–40° but short precipitous slopes and cliffs common; unstable, with terracettes, slumps, landslides, gullies, and bouldery surfaces.
(3) *Undulating terrain* (10%): relief generally less than 30 m; slopes less than 10°.
(4) *Valley floors* (10%): up to 100 m wide, slopes 0–4°; meandering channels commonly flanked by low terraces.

Stream Pattern.—Dense dendritic.

Soils.—Red and brown clay; also lithosols; shallow sandy clay loam to clay over weathered rock.

Drainage.—Well to excessively drained.

Vegetation.—Mainly small-crowned forest, in the east with *Hopea*, slightly deciduous in climatic zone III. Also medium-crowned forest. Minor eucalypt savannah in climatic zone III. Open irregular forest on valley floors.

Forest Potential.—Forest resources low (FRI–33); moderate and low stocking rate forests cover 40% and 55% of the land respectively; *Hopea* locally dominant in the east. Access poor (AI–21); slope hazard on (2) and locally on (1); access category S2. Forest productivity very low due to poor access.

Land Use Potential.—Class VII. Unsuitable for cultivation because of erosion hazard and shallow soils.

Correlations.—Includes most of Mt. Green land system of the Buna–Kokoda area and lowest part of Edebu land system of the Port Moresby–Kairuku area.

Relationships.—Grades into YXd land-form type near Port Moresby and UHr land-form type north-west of Mt. Lamington. Minor unmapped inclusions of UHr and YKr land-form types occur in northern part of area. XHv is distinguished from XHs land-form type by generally slightly greater relief, steeper characteristic slopes, and less marked summit accordance.

XBp Land-form Type (46 km²)

Closely dissected convex surface consisting of low parallel ridges on mainly basaltic volcanic rocks (Plate 14, Fig. 2).

Terrain Parameters.—Altitude: 150–900 m. Relief: generally 30–100 m, locally >300 m. Characteristic slopes: 15–30°. Grain: mainly 100–250 m.

Climate.—Zones III, IV.

Geology.—Basaltic lavas, probably mainly pillow lavas, and minor limestone (calcilutite); Tertiary and possibly Upper Cretaceous.

Land Forms.—Closely and shallowly dissected convex surface dipping north and west at 5–10° and incised by several very deep gorges. Consist mainly of low accordant parallel ridges and narrow, V-shaped valleys.

(1) *Low ridges* (70%): 30–100 m high; narrow crests; short side slopes of 15–30°.
(2) *Gorges* (30%): over 300 m deep; amphitheatre-headed; with many bare rock faces.

Stream Pattern.—Generally parallel.

Soils.—Probably acid red and brown clay and lithosols.

Drainage.—Well to excessively drained.

Vegetation.—Mainly small-crowned forest with *Castanopsis* and *Casuarina*. Sides of gorges mostly bare.

Forest Potential.—Forest resources very low (FRI–14); low stocking rate forest covers 35%; *Castanopsis* common. Access very poor (AI–11); slope hazard throughout; access category S3. Forest productivity very low.

Land Use Potential.—Classes VI–VIII.
(1) Unsuitable for cultivation because of erosion hazard.
(2) Unsuitable for commercial land use because of excessive slopes.

Correlations.—Not present in previously surveyed areas.

Relationships.—Sharply bounded by other land-form types.

XBu Land-form Type (55 km²)

Irregularly undulating terrain and rounded ridges of low relief on basaltic volcanic rocks (Plate 15, Fig. 1).

Terrain Parameters.—Altitude: 0–100 m. Relief: 15–80 m. Characteristic slopes: 5–10°. Grain: 250–1000 m.

Climate.—Zone III.

Geology.—Basaltic lavas and pyroclastics; Tertiary.

Land Forms.—(1) *Irregularly undulating terrain* (50%): relief less than 30 m, slopes up to 10°.
(2) *Ridges* (45%): up to 80 m high with narrow rounded crests, slopes 0–5°, and irregular side slopes up to 300 m long, generally 20° but steeper at coast.
(3) *Valley floors* (5%): up to 300 m wide, slopes less than 1°; meandering stream channels.

Stream Pattern.—Dendritic, with widely spaced major streams and closely spaced tributaries.

Soils.—Red and brown friable clay; dark sandy clay, probably commonly gravelly.

Drainage.—Well drained.

Vegetation.—Small-crowned, dense, slender, moderately tall to tall forest (*Hopea, Vatica, Anisoptera, Eucalyptopsis, Pterocarpus*).

Forest Potential.—Forest resources low (FRI–24); moderate and low stocking rate forests cover 90% of the area; locally *Hopea* dominant and other Dipterocarpaceae common. Access good to very good (AI–81); minor slope hazard on (2); access category S0. Forest productivity moderate to high.

Land Use Potential.—Classes IV–VII. Unsuitable to marginally suitable for cultivation because of erosion hazard.

Correlations.—Not present in previously mapped areas.

Relationships.—Locally merges with HBb land-form type, otherwise boundaries generally well defined.

XXu Land-form Type (950 km²)

Undulating terrain and low ridges on sedimentary and igneous rocks (Plate 4).

Terrain Parameters.—Altitude: 0–500 m. Relief: 30–70 m. Characteristic slopes: 5–10°. Grain: 250–500 m.

Climate.—Mainly zones I and II, small part in zone III.

Geology.—Moderately to steeply dipping siltstone, mudstone, chert, tuff, conglomerate, limestone, and basaltic volcanics and gabbro; Tertiary. Also flat-lying gravel, clay, silt, and sand; Pleistocene and Recent.

Land Forms.—Undulating terrain and low hill ridges up to 70 m high.
(1) *Interfluves* (50%): mainly flat crests and convex upper and concave lower slopes up to 10°.
(2) *Hill ridges* (30%): strike ridges and irregular ridges and spurs; crests even to irregular and peaked, mostly rounded and less than 30 m wide; side slopes straight or irregular, mainly 10–25° but steeper locally.
(3) *Foot slopes* (15%): 2–10°, commonly undulating in cross profile with up to 5 m relief; gullied microrelief common.
(4) *Valley floors* (5%): mainly less than 70 m but locally up to 800 m wide, slopes generally less than 1°; stream channels locally incised up to 5 m.

Stream Pattern.—Dendritic, open.

Soils.—Brown and red sandy clay loam to clay, texture contras common, mainly shallow to moderately deep, often gravelly, acid neutral, or alkaline; dark cracking clay on valley floors.

Drainage.—Well to excessively drained except valley floors which are imperfectly to poorly drained.

Vegetation.—Climatic zone II, north coast: mainly mid-height grassland; also mosaic of grassland and medium-crowned slightly deciduous forest (*Anisoptera, Intsia, Terminalia*). Climatic zones I and II, south and west coasts: mainly eucalypt savannah (*Eucalyptus alba, E. papuana, E. confertiflora*); also large areas of monsoonal woodland (*Gyrocarpus, Harpullia, Eucalyptus, Acacia, Colona, Adenanthera*) and grassland. Scattered remnants of small-crowned, slightly to strongly deciduous forest (*Bombax, Terminalia, Garuga, Brachychiton, Celtis, Intsia, Albizia, Manilkara*). Commonly a thin band of forest or woodland along creeks. Climatic zone III, south coast: small-crowned forest, with *Hopea* common to locally predominant. Minor medium-crowned forest. Most grassland and ground layer in savannah low to mid-height, predominantly of *Themeda australis;* in places *Heteropogon contortus, Imperata cylindrica,* and *Ophiuros tongcalingii* dominant or co-dominant; *Sorghum nitidum, Themeda novoguineensis,* and *Arundinella setosa* normally present. Tall grassland (*Saccharum spontaneum/Imperata cylindrica*) in depressions and on valley floors.

Forest Potential.—Forest resources very low (FRI–9); low stocking rate forest covers 15% of area in climatic zones II and III, and high (1%) and medium (10%) stocking rate forests locally dominated by *Hopea* occur only in climatic zone III. Access good (AI–81); minor slope hazard on (2), minor drainage hazard on (4); access category S0. Forest productivity very low due to very low resources.

Land Use Potential.—Classes III, VI–VII.
(1), (3) Suitable for cultivation, but have local erosion, water stress, stoniness, and alkalinity hazards.
(2) Unsuitable for cultivation because of erosion hazard and soil moisture stress.
(4) Suitable for cultivation but drainage, water stress, and local alkalinity hazards.

Correlations.—Includes part of Bewabewa land system of the Wanigela–Cape Vogel area; part of Boborobo land system of the Safia–Pongani area; and Fairfax, Diumana, Bomana Creek, Diulu, and part of Nikura land systems of the Port Moresby–Kairuku area.

Relationships.—Locally grades into and contains minor unmapped inclusions of YHb, YKr, and USu land-form types.

YSi Land-form Type (240 km²)

Irregular hilly terrain of moderate relief on mainly poorly consolidated sedimentary rocks (Plate 16, Fig. 1).

Terrain Parameters.—Altitude: 280–650 m. Relief: 50–200 m. Characteristic slopes: 20–30°. Grain: 250–500 m.

Climate.—Zones II, III.

Geology.—Poorly consolidated mudstone, siltstone, and minor conglomerate (Domara River Beds); Plio–Pleistocene.

Land Forms.—Hills and ridges with irregular hummocky slopes.
(1) *Crests* (5%): up to 200 m wide, uneven.
(2) *Irregular slopes* (60%): over 300 m long, 5–35°, commonly gullied; local small depressions and lakes.
(3) *Steep straight slopes* (25%): 25–35°, less than 200 m long; interspersed with (2) and (4).
(4) *Moderately steep straight slopes* (10%): 10–15°; mainly upper slopes.

Stream Pattern.—Dendritic, open.

Soils.—Generally shallow and commonly gravelly clay.

Drainage.—Well to excessively drained.

Vegetation.—Mainly medium-crowned slightly deciduous forest. Also mosaic of forest and eucalypt savannah, with the savannah mainly on crests and upper slopes. Much secondary forest.

Forest Potential.—Forest resources very low (FRI–12); forests of moderate and low stocking rates each cover 20% of the area. Access moderate (AI–41); slope hazard on (2), (3), and less so on (4); access category S2. Forest productivity very low.

Land Use Potential.—Classes VI–VII. Mostly unsuitable for cultivation because of erosion hazard and stony soils.

Correlations.—Comprises Avikaro land system of the Safia–Pongani area.

Relationships.—Boundaries with adjacent hilly land-form types commonly gradational.

YHp Land-form Type (180 km²)

Hilly terrain with parallel and branching ridges of moderate relief on consolidated sedimentary rocks (Plate 19, Fig. 1).

Terrain Parameters.—Altitude: 30–400 m. Relief: 30–200 m. Characteristic slopes: 20–35°. Grain: 100–250 m.

Climate.—Zone III.

Geology.—Cherty siltstone and calcareous mudstone; probably Tertiary.

Land Forms.—Parallel and branching ridges up to 200 m high, and irregularly undulating terrain.
(1) *Ridge crests* (5%): mainly rounded, generally less than 20 m but locally up to 200 m wide, undulating to hummocky, slopes generally less than 10°.
(2) *Side slopes* (50%): mainly 20–35°, less than 200 m long, with gullies, terracettes, and surface gravel.
(3) *Irregularly undulating terrain* (40%): mainly as long lower slopes but also as small plateaux and broad benches; slopes generally less than 15°.
(4) *Valley floors* (5%): up to 600 m wide, slopes less than 1°, mostly swampy in east.

Stream Pattern.—Dendritic to parallel, moderately dense.

Soils.—Shallow to moderately deep sandy clay to clay, commonly gravelly.

Drainage.—Generally well drained, but valley floors poorly drained.

Vegetation.—Dense medium-crowned forest with *Garuga* moderately common. Minor small-crowned forest in east, and regrowth and secondary forest in south near coast. Swamp woodland with sago palm and *Melaleuca* on swampy valley floors in east.

Forest Potential.—Forest resources moderate (FRI–41); moderate and low stocking rate forests cover 80% and 15% of the area respectively. Access moderate (AI–42); slope hazard on (2), minor drainage hazard on (4); access category S2. Forest productivity moderate.

Land Use Potential.—Classes IV–VII. Marginally suitable to unsuitable for cultivation because of erosion hazard.

Correlations.—Not present in previously mapped areas.

Relationships.—Grades into and has minor unmapped inclusions of USu land-form type.

YHb Land-form Type (1350 km²)

Branching ridges and spurs of mainly moderate relief, with smooth or little-dissected slopes, on mostly consolidated sedimentary rocks (Plate 10; Plate 18, Fig. 2).

Terrain Parameters.—Altitude: 0–1700 m. Relief: 30–200 m, mostly 100–150 m. Characteristic slopes: 20–35°. Grain: mainly 250–500 m.

Climate.—Zones I–III.

Geology.—Mainly moderately to steeply dipping mudstone, siltstone, sandstone, tuff, conglomerate, shale, limestone, and chert; also andesitic and basaltic lava and gabbro; Tertiary and possibly Upper Cretaceous.

Land Forms.—Branching ridges and spurs and minor strike ridges up to 200 m high.
(1) *Ridge and spur crests* (5%): generally 3–30 m wide; rounded, even to very uneven and peaked, with slopes up to 20°.
(2) *Side slopes* (80%): up to 500 m long, straight, irregular, or with straight upper slopes and concave lower slopes; straight slopes 20–35°, concave slopes 10–30°; minor very short slopes over 35°; terracettes, gullies, and slumps common.
(3) *Foot slopes* (10%): 2–10°, locally absent, gently undulating in cross profile.
(4) *Valley floors* (5%): up to 800 m but generally less than 100 m wide, slopes mostly less than 1°; stream channels irregularly incised up to 3 m; only main streams perennial.

Stream Pattern.—Dendritic, moderately to very dense.

Soils.—Mostly shallow and gravelly, also moderately deep acid clay.

Drainage.—Mostly excessively drained.

Vegetation.—Mainly eucalypt savannah, grassland, woodland, and small- to medium-crowned, slightly to strongly deciduous forest. Grasses mostly low to mid-height, the main grass being *Themeda australis;* tall grassland (*Saccharum spontaneum/Imperata cylindrica*) occurs locally in depressions, along drainage lines, on foot slopes, and on valley floors. Vegetation types commonly form mosaic, with savannah and grassland on crests and upper slopes and woodland and forest on mid and lower slopes. Gallery woodland characteristically lines streams in savannah and grassland areas. Small-crowned forest predominant in climatic zone III.

Forest Potential.—Forest resources very low (FRI–7); forests of moderate and low stocking rates each cover 10% of the area. Access poor (AI–34); slope hazard on (2) and (1); access category S2. Forest productivity very low.

Land Use Potential.—Classes VI–VII. Mostly unsuitable for cultivation because of erosion hazard and stony soils.

Correlations.—Includes parts of Bewabewa and Koianaki land systems of the Wanigela–Cape Vogel area; part of Arumbai land system of the Safia–Pongani area; and Aropokina, most of Kopu, part of Palipala, and small part of Kabuka land systems of the Port Moresby–Kairuku area.

Relationships.—Locally contains unmapped inclusions of and grades into XXu and ZXb land-form types; some minor inclusions of APr and AWs land-form types.

YKc Land-form Type (30 km²)

Limestone cuestas of moderate relief (Plate 14, Fig. 2).

Terrain Parameters.—Altitude: 0–400 m. Relief: 100–200 m. Characteristic slopes: 10–20°. Grain: 500–1000 m.

Geology.—Limestone, coralline in part; Tertiary (Pliocene).

Land Forms.—Cuestas up to 200 m high.
(1) *Crests* (<5%): 0–20 m wide, even to uneven.
(2) *Dip slopes* (75%): 5–20°, straight to irregular and stepped; closely spaced gullies, slumps, and terracettes common.
(3) *Scarp slopes* (25%): 30° to near 90°, with bare rock faces above debris slopes.

Stream Pattern.—Irregular rectangular pattern of incised streams.

Soils.—Shallow, commonly dark, alkaline clay.

Drainage.—Mostly excessively drained.

Vegetation.—Medium-crowned forest with many deciduous trees. Areas of low to mid-height grassland (*Themeda australis, Eulalia leptostachys*) near coast.

Forest Potential.—Forest resources low (FRI–21); forests of moderate and low stocking rate cover 35% and 25% respectively. Access moderate (AI–41); major slope hazard on (3), minor on (2); access category S2. Forest productivity low to very low.

Land Use Potential.—Classes VII–VIII. Unsuitable for cultivation because of steep slopes and shallow soils.

Correlations.—Includes Castle Hill, which forms small part of Tarakaruru land system of the Wanigela–Cape Vogel area.

Relationships.—Sharply bounded by adjacent land-form types.

YKr Land-form Type (700 km²)

Steep rounded ridges and hills of moderate relief mainly on limestone (Plate 4).

Terrain Parameters.—Altitude: 0–230 m. Relief: 30–200 m. Characteristic slopes: 20–35°. Grain: variable, 100–2000 m.

Climate.—Mainly zones I–II, very small part in zone III.

Geology.—Coralline, detrital, and cherty limestone, chert, and minor non-calcareous mudstone, siltstone, sandstone, and tuff; Plio–Pleistocene on Cape Vogel, Upper Cretaceous to Pliocene elsewhere.

Land Forms.—Rounded branching ridges and spurs, symmetrical and asymmetrical strike ridges, and conical hills, up to 200 m high, with local undulating plateau surfaces; rocky outcrops common.
(1) *Ridge and hill crests* (10%): rounded, 5–50 m wide, even to smoothly undulating, slopes up to 20°.

(2) *Upper slopes* (55%): mostly 20–35°, straight or uneven with small slumps and terracettes very common; cliffs up to 70 m high locally present.
(3) *Foot slopes* (20%): smoothly concave or gently undulating, slopes up to 15°.
(4) *Dip slopes of asymmetrical ridges* (5%): 15–25°, straight.
(5) *Scarps* (<5%): mainly 20–35° but locally precipitous slopes and cliffs with debris slopes below.
(6) *Plateau surfaces* (5%): gently undulating, slopes up to 15°, local relief less than 15 m.
(7) *Valley floors* (5%): generally less than 50 m wide, slopes up to 2°, with slightly incised ephemeral streams.

Stream Pattern.—Dendritic, generally open but locally dense.

Soils.—(1), (2), (4), (5) Reddish and dark brown clay lithosols, commonly gravelly, locally alkaline.
(3) Upper parts brown and red gravelly and non-gravelly clay, often texture contrast; lower parts dark sticky clay, locally texture contrast, locally gravelly.
(6) Shallow dark clay.
(7) Dark cracking clay.

Drainage.—Well to excessively drained except lower parts of (3), and (7), which are poorly drained.

Vegetation.—Mainly eucalypt savannah (*E. papuana, E. alba, E. confertiflora,* and ground layer of *Themeda australis*); also large areas of monsoonal woodland and low to mid-height grassland (*Themeda australis, Ophiuros tongcalingii, Sorghum nitidum, Heteropogon contortus, Imperata cylindrica, Saccharum spontaneum, Schima nervosum,* and *Themeda novoguineensis*). Tall grassland locally on foot slopes, drainage depressions, and valley floors. Leguminous herbs rare to common. Woodland is slightly deciduous (eucalypts, *Protium, Alstonia brassii, Tristiropsis, Terminalia, Desmodium umbellatum, Timonius, Rhus, Antidesma*) to strongly deciduous (*Gyrocarpus, Celtis, Bombax, Terminalia, Garuga, Albizia* sp.), and in many places secondary.

Forest, commonly disturbed, occurs in narrow strips along streams and as remnant patches mainly on valley floors; it is slightly deciduous (*Terminalia, Intsia, Pterocarpus, Alstonia brassii, A. scholaris, Ficus, Tristiropsis, Litsea, Horsfieldia*) to strongly deciduous (floristically similar to strongly deciduous woodland).

Forest Potential.—Forest resources nil (FRI–1); virtually no forest. Access poor (AI–33); major slope hazard on (2), (4), (5), minor slope hazard on (1), (3), (6), some drainage hazard on (6), (7); access category S2. Forest productivity nil.

Land Use Potential.—Classes VII, III–IV.
(1), (2), (4), (5) Not suitable for cultivation because of erosion, soil stoniness, shallowness, moisture stress, and local alkalinity hazards.
(3), (6), (7) Suitable to marginally suitable for cultivation, with hazards due to soil moisture stress and local poor drainage, erosion, stoniness, and alkalinity.

Correlations.—Includes part of Tarakaruru land system of the Wanigela–Cape Vogel area and Pokama, most of Hanuabada and Kabuka, part of Palipala, and small part of Kopu land systems of the Port Moresby–Kairuku area.

Relationships.—Locally grades into ZKr and YHb land-form types, which also occur as minor inclusions within YKr.

YMp Land-form Type (650 km²)

Parallel ridges of low to moderate relief on foliated metamorphic rocks, developed on extensive closely dissected planar surfaces (Plate 17, Fig. 1; Plate 22, Fig. 1).

Terrain Parameters.—Altitude: 100–3000 m. Relief: 30–200 m. Characteristic slopes: 25–40°. Grain: 100–250 m.

Climate.—Mainly zones IV and V; small part in zone III.

Geology.—Phyllite and schist (Owen Stanley and Goropu Metamorphics); Tertiary and probably Mesozoic.

Land Forms.—Mainly accordant parallel ridges up to 200 m high with minor hummocky terrain and flat-iron surfaces.
(1) *Ridge crests* (30%): mostly 15–50 m wide, locally wider, even to undulating and hummocky; axial slopes strongly convex to straight, 5–30°.
(2) *Side slopes* (50%): mainly 25–40° and less than 300 m long; unstable, with gullies and small slumps common.
(3) *Hummocky terrain* (10%): confined to highest parts of land-form type with overall slopes less than 10°; local relief less than 30 m.
(4) *Flat-iron surfaces* (10%): confined to lowest parts of land-form type; slopes 10–30°, incised by parallel gullies.

Stream Pattern.—Dense parallel.

Soils.—Acid yellow-brown sandy loam to clay lithosols, commonly humic above 2000 m.

Drainage.—Well drained.

Vegetation.—Above 1400 m mainly lower montane forest, commonly with *Nothofagus* predominant; coniferous lower montane forest above 2400 m (*Papuacedrus, Dacrycarpus, Phyllocladus,* scattered emergent *Araucaria*); also extensive areas of low grassland (*Eulalia leptostachys*) locally in mosaic with bracken fern (*Pteridium*) on Mt. Orian.

Below 1400 m medium-crowned forest, very mixed below 500 m, commonly with *Castanopsis* and *Lithocarpus* predominant above 500 m; minor mid-height grassland (*Eulalia leptostachys, Themeda australis, Imperata cylindrica*), small-crowned slightly deciduous forest, and eucalypt savannah.

Forest Potential.—Forest resources low (FRI–33); forests of moderate stocking rate cover 55% of the area; 15% of this is dominated by *Nothofagus* which locally has a high stocking rate; forests of low stocking rate cover 25%; locally at high altitudes coniferous forests and emergent *Araucaria*. Access poor (AI–12); major slope hazard on (2), minor on (1) and (4); access category S2. Forest productivity very low mainly due to slope hazard and partly to high altitude location.

Land Use Potential.—Classes VII–VIII. Mostly unsuitable for commercial land use, because of erosion hazard and shallow soils.

Correlations.—Includes part of Maneau land system of the Wanigela–Cape Vogel area.

Relationships.—Boundaries well defined. Minor inclusions of MMe land-form type occur where deeply incised major valleys with very steep side slopes are too small to be mapped out separately.

YXd Land-form Type (550 km²)

Branching ridges and spurs of moderate relief, with closely dissected slopes, on sedimentary, metamorphic, and igneous rocks (Plate 14, Fig. 2).

Terrain Parameters.—Altitude: 15–1500 m. Relief: generally 80–200 m but locally higher adjacent to deeply incised streams. Characteristic slopes: 30–45°. Grain: 250–500 m.

Climate.—Mainly zones III and IV, small part in Musa basin in zone II.

Geology.—Sandstone, siltstone, mudstone, phyllite, basaltic and andesitic volcanic rocks; Tertiary and Upper Cretaceous.

Land Forms.—Branching hill ridges and conspicuous spurs of ridge-and-ravine form.
(1) *Ridge and spur crests* (10%): generally less than 15 m wide; undulating to peaked, with more or less accordant pyramidal summits, slopes up to 25°; minor local broad crests up to 200 m wide.
(2) *Side slopes* (90%): mainly 100–300 m long, 30–45°, locally 15–30°, especially on lower slopes; dissected by closely spaced gullies; slumps and terracettes common; precipitous slopes and cliffs occur adjacent to incised streams.
(3) *Valley floors* (<5%): up to 100 m wide, slopes up to 4°, meandering stream channels.

Stream Pattern.—Dense dendritic to pinnate.

Soils.—Brown clay lithosols, commonly gravelly, neutral to slightly acid.

Drainage.—Mostly excessively drained.

Vegetation.—Mainly small-crowned, slightly deciduous forest (*Intsia, Anisoptera, Garuga, Terminalia, Buchanania, Neonauclea*). Also medium-crowned forest above 500 m with *Castanopsis* and *Lithocarpus* common. Minor eucalypt savannah. Many small patches of mid-height grassland (*Imperata cylindrica, Themeda australis,* in east *Eulalia leptostachys*) and secondary forest, particularly near rivers. *Deplanchea* common in grassland near forest edges.

Forest Potential.—Forest resources low (FRI–26); moderate and low stocking rate forests cover 20% and 65% respectively; *Castanopsis* common on (1). Access nil (AI–5); slope hazard on (2) and (1); access category S3. Forest productivity nil to very low due to slope hazard.

Land Use Potential.—Classes VII–VIII. Mostly unsuitable for commercial land use because of erosion hazard.

Correlations.—Includes part of Fiobobo land system of the Safia–Pongani area and Edebu, part of Iawarere, and small part of Uberi land systems of the Port Moresby–Kairuku area.

Relationships.—Locally grades into and has unmapped inclusions of ZBb and XHv land-form types.

ZSv Land-form Type (850 km²)

Very steep-sided ridges of variable relief on poorly consolidated sedimentary rocks (Plate 13, Fig. 1; Plate 22).

Terrain Parameters.—Altitude: 0–1100 m. Relief: variable, generally 100–400 m. Characteristic slopes: 30–45°. Grain: mostly 100–250 m.

Climate.—Mostly zones II and III, small part in zone IV.

Geology.—Poorly consolidated flat-lying to moderately steeply dipping conglomerate, sandstone, mudstone, and siltstone and minor basaltic volcanic rocks; Pliocene and Pleistocene.

Land Forms.—Very steep-sided knife-edged ridges and spurs and V-shaped valleys, with minor local plateaux and undulating summit surfaces, moderate to steep slopes, and flat valley floors.
(1) *Ridges* (90%): generally less than 400 m high but up to 1000 m high on the Gwoira Range; crests uneven, commonly less than 3 m wide, slopes locally over 20°; side slopes mainly 30–45°, straight or irregular with local precipitous slopes and cliffs; slopes very unstable, and gullies, landslides, slumps, slump alcoves, terracettes, scree slopes, and rock outcrops common to very common; side slopes include steep dip slopes and scarps incised by shallow to very deep gullies.
(2) *Plateaux* (<5%): generally smooth surfaces sloping at about 1°; represent remnant fan surfaces; present only in eastern part of the area.
(3) *Undulating summit surfaces* (<5%): irregular surfaces with slopes up to 15°.
(4) *Moderate to steep slopes* (5%): mainly south of Musa basin; irregular slopes 10–30°.
(5) *Valley floors* (<5%): up to 700 m wide, slopes up to 2°, commonly terraced with incised sinuous stream channels; small lakes present locally in valleys blocked by landslides.

Stream Pattern.—Dendritic to locally parallel, mostly moderately dense.

Soils.—Very shallow clay to sandy clay loam lithosols, commonly gravelly; stony land and rock outcrop common.

Drainage.—Excessively drained.

Vegetation.—In climatic zones II and III mainly mosaic of grassland, mostly on crests and upper slopes, and small- and medium-crowned, commonly slightly deciduous forest, mostly on lower slopes and along streams and gullies; also areas of grassland and eucalypt savannah. Grasses low on ridge crests, low to mid-height on steep slopes and plateaux, mid-height to tall on less steep slopes and valley floors; predominant grass is *Themeda australis;* locally co-dominant are *Eulalia leptostachys* (in east), *Arundinella setosa,* and *Heteropogon contortus;* also commonly present are *Imperata cylindrica, Ophiuros tongcalingii, Sorghum nitidum, Saccharum spontaneum,* and *Capillipedium.* Leguminous and other herbs very rare to moderately common and include *Indigofera trifoliata, Cassia minosoides, Desmodium, Crotalaria, Tephrosia, Buchnera tomentosa, Euphorbia serrulata, Polygala, Phyllanthus, Spathoglottis,* and *Nepenthes.*

In climatic zone IV medium-crowned forest with *Lithocarpus* common.

Forest Potential.—Forest resources very low (FRI–13); forests of medium and low stocking rates cover 25% and 20% respectively. Access nil to very poor (AI–5); slope hazard; access category S3. Forest productivity very low to nil due to steep slopes.

Land Use Potential.—Classes VII–VIII. Unsuitable for commercial land use because of erosion hazard due to very steep slopes.

Correlations.—Comprises Tama land system of the Wanigela–Cape Vogel area and Adau, small part of Gorabuna, and part of Arumbai land systems of the Safia–Pongani area.

Relationships.—Generally abruptly bounded by other land-form types. Locally contains minor inclusions of FSt land-form type.

ZH Land-form Type (55 km²)

Ridges and spurs of high relief on mainly sedimentary rocks (Plate 15, Fig. 2).

Terrain Parameters.—Altitude: 30–400 m. Relief: 150–300 m. Characteristic slopes: 20–40°. Grain: 500–1500 m.

Climate.—Zone III.

Geology.—Mainly greywacke, mudstone, and conglomerate, minor andesitic and basaltic volcanic rocks; Tertiary (Miocene and Pliocene).

Land Forms.—Deeply dissected anticlinal structure consisting of asymmetrical ridges and spurs up to 300 m high.
(1) *Ridge crests* (5%): rounded, mainly 6–60 m wide, slopes 0–15°.
(2) *Steep side slopes* (50%): 15–30°, generally straight, up to 300 m long; include local dip slopes.
(3) *Very steep side slopes* (40%): over 30°, with local precipitous slopes and cliffs, mainly as scarps.
(4) *Gentle side slopes* (5%): 1–5°, short and straight, forming narrow benches.

Stream Pattern.—Dendritic to subparallel.

Soils.—Yellowish brown clay loam, shallow and stony on very steep slopes, acid.

Drainage.—Well to excessively drained.

Vegetation.—Medium-crowned forest, in many places with open and irregular canopy; also bare patches.

Forest Potential.—Forest resources moderate (FRI–42); forests of moderate and low stocking rates cover 80% and 15% respectively. Access very poor (AI–19); slope hazard; access category S3. Forest productivity very low due to steep slopes.

Land Use Potential.—Classes VII–VIII. Mostly unsuitable for commercial land use because of erosion hazard.

Correlations.—Includes Kurai land system of the Kerema–Vailala area.

Relationships.—Sharply bounded by adjacent land-form types.

ZKr Land-form Type (140 km²)

Steep-sided rounded ridges of high relief on mainly limestone (Plate 4; Plate 23, Fig. 1).

Terrain Parameters.—Altitude: 0–500 m. Relief: 200–400 m. Characteristic slopes: 20–35°. Grain: 250–500 m.

Climate.—Mainly zones I and II, small part in zone III.

Geology.—Cherty limestone, coralline limestone, and minor thin-bedded intercalated mudstone; Tertiary.

Land Forms.—Strike ridges with mainly short spurs.
(1) *Crests* (5%): rounded, 5–50 m wide, generally undulating, slopes up to 20%.
(2) *Side slopes* (85%): mainly straight, 20–35°, locally steeper; slumps and terracettes very common.
(3) *Foot slopes* (5%): concave or gently undulating, 2–25°.
(4) *Valley floors* (5%): discontinuous, up to 100 m wide, slopes up to 2°; streams mainly ephemeral.

Stream Pattern.—Pinnate to dendritic.

Soils.—Mainly alkaline dark lithosols.

Drainage.—Mainly excessively drained.

Vegetation.—As YKr land-form type.

Forest Potential.—Forest resources nil (FRI–1). Access very poor (AI–22); slope hazard; access category S3. Forest productivity nil.

Land Use Potential.—Class VIII. Mostly unsuitable for commercial land use because of erosion hazard.

Correlations.—Includes Tovobada and small part of Hanuabada land systems of the Port Moresby–Kairuku area.

Relationships.—Grades with decreasing relief into YKr land-form type.

ZKv Land-form Type (290 km²)

Very steep knobbly strike ridges of variable relief mainly on limestone (Plate 17, Fig. 2).

Terrain Parameters.—Altitude: 0–700 m. Relief: variable, mainly 30–400 m, locally up to 650 m. Characteristic slopes: 30–45°. Grain: variable, mainly 500–1000 m.

Climate.—Zone III.

Geology.—Limestone, commonly cherty, probably with minor intercalated basaltic volcanics and detrital sediments; Tertiary.

Land Forms.—Strike ridges with inconspicuous spurs, rock outcrops and bouldery slopes common, mostly less than 400 m high but up to 650 m high on Momore Range in south-east.
(1) *Ridge crests* (<5%): mostly 5–50 m wide, commonly uneven and knobbly, with very variable slopes.
(2) *Very steep side slopes* (75%): gullied and irregular; mainly 30–45° but many local precipitous slopes and cliffs.
(3) *Less steep upper slopes and plateau areas* (20%): irregular surfaces, slopes 0–35°.
(4) *Foot slopes* (5%): gently concave, 0–15°.

Stream Pattern.—Pinnate, streams mainly subsurface.

Soils.—Clay lithosols, stones, and boulders common.

Drainage.—Excessively drained.

Vegetation.—Largely small-crowned, low, poor forest, minor medium-crowned forest.

Forest Potential.—Forest resources low (FRI–26); moderate and low stocking rate forests cover 10% and 80% respectively. Access very poor (AI–11); slope hazard; access category S3. Forest productivity very low to nil due mainly to steep slopes.

Land Use Potential.—Classes VII–VIII. Mainly unsuitable for commercial land use because of erosion hazard and shallow soils.

Correlations.—Not present in previously surveyed areas.

Relationships.—Boundaries generally well defined, locally gradational with ZBb land-form type, especially on the south coast west of Magarida.

ZP Land-form Type (320 km²)

Closely dissected moderate to gentle slopes and plateau surfaces of variable relief; plutonic igneous rocks mantled by volcanic ash (Plate 15, Fig. 2).

Terrain Parameters.—Altitude: 600–1700 m. Relief: very variable, 10–300 m. Characteristic slopes: 30–45°. Grain: 100–250 m.

Climate.—Mainly zone IV, small part in zone V.

Geology.—Plutonic ultramafic and basaltic igneous rocks, Tertiary and/or Cretaceous, overlain by veneer up to 40 m thick of andesitic volcanic ash; late Pleistocene to Recent.

Land Forms.—Plateaux and slopes up to 20°, closely dissected to form an intricate pattern of hill ridges and spurs. Some deeply incised major streams.
(1) *Crests* (10%): mainly less than 50 m wide, even to uneven, slopes 0–20°.
(2) *Side slopes* (90%): generally 30–45°, locally precipitous; straight or irregular and very short to long.
(3) *Valley floors* (<5%): up to 70 m wide, slopes 1–10°.

Stream Pattern.—Dense dendritic.

Soils.—Sandy loam to sandy clay ash soils, deep, friable, acid; also red and brown clay on steeper slopes, shallow on steepest slopes.

Drainage.—Well drained.

Vegetation.—Lower montane forest (above 1400 m) and medium-crowned forest, both very dense and little disturbed by man. Minor small-crowned forest with *Araucaria*.

Forest Potential.—Forest resources low (FRI–37); forests of moderate and low stocking rates cover 75% and 10% respectively; minor local stands of emergent *Araucaria*. Access very poor (AI–5); slope hazard; access category S3. Forest productivity very low mainly due to steep slopes.

Land Use Potential.—Class VII. Mostly unsuitable for cultivation because of erosion hazard.

Correlations.—Comprises small part of Botue land system of the Buna–Kokoda area, and Owalama land system of the Safia–Pongani area.

Relationships.—Boundaries mostly sharply defined. Includes minor unmapped areas of MUv land-form type.

ZBb Land-form Type (4400 km²)

Branching very steep-sided ridges and spurs of variable relief on mainly basaltic volcanic rocks (Plates 6, 12; Plate 15, Fig. 1).

Terrain Parameters.—Altitude: 0–1500 m. Relief: variable, 30–400 m. Characteristic slopes: 25–40°. Grain: 500–1000 m.

Climate.—Mainly zones III and IV, small part in zone II.

Geology.—Mainly basaltic volcanic rocks—lava, pillow lava, agglomerate, breccia, and tuff; also gabbro, phyllite, and minor sandstone, siltstone, conglomerate, limestone, and ultramafic rocks; Tertiary and Cretaceous.

Land Forms.—Branching hill ridges and spurs up to 400 m high separated by narrow steep-sided V-shaped valleys (ridge-and-ravine topography).
(1) *Ridge and spur crests* (10%): 0–30°, uneven and peaked, generally less than 15 m but locally up to 200 m wide.
(2) *Side slopes* (90%): straight or irregular, mostly 25–40°, locally steeper with precipitous slopes and cliffs, especially adjacent to incised streams; closely dissected by gullies; terracettes, slumps, landslides, bouldery surfaces, and rock outcrops common.
(3) *Foot slopes* (<5%): concave, 5–20°.
(4) *Valley floors* (<5%): up to 200 m wide, slopes less than 5%; commonly terraced with slightly incised meandering channels.

Stream Pattern.—Dense dendritic.

Soils.—Red and brown or yellowish brown clay to sandy clay loam lithosols, commonly gravelly or stony, generally shallow to very shallow but locally deep, neutral to acid.

Drainage.—Excessively to well drained.

Vegetation.—Mainly small-crowned and often thin-stemmed forest (*Hopea, Pometia, Canarium, Pterocarpus, Buchanania, Anisoptera*); also medium-crowned forest. *Hopea* locally predominant, especially in east. Some small-crowned slightly deciduous forest and minor eucalypt savannah and mid-height grassland in climatic zones II and III.

Forest Potential.—Forest resources low (FRI–30); forests of moderate and low stocking rates cover 30% and 55% respectively; *Hopea* locally dominant in the east. Access very poor (AI–5); slope hazard; access category S3. Forest productivity very low to nil due to steep slopes.

Land Use Potential.—Class VII. Mostly unsuitable for cultivation because of erosion hazard.

Correlations.—Includes parts of Oivi, Hegahorte, and Iauga and small part of Mt. Green land systems of the Buna–Kokoda area; Sesegara land system of the Wanigela–Cape Vogel area; parts of Suwari and Fiobobo and small part of Sesaro land systems of the Safia–Pongani area; and parts of Iawarere and Rouna land systems of the Port Moresby–Kairuku area.

Relationships.—*Contains local unmapped inclusions of PBy,* XHv, and MBv land-form types. Boundaries with MBv land-form type commonly gradational, but other boundaries generally well defined.

ZBm Land-form Type (140 km²)

High hill ridges with moderate slopes on mainly basaltic volcanics (Plate 16, Fig. 1).

Terrain Parameters.—Altitude: 300–1000 m. Relief: 150–300 m. Characteristic slopes: 10–20°. Grain: 500–1500 m.

Climate.—Zone III.

Geology.—Mainly hornfelsed basalt, with minor associated calcareous rocks; probably Tertiary and Cretaceous. Also minor patches of poorly consolidated sedimentary rocks, mainly conglomerate (Domara River Beds); Plio–Pleistocene.

Land Forms.—Irregular ridges and spurs 150–300 m high.
(1) *Crests* (10%): up to 200 m wide, generally rounded, slopes 0–15°.
(2) *Side slopes* (80%): 5–35°, irregularly hummocky with small depressions and lakes associated with slumps.
(3) *Corrugated surfaces* (10%): present on major slumps, slopes mainly 10–30°.

Stream Pattern.—Dendritic, irregular.

Soils.—Mainly moderately deep to shallow colluvial soils, generally gravelly, weakly acid to neutral.

Drainage.—Well drained.

Vegetation.—Mainly small-crowned slightly deciduous forest, largely secondary especially in south-east. Also small-crowned evergreen forest with *Casuarina* and scattered to locally dense *Araucaria*. Eucalypt savannah and patches of grassland common near rivers.

Forest Potential.—Forest resources very low (FRI–13); forests of moderate and low stocking rates cover 10% and 35% respectively; local stands of low to high stocking rate *Araucaria*. Access moderate (AI–42); moderate slope hazard on (2) and (3), minor on (1); access category S2. Forest productivity very low.

Land Use Potential.—Classes III, VI–VII. Gentle slopes suitable for cultivation; steep slopes unsuitable for cultivation because of erosion hazard.

Correlations.—Comprises most of Aimare land system of the Safia–Pongani area.

Relationships.—Boundaries with adjacent land-form types mostly gradational.

ZXb Land-form Type (1450 km²)

Branching ridges and spurs of high relief on mainly sedimentary rocks (Plate 13, Fig. 2; Plate 16, Fig. 1; Plate 24, Fig. 1).

Terrain Parameters.—Altitude: 0–700 m. Relief: 200–400 m. Characteristic slopes: 20–35°. Grain: generally 500–1000 m.

Climate.—Zones I–III.

Geology.—Moderately to steeply dipping mudstone, siltstone, sandstone, conglomerate, limestone, and tuff; also local basaltic lava and pyroclastics, and gabbro; Tertiary.

Land Forms.—Ridges with conspicuous spurs 200–400 m high; also minor plateau surfaces and narrow valley floors.
(1) *Ridge and spur crests* (5%): rounded, mainly less than 30 m wide, even to uneven and peaked, slopes up to 20°.
(2) *Plateau surfaces* (<5%): gently undulating with slopes mostly less than 5°.
(3) *Steep side slopes* (70%): straight or irregular, mainly 20–35°, with local precipitous slopes and cliffs, rock outcrops, bouldery surfaces, terracettes, slumps, and gullies.
(4) *Moderate side slopes* (20%): mainly lower slopes, 5–20°, straight, concave, or uneven.
(5) *Valley floors* (5%): up to 300 m wide, slopes generally less than 0°35′ but up to 2° in some tributary valleys; meandering stream channels locally incised.

Stream Pattern.—Dendritic, moderately to very dense.

Soils.—Mainly neutral dark brown clay to sandy clay loam lithosols.

Drainage.—Excessively to well drained.

Vegetation.—North coast: mosaic of small- and medium-crowned forest, commonly secondary, and mid-height grassland, mainly *Themeda australis*.

Musa basin: mosaic of medium-crowned forest and eucalypt savannah.

South and west coasts: eucalypt savannah, mosaic of small-crowned forest and savannah, and areas of small-crowned forest. Forest commonly slightly deciduous, usually thin-stemmed and rather low, and in many places secondary. Also monsoonal woodland, and low to mid-height grassland (*Themeda australis*). In climatic zones I and II forest along creeks and on lower slopes, eucalypt savannah on crests and upper slopes.

Forest Potential.—Forest resources very low (FRI–14); forests of moderate and low stocking rates cover 10% and 30% respectively. Access poor (AI–39); moderate slope hazard on (1), (3), (4); access category S2. Forest productivity very low.

Land Use Potential.—Class VII. Mostly unsuitable for cultivation because of erosion hazard.

Correlations.—Includes parts of Bewabewa and Koianaki land systems of the Wanigela–Cape Vogel area; part of Arumbai land system of the Safia–Pongani area; Dubuna and small part of Rouna land systems of the Port Moresby–Kairuku area; and part of Nabo land system of the Korema–Vailala area.

Relationships.—Locally grades into YHb and ZBb and contains minor inclusions of YHb, ZSv, APr, and AWs land-form types.

ZXi Land-form Type (38 km²)

Ridges of variable relief on basaltic volcanic and low-grade metamorphic rocks west of Mt. Albert Edward (Plate 17, Fig. 1).

Terrain Parameters.—Altitude: 1900–2700 m. Relief: 30–400 m. Characteristic slopes: 20–30°. Grain: 500–1000 m.

Climate.—Zone V.

Geology.—Basaltic volcanic rocks and low-grade metamorphic rocks (phyllite); probably Tertiary.

Land Forms.—Long rounded ridges with few spurs and higher branching ridges and spurs.
(1) *Ridges with few spurs* (65%): generally less than 150 m high; smooth rounded crests; side slopes mostly 20–30°.
(2) *Branching ridges and spurs* (30%): up to 400 m high; ridge-and-ravine form, with very narrow to knife-edged crests, slopes up to 30°, and gullied side slopes 30–45°.
(3) *Valley floors* (5%): up to 200 m wide.

Stream Pattern.—Subparallel to dendritic.

Soils.—Probably as MBv land-form type.

Drainage.—Well drained.

Vegetation.—Lower montane forest with *Nothofagus* very common, particularly in eastern part.

Forest Potential.—Forest resources low (FRI–32); forests of moderate and low stocking rates cover 80% and 5% respectively

Nothofagus very common. Access poor (AI–10); slope hazard; access category S3. Forest productivity very low due to altitudinal position and steep slopes.

Land Use Potential.—Class VII. Mostly unsuitable for cultivation because of erosion hazard.

Correlations.—Not present in previously mapped areas.

Relationships.—Well-defined boundaries with adjacent land-form types. Ridge-and-ravine land forms are similar to those of MBv and ZBb land-form types.

MBv Land-form Type (8600 km²)

Very steep mountain ridges and spurs on mainly basaltic volcanic rocks (Plate 6; Plate 17, Fig. 1).

Terrain Parameters.—Altitude: 0–3000 m. Relief: >400 m. Characteristic slopes: 30–40°. Grain: 500–>2000 m.

Climate.—Mainly zone IV, but also zones II, III, V.

Geology.—Mainly basaltic lava, pillow lava, agglomerate, and tuff; also gabbro and minor intrusive granitic, intermediate, and ultramafic rocks, phyllite, limestone, and calc-silicate rocks, sandstone, and mudstone; Tertiary and Mesozoic. Volcanic and sedimentary rocks are generally steeply dipping and mostly tend NW. to WNW.

Land Forms.—Mountain ridges and spurs with narrow V-shaped valleys (ridge-and-ravine topography).
(1) *Crests* (5%): mostly less than 15 m wide, even to uneven, slopes up to 35°.
(2) *Very steep side slopes* (90%): generally over 500 m long, 30–40°, straight to weakly concave, and closely dissected by narrow gullies; unstable with terracettes, slumps, screes, gullies, and landslides very common; precipitous slopes and cliffs over 300 m high occur locally, mainly adjacent to incised major streams on the north side of Owen Stanley Range east of longitude 149°E.
(3) *Less steep side slopes* (<5%): mainly foot slopes; 5–35°, concave or uneven.
(4) *Valley floors* (<5%): less than 30 m wide, slopes up to 2°; commonly with narrow terraces adjacent to shallowly incised streams.

Stream Pattern.—Moderately dense dendritic.

Soils.—Red and brown clay and sandy clay, generally shallow and commonly gravelly and stony, acid, humic above 2000 m.

Drainage.—Well drained.

Vegetation.—Below 1400 m mainly medium-crowned mid-height to tall forest. Lower montane forest above 1400 m. Gardens, garden regrowth, and young secondary forest common along main rivers. Also grassland in areas of intensive shifting agriculture and small-crowned slightly deciduous forest and minor grassland and savannah in climatic zones II and III.

Forest Potential.—Forest resources low (FRI–36); forests of moderate and low stocking rates cover 60 and 30% respectively. Access very poor (AI–4); slope hazard; access category S3. Forest productivity nil to very low due to steep slopes, and high altitude in parts.

Land Use Potential.—Classes VI–VIII. Unsuitable for cultivation because of erosion hazard.

Correlations.—Includes part of Hegahorte land system of the Buna–Kokoda area; Amora, Foasi, and small part of Aimare land systems of the Safia–Pongani area; and part of Iawarere land system of the Port Moresby–Kairuku area.

Relationships.—Boundaries with ZBb, MMv, and MMe land-form types commonly gradational. Minor unmapped inclusions of various land-form types occur locally.

MUv Land-form Type (2650 km²)

Very steep mountain and hill ridges on mainly ultramafic plutonic rocks (Plates 6, 8, 11).

Terrain Parameters.—Altitude: 80–2350 m. Relief: variable, but mostly >400 m. Characteristic slopes: 30–45°. Grain: very coarse, >1500 m.

Climate.—Mostly zone IV, but also zones V, III, and II.

Geology.—Mainly ultramafic plutonic rocks, also minor associated basaltic rocks; Cretaceous or Tertiary. Mantle of late Pleistocene to Recent andesitic ash on many surfaces in vicinity of Mt. Lamington volcano.

Land Forms.—Massive mountain and hill ridges with generally inconspicuous spurs; rocky outcrops and boulders common.
(1) *Crests* (10%): mostly 0–50 m wide, but also 50 to over 200 m wide, even to gently undulating; crestal slopes 0–30°.
(2) *Very steep side slopes* (70%): 30–45°, straight or irregular; generally shallowly dissected, locally deeply dissected, by narrow gullies; cliffs, precipitous slopes, landslides, and slumps common, especially adjacent to overdeepened streams, at gully heads, and along fault scarps.
(3) *Less steep upper slopes* (10%): not always present, 5–30°, irregularly undulating.
(4) *Concave slopes* (10%): on some lower slopes and associated with slumps, 5–25°, smooth to hummocky.
(5) *Alluvial terraces* (<5%): up to 100 m wide and 15 m above incised streams.

Stream Pattern.—Coarse dendritic, locally angular due to streams following fault and joint lines.

Soils.—Shallow weakly acid gravelly and stony clay; also ash soils (yellow-brown sandy clay loam to sandy loam).

Drainage.—Well to excessively drained.

Vegetation.—Mainly small-crowned, thin-stemmed forest. Lower montane forest above 1400 m. Extensive areas of low to mid-height grassland and minor eucalypt savannah and small-crowned slightly deciduous forest in climatic zones II and III south-east of Musa basin. Medium-crowned forest on moderate slopes and where ash-covered. *Casuarina papuana* common to predominant in small-crowned lowland hill forest, and in lower montane forest south-east of Musa basin, and scattered to moderately dense in grassland. Scattered *Araucaria* present south and west of Musa basin.

Forest Potential.—Forest resources low (FRI–30); forests of moderate and low stocking rates cover 45% and 35% respectively; scattered *Araucaria* in places. Access very poor (AI–13); slope

hazard; access category S3. Forest productivity very low due to steep slopes.

Land Use Potential.—Classes VI–VIII. Mostly unsuitable for cultivation because of erosion hazard.

Correlations.—Includes most of Botue and part of Oivi land systems of the Buna–Kokoda area; Didana land system of the Wanigela–Cape Vogel area; and Avuru, Didana, Guaya, and part of Suwari land systems of the Safia–Pongani area.

Relationships.—Boundaries generally sharply defined, commonly by faults. Locally includes small unmapped areas of Zp land-form type.

MMv Land-form Type (8550 km²)

Very steep mountain ridges on metamorphic rocks (Plates 7, 8, 11; Plate 18, Fig. 1).

Terrain Parameters.—Altitude: 300–4000 m. Relief: >800 m. Characteristic slopes: 30–40°. Grain: >1000 m.

Climate.—Mainly zones V and IV, but also zone VI and very minor III.

Geology.—Mainly schist and phyllite (Owen Stanley Metamorphics and Goropu Metamorphics); Tertiary and Mesozoic. Mantle of late Pleistocene and Recent andesitic volcanic ash near Mt. Lamington and Waiowa volcanoes.

Land Forms.—Very high massive mountain ridges separated by deep, steep-sided, V-shaped valleys, spurs generally inconspicuous.
(1) *Ridge crests* (5%): mostly rounded and 5–50 m wide, but range from 0 to over 50 m in width; locally very irregular; slopes 0–30°.
(2) *Side slopes* (90%): over 1000 m long, straight or irregular, 30–40°, generally incised by shallow gullies; precipitous slopes, cliffs and rocky crags locally present, and landslides and slumps common.
(3) *Foot slopes* (5%): 5–30°, locally present adjacent to major rivers.

Stream Pattern.—Coarse dendritic.

Soils.—Colluvial silty clay loam and clay, commonly shallow (lithosols) and gravelly, weakly acid, humic above 2000 m; also rock outcrop.

Drainage.—Well drained.

Vegetation.—Below 1400 m: mainly medium-crowned forest; in climatic zone III, also minor eucalypt savannah and small-crowned forest in mosaic with grassland; *Castanopsis* and *Lithocarpus* common in forest.

Above 1400 m: lower montane forest rich in conifers above 2400 m, especially on crests, and locally including scattered *Araucaria;* small scattered areas of grassland above 2700 m, mainly in valleys but also in narrow strips along crests; scattered to dense tree ferns common in valley grasslands; minor montane forest in mosaic with grassland above 3400 m.

Extensive areas of garden, secondary forest, and grassland present below 2700 m on side slopes adjacent to main rivers, especially in north-west.

Forest Potential.—Forest resources low (FRI–33); forests of moderate and low stocking rates cover 65% and 15% respectively; *Castanopsis* dominant on (1) at low altitudes; scattered emergent *Araucaria* locally present in coniferous forest. Access nil (AI–5); slope hazard; access category S3. Forest productivity nil to very low due to steep slopes and to high altitude in parts.

Land Use Potential.—Class VIII. Unsuitable for commercial land use because of erosion hazard.

Correlations.—Includes Misima land system of the Buna–Kokoda and Safia–Pongani areas and part of Mancau land system of the Wanigela–Cape Vogel area.

Relationships.—Locally grades imperceptibly into MBv and PMi land-form types.

MMe Land-form Type (1600 km²)

Extremely steep and precipitous mountain ridges and spurs on metamorphic rocks (Plate 16, Fig. 2; Plate 23, Fig. 2).

Terrain Parameters.—Altitude: 150–4000 m. Relief: >600 m. Characteristic slopes: 40–50°. Grain: >1500 m.

Climate.—Mainly zones IV–VI, very small part in zone III.

Geology.—Phyllite and schist (Owen Stanley and Goropu Metamorphics), with minor ultramafic rocks on Mt. Suckling; Tertiary and Mesozoic.

Land Forms.—Very high mountain ridges and spurs.
(1) *Crests* (5%): mainly less than 15 m wide, uneven, slopes up to 35°; above 3000 m locally up to 200 m wide and smoothly undulating, with small swampy depressions.
(2) *Very steep slopes* (85%): mainly 35–60° and over 1000 m long; unstable with gullies, cliffs, screes, and major slumps and landslides very common.
(3) *Concave slopes* (10%): mainly near Mt. Suckling; over 1000 m long and up to 35°, smooth to undulating and hummocky.

Stream Pattern.—Coarse dendritic.

Soils.—Lithosols, scree, and rock outcrop on summit areas; gravelly colluvial soils and red and brown clay lower down.

Drainage.—Excessively to well drained; broad summit crests poorly drained to swampy.

Vegetation.—Mainly lower montane and coniferous lower montane forest on Mt. Suckling and further east commonly in mosaic with mid-height grassland. Medium-crowned forest below 1400 m. Above 3400 m low tussock grassland, ericaceous and coniferous scrub, and some low montane forest. Seral vegetation south and west of Waiowa volcano. Scattered to fairly dense emergent *Araucaria cunninghamii* (hoop pine) in lower montane forest on Mt. Suckling and further east. Cliffs and some landslides bare.

Forest Potential.—Forest resources low (FRI–31); forests of moderate and low stocking rates cover 50% and 30% respectively. *Araucaria cunninghamii* stands of variable stocking rate common. Access nil (AI–4); slope hazard; access category S3. Forest productivity very low due to steep slopes and to high altitude in parts.

Land Use Potential.—Class VIII. Unsuitable for commercial land use because of erosion hazard.

Correlations.—Includes part of Mancau land system of the Wanigela–Cape Vogel area, and Suckling Complex land system of the Safia–Pongani area.

Relationships.—Grades into MMv and MBv land-form types with decreasing relief and slope angles. Includes the very steep-sided valleys incised into YMp land-form type.

PART III. A CLIMATIC CLASSIFICATION FOR EASTERN PAPUA

By J. R. McAlpine*

I. Introduction

The range of climates found in eastern Papua encompasses most of the major climatic types found in Papua New Guinea and ranges from dry tropical savannah through monsoonal to tropical rain forest types. Superimposed on this is a decrease in temperature with increasing elevation, resulting in climates that resemble those of the moist mesothermal areas of higher latitudes but possess a restricted seasonal temperature range.

In order to exemplify this variety of climates a simple and subjective climatic classification has been erected to indicate the types and areal extent of combinations of climatic elements that occur in the region. This classification is preceded by a brief discussion of the main individual elements incorporated in it. While virtually all surface climatic data have been considered in this analysis it is not possible in the limited space available to fully summarize this material. As a result "type" station data only are presented to illustrate the major climatic features and variations.

For greater detail the reader is referred to other climatic data which are included in companion reports in the Land Research Series covering specific sections within this larger eastern Papua region (Fitzpatrick 1965*a*, *b*; McAlpine 1969; Slatyer 1964). For discussion of the major and local climatic controls operating in this region the reader is referred to Brookfield and Hart (1966), Fitzpatrick *et al.* (1966), and the reports referred to above.

II. General Climatic Characteristics

(*a*) *Rainfall*

Mean monthly and annual rainfall data for a number of stations are presented in Table 4; Figure 4 indicates their spatial distribution. No attempt has been made to use a standard period for analysis owing to the shortness of and gaps in nearly all lengths of record.

Mean annual rainfall varies from 1180 mm at Port Moresby to 4400 mm at Yodda Kokoda and at all stations exhibits a distinct seasonal pattern. The "dry" season centres around July and the "wet" season around February–March at all stations except those in the extreme east where seasonality is either reversed (e.g. Alotau) or absent. Table 4 indicates that the lower the mean annual rainfall, the greater will be the contrast between wet and dry season falls. For instance, at the dry station, Port Moresby, the wettest month has almost 10 times the rainfall of the

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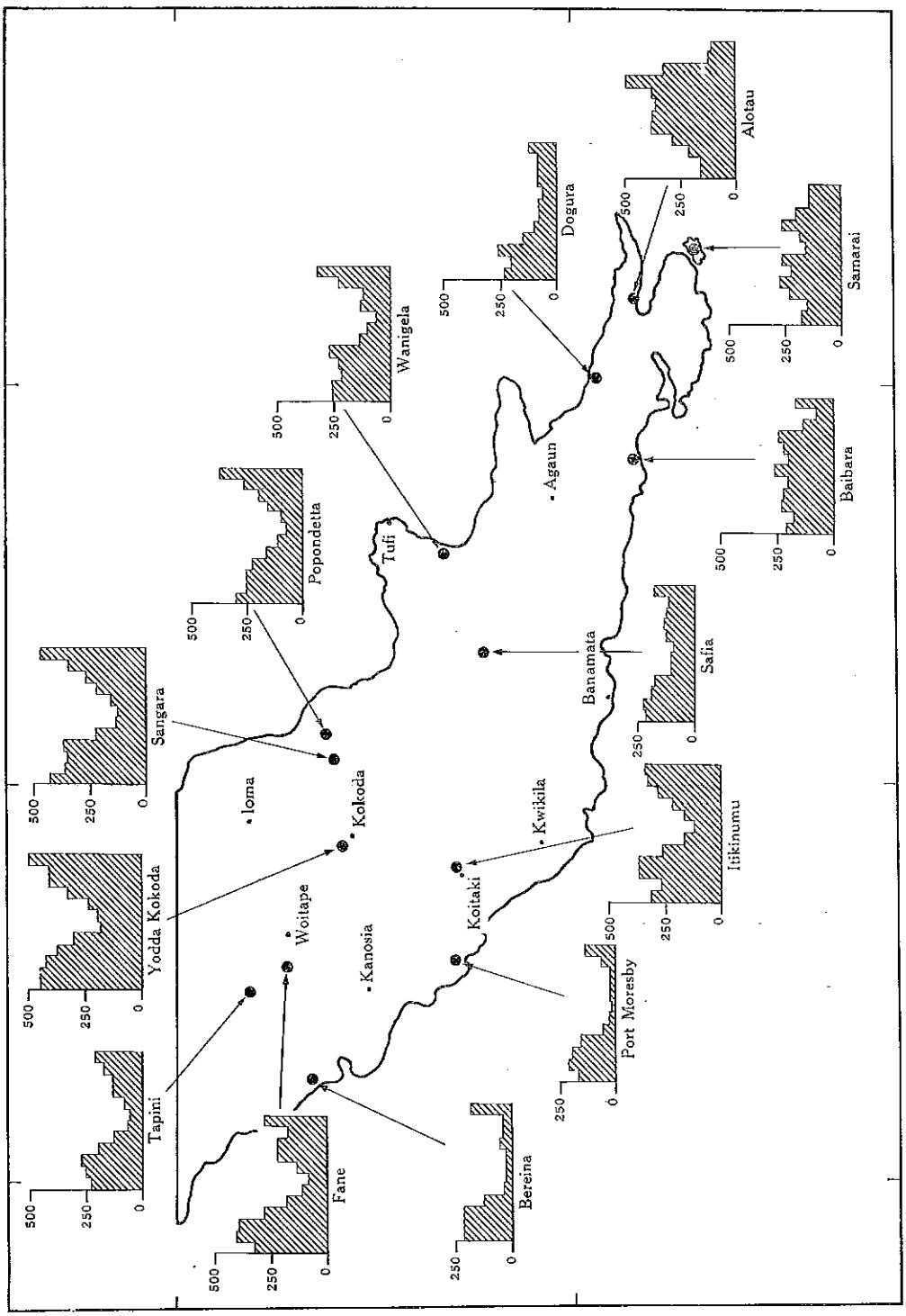

Fig. 4.—Rainfall distribution (mm) (Jan.–Dec.) in eastern Papua.

TABLE 4

MEAN MONTHLY AND ANNUAL RAINFALL (MM) WITH HIGHEST AND LOWEST ANNUAL RAINFALL ON RECORD

Station	Length of record (yr)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Highest annual	Lowest annual
Agaun (960 m)	9 (4*)	464	422	310	273	135	99	129	102	131	170	175	246	2684	3388	1836
Alotau (9 m)	7 (6)	156	160	206	275	357	330	304	336	490	320	112	108	3199	4006	2067
Amazon Bay (46 m)	7 (6)	277	140	263	209	237	221	232	144	195	156	64	115	2064	2695	1410
Baibara (1 m)	18 (14)	210	190	232	227	206	270	206	215	246	139	77	161	2491	4788	1100
Baramatta (2 m)	10 (8)	112	178	185	263	270	296	246	129	285	84	97	108	2222	3205	1731
Bereina (15 m)	15 (12)	210	223	222	127	45	28	21	25	52	50	44	176	1183	1596	934
Dogura (65 m)	26 (25)	249	215	259	153	90	86	83	57	74	73	74	117	1492	1998	1006
Fane (1386 m)	13 (12)	329	413	400	273	193	112	96	139	224	228	200	294	2908	3325	2283
Ioma (143 m)	40 (27)	446	412	398	343	259	207	160	194	249	291	447	455	3926	5052	2913
Itikinumu (518 m)	35 (34)	315	269	370	372	265	168	112	167	211	277	326	337	3180	4798	2234
Kanosia (61 m)	13 (11)	189	212	248	139	62	56	46	58	105	99	66	219	1501	2024	1062
Koitaki (500 m)	37 (30)	282	295	342	306	218	147	104	148	209	246	280	298	2860	4170	1578
Kokoda (366 m)	34 (26)	320	343	331	311	234	168	178	222	276	331	351	351	3496	4477	2771
Kwikila (61 m)	63 (41)	155	131	176	148	79	50	44	43	58	50	65	110	1147	2198	537

Napa Napa (46 m)	8 (6)	176	232	219	65	29	33	10	25	39	17	26	124	959	1230	632
Onoge (1490 m)	13 (12)	318	321	317	185	95	58	34	76	138	146	126	249	2046	2393	1607
Popondetta (84 m)	14 (13)	305	253	260	221	160	109	68	88	151	197	255	359	2405	3031	1895
Port Moresby (35 m)	29 (28)	169	209	200	163	58	44	22	36	38	36	64	144	1182	1570	659
Rouna (158 m)	12 (11)	275	294	315	158	136	58	39	69	132	91	84	191	1828	2268	1362
Safia (119 m)	10 (5)	204	227	173	125	90	91	71	112	123	107	96	155	1550	1846	1075
Samarai (41 m)	16 (11)	175	162	237	279	225	266	161	184	260	207	137	141	2393	3072	1692
Sangara (274 m)	15 (11)	428	365	354	363	223	136	123	155	217	259	343	490	3418	4017	2724
Tapini (990 m)	19 (17)	245	258	275	200	122	59	55	79	132	140	168	217	1950	2286	1559
Tufi (34 m)	19 (18)	374	437	345	435	300	187	144	86	110	169	284	313	3176	4193	1778
Wanigela (3 m)	15 (14)	264	260	223	236	265	148	104	66	144	117	236	324	2352	2969	1487
Woitape (1493 m)	15 (10)	339	358	402	290	190	117	112	177	267	312	267	338	3180	3579	2558
Yodda Kokoda (305 m)	20 (18)	454	459	429	379	307	197	207	247	328	419	428	510	4404	5266	3513

* Figure in parentheses indicates the number of years with complete records.

driest, whereas at the wettest station, Yodda Kokoda, this ratio falls to 2·5. As a result spatial differences in rainfall, as indicated by mean monthly figures, are much greater in the dry than in the wet season. A fuller account of rainfall seasonality is given by Fitzpatrick *et al.* (1966).

Despite these seasonal contrasts annual rainfall variability is generally low, as can be seen from the extremes included in Table 4 and also by the fact that the coefficients of variation (standard deviation as a percentage of mean) for all stations with records over 20 years in length are below 20%.

An analysis of daily rainfall data for a standard 10-yr period for a limited number of stations has been used to give some indication of rainfall intensity. Generally falls of over 100 mm per day can be expected to occur on only 1–1·3% of rainy days at drier stations (Port Moresby, Dogura) but on 2–3% of rainy days in wetter areas (Kokoda, Popondetta, Samarai). In both localities the heaviest falls mostly occur during the wet season. As could be expected, the percentage of rainy days is similar at all these stations during the wet season (50–60%) but is considerably lower for the drier stations (20–30%) than the wetter (40–50%) during the dry season.

The very limited data from highland stations within eastern Papua provide no evidence of an increase of rainfall with altitude (a fact noted elsewhere in Papua New Guinea). It is more likely that the relation between rainfall and altitude is an expression of the relative local effects of major and local circulations on particular orographic situations. This is indicated in eastern Papua by the fact that the area of highest rainfall occurs in the lowland funnel-shaped Kokoda valley and that the very limited data for higher altitude stations indicate nearly as great a variation in mean annual rainfall and seasonality as is found at stations near sea level. It is also borne out by the rapid changes in rainfall which occur over limited distances in upland situations (e.g. the Tapini–Woitape area).

(*b*) *Temperature*

The only temperature data available within the area are for a number of stations at or near sea level. Data for two stations, Popondetta, 20 km inland, and Samarai, on the coast, are presented in Table 5 to illustrate the main features of the lowland temperature regime. These are that mean diurnal range is always greater than mean seasonal range; that inland mean maximum temperatures are higher and mean minimum temperatures lower than at coastal stations and that as a result diurnal temperature ranges are higher inland ($\simeq$ 10 degC) than on the coast ($\simeq$ 5 degC); that the slight seasonality in temperature that does exist tends to be greater for day than for night temperatures, particularly on the coast; and that absolute maxima and minima recorded are only slightly above or below the mean maxima and minima figures.

Although there are no temperature data available at higher altitudes in eastern Papua, the decrease of temperature with increasing elevation is known from lapse rate theory and documented from other highland areas of Papua New Guinea (Fitzpatrick 1965*a*, *b*; McAlpine 1970*a*). In these areas the rate of decrease calculated in mean temperature is 0·5 degC per 100 m. Data from the town of Mount Hagen located at an altitude of 1750 m in the Western Highlands District and from Mt. Wilhelm (McVean 1968), 3480 m above sea level in the Chimbu District, are included

TABLE 5

MEAN MONTHLY TEMPERATURE CHARACTERISTICS (°C)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Popondetta													
Absolute maximum	33·1	33·9	31·9	31·9	31·9	30·6	30·8	31·1	31·4	32·3	31·8	31·8	33·9
Mean maximum	31·9	32·1	31·3	31·1	30·7	30·2	30·1	30·7	30·7	30·8	31·4	31·5	31·1
Mean minimum	22·0	22·2	22·3	21·4	21·6	20·9	20·3	20·7	21·0	21·4	21·6	21·8	21·4
Absolute minimum	21·4	21·3	22·2	20·9	21·2	20·7	19·9	19·8	20·8	21·3	21·3	21·4	19·8
Samarai													
Absolute maximum	32·2	32·4	32·3	30·4	28·9	28·2	28·3	28·1	29·6	29·0	30·2	31·9	32·4
Mean maximum	31·3	31·6	30·8	29·6	28·4	28·4	27·2	27·0	27·7	28·4	29·6	30·5	29·1
Mean minimum	24·4	24·7	24·5	24·1	23·8	22·9	22·6	22·7	22·9	23·5	23·7	23·9	23·7
Absolute minimum	23·1	23·6	24·3	23·4	23·0	21·6	21·6	21·7	21·5	22·7	22·9	22·4	21·5
Mount Hagen													
Mean maximum	24·2	24·2	23·8	23·9	24·4	23·2	22·4	22·7	23·3	23·9	24·3	24·0	23·7
Mean minimum	13·4	13·3	13·4	13·7	13·4	12·4	12·5	12·7	12·6	12·5	12·7	13·3	13·0
Mount Wilhelm													
Mean maximum	11·1	11·1	10·8	10·7	11·2	11·2	11·2	12·1	12·6	11·7	11·5	11·1	11·5
Mean minimum	4·2	4·2	4·8	4·0	4·1	3·7	3·2	3·6	2·7	4·2	4·1	4·2	3·8

TABLE 6

RELATIVE HUMIDITY, EVAPORATION, AND CLOUD COVERAGE

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						Popondetta							
Average index of relative humidity*	84	82	84	83	84	86	82	81	81	82	82	83	83
Evaporation (mm)†	142	142	122	119	104	99	114	122	130	135	142	142	1513
Cloud (oktas)													
Total, 0900 hr	7	6	6	6	6	6	7	6	6	7	6	6	6
Total, 1500 hr	7	7	7	6	6	7	7	7	7	7	7	7	7
						Port Moresby							
Average index of relative humidity*	78	80	80	82	81	79	76	75	75	74	73	75	77
Evaporation (mm)†	165	147	140	127	119	122	130	137	150	170	190	188	1786
Cloud (oktas)													
Total, 0900 hr	6	7	6	6	5	5	5	5	5	5	5	6	6
Total, 1500 hr	7	7	7	6	6	5	6	5	5	5	5	6	6
						Samarai							
Average index of relative humidity*	82	82	84	87	88	87	85	86	86	86	86	86	85
Evaporation (mm)†	168	163	137	104	84	81	91	89	107	117	132	152	1425
Cloud (oktas)													
Total, 0900 hr	5	5	6	6	6	6	6	6	6	6	5	5	6
Total, 1500 hr	6	6	6	6	6	6	6	6	6	6	5	5	6

* Ratio of average 0900 hr vapour pressure to saturation vapour pressure at average mean temperature.

† Estimates based on method of Fitzpatrick (1963).

in Table 5 to give an indication of differences at particular levels between lowland (0–1500 m), lower montane (1500–3000 m), and montane (>3000 m) temperature regimes in eastern Papua. However, as noted in the lapse rate quoted above, temperature change with elevation is a continuum and the regime altitudinal zones given here are arbitrary and presented only to give a broad indication of spatial temperature zonation on the accompanying land-form type map.

(*c*) *Other Climatic Characteristics*

Data for relative humidity, cloudiness, and estimates of free water evaporation are presented for three stations in Table 6. The last are based on the method of Fitzpatrick (1963). The table indicates a general and expectable tendency for higher evaporation to be associated with lower rainfall, less cloud, and low humidity. Kalma (1972) estimates that in the area mean annual total solar radiation reaching the ground varies from 205 W-h/cm^2 at Port Moresby to 165 W-h/cm^2 along the north coast and dividing ranges. Seasonally mean daily radiation reaches a maximum in October and a minimum in July.

TABLE 7

MEAN NUMBER OF WEEKS PER QUARTER WITH SOIL MOISTURE STORAGE AT SPECIFIED LEVELS

Station and quarter	Storage levels				Mean annual water surplus (mm)
	Full	1–49% depleted	50–99% depleted	Empty	
Port Moresby					
Jan.–Mar.	7·0	4·5	1·4	0·1	350
Apr.–June	1·1	3·8	6·6	1·5	
July–Sept.	0·0	0·4	4·3	8·3	
Oct.–Dec.	0·4	0·6	3·9	8·1	
Dogura					
Jan.–Mar.	7·9	4·8	0·3	0·0	550
Apr.–June	2·8	6·4	3·5	0·3	
July–Sept.	0·6	2·9	7·5	2·0	
Oct.–Dec.	4·8	5·0	2·3	0·9	
Popondetta					
Jan.–Mar.	8·7	3·7	0·6	0·0	1300
Apr.–June	6·9	5·5	0·6	0·0	
July–Sept.	2·3	5·7	4·8	0·2	
Oct.–Dec.	7·9	4·6	0·5	0·0	
Kokoda					
Jan.–Mar.	10·8	1·9	0·3	0·0	2300
Apr.–June	9·5	3·4	0·1	0·0	
July–Sept.	7·4	4·8	0·8	0·0	
Oct.–Dec.	9·1	3·7	0·2	0·0	

No similar data are available for higher-altitude stations within the region but, again using Mt. Hagen as an analogue, mean annual evaporation at 1750 m elevation is approximately 1100 mm and lysimeter data from Mt. Wilhelm indicate that annual free water evaporation at 3480 m is probably between 400 and 500 mm.

(*d*) *Water Balance*

The considerable range of precipitation and evaporation regimes present in eastern Papua could be expected to result in significant spatial differences in components of the water balance. A simple weekly water balance model (McAlpine 1970*b*) has been applied to a number of stations for a 10-yr standard period to provide some quantitative estimates of these differences, assuming a 100 mm maximum available soil water capacity. Table 7 and Figure 5 present the results

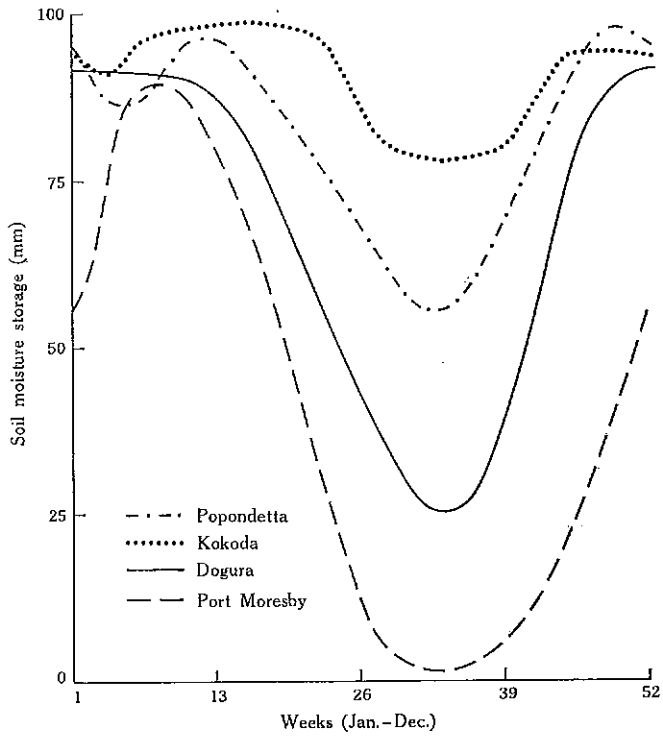

Fig. 5.—Mean weekly soil moisture regimes.

for four stations for the soil moisture storage and water surplus components of the water balance. Figure 5 presents graphs of mean weekly soil moisture storage and clearly indicates the markedly different seasonal soil water regimes present in the area. Table 7 gives the actual number of weeks with soil moisture depleted to specified levels and indicates that the occurrence of weeks with low levels of soil moisture storage, and hence possible plant stress, is rare to non-existent at all stations during the wettest quarter of the year but that during drier periods inter-station differences are quite marked. Although there are no rainfall data above 1500 m, decreasing rates of evaporation with increasing elevation alone may be assumed to lessen considerably the intensity and frequency of any levels of soil moisture depletion that may occur.

III. Climatic Classification

In an attempt to integrate climatic data for the area a simple subjective classification is presented. It must be emphasized that the data on which the classification is based are limited in amount and, more importantly, in spatial distribution. As noted above, this latter difficulty is most obvious in the highland areas of eastern Papua. For some climatic elements this problem can be partly overcome by the extrapolation of data from higher-altitude areas elsewhere in Papua New Guinea but unfortunately this is not the case for rainfall, the most variable element.

The classification is presented in Table 8 and is based firstly on altitude, to give an indication of changing temperature regimes, and secondly on mean annual rainfall. The altitudinal ranges adopted conform with the vegetation–altitudinal zones given in Part VI. Data from type stations are then used to further exemplify the resulting climatic types in two ways, firstly by the use of direct comparative figures and secondly by indicating the direction and rate of change for particular parameters between climatic types. Classificatory unit names are partly based on the Köppen classification and approximate Köppen equivalents are indicated.

The types of climates thus defined are given below. Their areal extent is indicated as zones on the accompanying land-form type map.

As is evidenced by the names given to these climatic zones, their extent has been mapped using both climatological data and vegetation distribution patterns. The zone numbers are those referred to in the land-form type descriptions in Part II.

(*a*) *Zone I. Lowland Savannah Climate*

This is the driest climate in the region extending along a narrow fringe on the south coast from Kwikila to Kukipi. This area experiences regular annual soil water droughts.

(*b*) *Zone II. Lowland Monsoon Climate*

This climatic type is moderately and irregularly affected by soil water droughts and occurs in four places: in a strip lying between the southern coastal lowland savannah zone and the higher-rainfall upland areas; in scattered rain shadow pockets within upland areas (e.g. at Tapini); in an area centred on Safia in the Musa basin; and in a coastal strip extending from the eastern end of the north coast to Cape Vogel.

(*c*) *Zone III. Lowland Rain Forest Climate*

This humid type covers the area below 1400 m and is intermediate between zones II above and IV below. This type is typical of much of coastal Papua New Guinea and soil water droughts within it may occur but are rare and of short extent.

(*d*) *Zone IV. Wet Lowland Rain Forest Climate*

This is a perhumid climatic type distinguished from zone III by the absence of soil water drought and its high annual water surplus. The main occurrence is in the Northern District while smaller areas are found round Cape Nelson and at the western end of Milne Bay.

TABLE 8

CLIMATE TYPES OF EASTERN PAPUA

Zone	Climatic type and Köppen equivalent	Altitudinal range (m)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Annual P/E ratio	Mean annual water surplus (mm)	Probability*	Station
I	Lowland savannah (Am)	<1400	26	<1250	<1	350	34	Port Moresby
II	Lowland monsoon (Am)	<1400	26	1250–2000	≤1	550	6	Dogura
III	Lowland rain forest (Af)	<1400	26	2000–3000	≃1·5	1300	<1	Popondetta
IV	Perhumid lowland rain forest (Af)	<1400	26	>3000	>2	2300	0	Kokoda
V	Lower montane forest (Cf)	1400–3400	18	>2000	>2	1800	0	(Mt. Hagen) (1750 m)
VI	Montane forest (Cf)	>3400	8+1	>2000	>3	?	0	(Mt. Wilhelm) (3480 m)

* Mean number of weeks per year soil moisture is depleted to <75% of available water capacity (100 mm).

(*e*) *Zone V. Lower Montane Forest Climate*

This type by definition occurs between 1400 and 3400 m and is probably one in which soil water drought is rare or non-existent. From about 2000 m upwards an increasing incidence of ground frosts may be expected.

(*f*) *Zone VI. Montane Forest Climate*

This type occurs above 3400 m. As a result of probably high precipitation/evaporation ratios soil water droughts would not occur but ground frosts may be expected on at least 50% of days.

IV. Acknowledgments

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PART IV. GEOLOGY OF EASTERN PAPUA

By D. H. BLAKE*

I. INTRODUCTION

Mainland eastern Papua consists of a linear core of Mesozoic sialic metamorphic rocks flanked by predominantly mafic igneous rocks of Mesozoic and Tertiary age and partly overlapped by younger Tertiary and Quaternary mixed volcanic and sedimentary rocks (Davies and Smith 1971). The Quaternary rocks include the products of several extinct and three recently active volcanoes; unconsolidated alluvial, colluvial, and littoral sediments; and minor raised reefs on the coast and glacial sediments on the highest mountains.

A synthesis of the geology of eastern Papua has been presented recently by Davies and Smith (1971). Published accounts of the general geology include reports by the Australasian Petroleum Company (1961) and Ruxton (1969) on the north-western part of the area; Glaessner (1952), Speight (1965), and Yates and de Ferranti (1967) on the Port Moresby area; Paterson and Kicinski (1956) and Paterson (1964) on the Buna–Kokoda area; Smith and Green (1961) and Ruxton (1967) on the Musa River area; Paterson and Kicinski (1956) and Haantjens *et al.* (1964) on the Wanigela–Cape Vogel area; and Davies (1968, 1971) on the Papuan Ultramafic Belt. The Quaternary volcanoes and their products have been the subjects of papers by Baker (1946), Fisher (1957), Taylor (1958), Morgan (1966), Ruxton (1966*a*, 1966*b*), Ruxton and McDougall (1967), and Jakeš and Smith (1970). There are also several unpublished geological reports issued by the Bureau of Mineral Resources (especially Bureau of Mineral Resources records 1959/31, 1959/32, 1965/69, 1967/68, 1968/66, 1969/12, 1969/126, 1970/72). In addition, several general discussions on the geology of Papua New Guinea refer to eastern Papua, in particular Glaessner (1950), Montgomery *et al.* (1950), Thompson (1967), and Thompson and Fisher (1967). A comprehensive bibliography is given in Manser and Freeman (1971).

The geological information given in this report and the accompanying geological map are based on the above works, on observations made during the 1969 survey, and on extrapolations by the author using air-photo interpretation.

II. STRATIGRAPHY

The stratigraphy of eastern Papua is summarized in Table 9, and the distribution of main rock units is shown on the geological map.

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(a) *Mesozoic*

The exposed sialic core of eastern Papua consists of the Owen Stanley Metamorphics (Davies and Smith 1971), which form the western part of the Owen Stanley Range, extending from the northern border of the area mapped south-eastwards to longitude 148°15'E. The dominant rock type is mica schist containing feldspar, quartz, and graphite. Also present are marble, basic schist, schistose

TABLE 9
STRATIGRAPHY OF EASTERN PAPUA

Age	Unit	Lithology
Recent	Alluvium	Sand, silt, clay, gravel, peat
	Littoral deposits	Sand, silt, clay, peat
Late Pleistocene to Recent	Volcanics	Basaltic, andesitic, and dacitic lava and pyroclastics
Pleistocene	Alluvium	Unconsolidated to poorly consolidated sand, silt, clay, gravel, breccia
	Raised reefs	Coralline limestone
	Glacial deposits	Boulder beds
	Volcanics	Basaltic, andesitic, and dacitic lava and pyroclastics
Plio–Pleistocene	Terrestrial deposits	Unconsolidated to moderately consolidated conglomerate, sandstone, siltstone, mudstone
Pliocene	Volcanics	Basaltic and andesitic lava and pyroclastics, conglomerate
Eocene to early Pliocene	Sedimentary rocks	Phyllite; sandstone, siltstone, mudstone, shale, conglomerate; limestone, chert
	Igneous rocks	Basaltic lava, pillow lava, agglomerate; gabbro, dolerite
Mesozoic	Owen Stanley Metamorphics	Mica schist; marble, basic schist, schistose conglomerate, gneiss
	Goropu Metamorphics	Basic and calcareous schist, phyllite, quartzite, marble, limestone
	Papuan Ultramafic Belt	Peridotite, pyroxenite, gabbro, basaltic lava, pillow lava

conglomerate, and gneiss. The mica schists were originally sedimentary rocks which, where they can be recognized, were mainly tuffaceous sandstone, siltstone, and mudstone. During metamorphism which probably took place during the Palaeocene, the sedimentary rocks were mostly completely recrystallized to green schist facies of regional metamorphism. Cretaceous fossils have been found at a few localities. Less metamorphosed rocks, mainly phyllites, crop out west and south of the Owen Stanley Metamorphics. The relationship of these phyllites to the schists is uncertain. Some of the phyllites are of Eocene age.

The predominantly mafic rocks of Mesozoic age are the Goropu Metamorphics of the Mt. Suckling–Dayman area and the Papuan Ultramafic Belt. The Goropu Metamorphics (Smith and Green 1961; Davies and Smith 1971) are made up of basic and calcareous schist, phyllite, quartzite, marble, and limestone. The meta-

morphic grade ranges up to green schist facies and the rocks are probably mostly or all of Cretaceous age. The Papuan Ultramafic Belt forms a zone of mountainous terrain up to 40 km wide on the north-eastern side of the Owen Stanley Range west of longitude 149°E. The belt consists of an ultramafic layer 4–8 km thick overlain by a gabbro and norite layer 4 km thick, which in turn is overlain by a basalt layer 4–6 km thick (Davies 1968, 1971; Davies and Smith 1971). The ultramafic rocks, mainly peridotite and pyroxenite, crop out on the west and south sides of the belt. The basalt layer is made up mainly of massive lava and pillow lava; these rocks are not distinguished from Tertiary basalt on the geological map, as they are similar in topographic expression and petrography to the Tertiary basalt of the south-eastern mainland.

Small areas of Mesozoic sedimentary rocks, mainly limestone, occur near Tapini, near Port Moresby, and south and east of Mt. Dayman.

(*b*) *Eocene to Early Pliocene*

(i) *Sedimentary Rocks.*—The main exposures of Tertiary sedimentary rocks are in the Tapini area, in hills along the coast between Cape Cupola and Milne Bay, in the Cape Ward Hunt area north of Popondetta, and on Cape Vogel.

The sedimentary rocks of the Tapini area (Macnab, unpublished Bureau of Mineral Resources record 1969/126; Davies and Smith 1971) consist of limestone, sandstone, phyllitic shale, siltstone, and conglomerate. They occur in a north–south fault zone and their stratigraphic relationships to adjacent basaltic volcanics is uncertain. The limestones have yielded Eocene and Upper Oligocene to Lower Miocene fossils. These sedimentary rocks are not distinguished from Tertiary basalt on the geological map.

The coastal hills between Cape Cupola and Milne Bay are formed mainly of sedimentary rocks, most of which range in age from Eocene to Pliocene, although some Upper Cretaceous and Palaeocene rocks also crop out. In the north-west, Cape Cupola and adjacent low hills are formed of Upper Oligocene to Pliocene mudstone, greywacke, siltstone, sandstone, and subordinate limestone; these rocks were deposited in the Aure Trough, part of the Tertiary Papuan Geosyncline (Australasian Petroleum Company 1961; Ruxton 1969). The Kurai Hills further inland are formed of mainly terrestrial sediments of Upper Miocene to Pliocene age, consisting of conglomerate, greywacke, and mudstone, with some andesitic and basaltic volcanic rocks.

The Palipala Hills south-east of Cape Cupola are formed mainly of Pliocene sandstone, conglomerate, shale, siltstone, and thin-bedded limestone (Speight 1965). The sequence, about 1500 m thick, is mostly terrestrial and is composed largely of volcanic detritus. Between Yule Island and Galley Reach, limestone, greywacke, siltstone, and conglomerate of Miocene age are exposed, overlain in places by Pliocene tuffaceous sandstone.

Continuing south-eastwards, the Port Moresby Beds, of mainly Eocene age, form most of the coastal hills in the Port Moresby area (Glaessner 1952; Yates and de Ferranti 1967). These beds consist of limestone, chert, calcareous sandstone and mudstone, shale, and minor tuffaceous rocks. In the vicinity of Port Moresby there are also outcrops of both older and younger sedimentary rocks; these are the Upper

Cretaceous Bogoro Limestone, the Upper Oligocene to Lower Miocene Dokuna Tuff and Bootless Inlet Limestone, and the Miocene Gidobada Limestone and Siro Conglomerate. The Port Moresby Beds and associated rocks extend south-eastwards to the Ormond River.

Along the south coast a complex of hills and ridges between Marshall Lagoon and Mori River is formed mainly of cherty siltstone, calcareous mudstone, and minor limestone. Microfossils identified by D. Belford (personal communication 1970) indicate that these beds are probably Pliocene or younger. However, a post-Pliocene age is considered unlikely because of the mature erosional form of the hills.

Hills of mainly Eocene limestone and chert occur on the coastal plain between Cloudy Bay and Magarida, along the coast just east of Magarida, and on the south side of Mullins Harbour. Eocene to Miocene sandstone, limestone, conglomerate, and siltstone crop out north and south-east of Mullins Harbour; the detrital rocks are formed mainly of volcanic material (Davies and Smith 1971).

North of Popondetta the Miocene Iauga Formation (Paterson and Kicinski 1956; Paterson 1964) forms low hills in the vicinity of Cape Ward Hunt and low foothills on the east side of the Otava and Ajule Kajale Ranges. The formation consists of tuffaceous and calcareous sandstone and conglomerate and pyroclastics of basaltic and andesitic composition.

The Cape Vogel peninsula (Paterson and Kicinski 1956) consists mainly of Miocene and Pliocene sandstone, siltstone, conglomerate, marl, tuff, and minor limestone. The rocks are generally finer-grained and more calcareous in the north than in the south. Similar sedimentary rocks, but with limestone more important, crop out near Cape Frere, south-east of Cape Vogel.

Small outcrops of Tertiary sedimentary rocks also occur in areas of predominantly volcanic rocks.

(ii) *Igneous Rocks.*—Tertiary igneous rocks crop out extensively in eastern Papua. The most common rock types are basaltic lava, pillow lava, and agglomerate. The main outcrop extends from the Ormond River (long. 148°E.) eastwards to East Cape. Here, within a sequence of mainly Eocene basaltic volcanics, there are minor lenses and interbeds of limestone and other sediments as well as several intrusions of gabbroic, monzonitic, and syenitic composition. North-west of the Ormond River the Eocene basalts pass laterally into mainly phyllitic sedimentary rocks which continue as far as the Vanapa River. Most of these phyllitic rocks could not be distinguished from basalt on air photographs and hence have not been mapped separately.

Other Tertiary igneous rocks in the area include volcanics that are probably of Pliocene age, north and east of Port Moresby (see subsection (*c*)); the Sadowa Gabbro of the Port Moresby area (Yates and de Ferranti 1967) which consists of gabbro and dolerite and is probably Oligocene; and basaltic lavas and pyroclastics south of Mullins Harbour which are probably of Pliocene age. Minor occurrences not shown on the geological map include lava and pyroclastics within the sediments of the Kurai Hills, within the Iauga Formation of the Cape Ward Hunt area, and within the mainly sedimentary sequence in the Kemp Welch River area. Also Oligocene submarine andesitic lava, some of which contains the mineral clinoenstatite (Dallwitz *et al.* 1966), crops out on the Cape Vogel peninsula.

(c) *Mid Pliocene to Recent*

(i) *Sedimentary Rocks.*—Plio–Pleistocene sediments are well developed in the Musa basin area, and sediments of probably similar age crop out south of Mt. Lamington, between Mt. Dayman and Goodenough Bay, and east along the north coast towards East Cape. In these areas the sediments typically form very steep-sided ridges with knife-edged crests. In the Musa basin area, conglomerate, greywacke, siltstone, sedimentary breccia, and mudstone, with some associated volcanics, were laid down in one or more intermontane basins. These rocks, the Domara River Beds (Smith and Green 1961; Ruxton 1967), are up to 1000 m thick and are made up mainly of rock fragments derived from the Papuan Ultramafic Belt, Goropu Metamorphics, Tertiary basalt, and contemporaneous volcanics. Between the Musa basin and Mt. Lamington, sediments similar to those of the Domara River Beds form the flat-lying Mamama Formation (Stanley *1919*; Ruxton *1967*), which is partly overlapped by Pleistocene and Recent volcanics. East of Mt. Dayman to Goodenough Bay the Plio–Pleistocene sediments consist of variably lithified, cross-bedded conglomerate, greywacke, sandstone, and siltstone over 1000 m thick. These are alluvial fan and deltaic deposits made up mainly of schist, basalt, and gabbro fragments. Further east along the coast towards East Cape there are several smaller occurrences of Plio–Pleistocene fan deposits, consisting of mostly unconsolidated sand and gravel, overlying Tertiary basalt and minor limestone.

Poorly consolidated sandstone, siltstone, conglomerate, and some limestone forming gently undulating terrain on the east side of Marshall Lagoon on the south coast are also possibly of Plio–Pleistocene age. Unlike the other Plio–Pleistocene sediments, these are probably mainly marine.

Unconsolidated and poorly consolidated sand and gravel, probably of Pleistocene age, form dissected alluvial fans along a fault-bounded trough separating the Owen Stanley Metamorphics from the Papuan Ultramafic Belt. Alluvial fan deposits of similar age elsewhere include the Silimidi Beds of the Musa basin and unconsolidated sand and gravel on the north and south sides of the Sibium Range, on the north side of the Goropu Mountains, and west and north of Milne Bay. The Silimidi Beds (Smith and Green 1961) crop out in the eastern part of the Musa basin, where they consist of poorly consolidated conglomerate, sedimentary breccia, greywacke, and lithified ultramafic breccia (Green 1961); rock fragments in the sediments are mainly derived from the Papuan Ultramafic Belt. Sand and gravel probably of Pleistocene age also form undulating terrain inland from Yule Island in the west, on the south coast mainly between Marshall Lagoon and Cloudy Bay, and south of Milne Bay.

Pleistocene raised reefs occur on Cape Vogel and along the coast eastwards to East Cape (Davies and Smith 1971) and also on the coast near Port Moresby (Speight 1965). Glacial deposits of Pleistocene age overlie Mesozoic schist on Mts. Albert Edward, Scratchley, and Victoria (Löffler 1970, 1972), the highest peaks in eastern Papua.

Unconsolidated clay, silt, sand, and gravel of Recent age form alluvial and littoral plains and undissected alluvial fans. The mineralogical composition of the sediments is dependent on both the source area and the depositional environment

(Ruxton 1970). Bouldery deposits occur on some active fans, and peat is locally developed in swampy areas.

(ii) *Volcanic Rocks.*—Volcanics ranging in age from Pliocene to Recent cover more than one-eighth of mainland eastern Papua.

On the north-east side of the Owen Stanley Range, volcanics of Pliocene to Recent age occur between longitude 147°30′ and 149°30′E. The oldest volcano recognized here is the deeply eroded Sesara volcano, 25 km south-east of Mt. Lamington. Sesara volcano is built up of basaltic lava, agglomerate, tuff, and minor sediments (Smith and Green 1961) and has been dated as early Pliocene (Ruxton and McDougall 1967). The Hydrographers volcano to the north, on the east side of Mt. Lamington, is a Pleistocene strato-volcano composed mainly of interlayered andesitic ash, agglomerate, and lava (Ruxton and McDougall 1967). Trafalgar volcano on Cape Nelson is another Pleistocene strato-volcano, the products of which range in composition from basalt to dacite (Jakeš and Smith 1970).

Late Pleistocene to Recent volcanics form most of the Managalase Plateau (Ruxton 1966*a*) between the Sesara and Hydrographers volcanoes. These volcanics consist of potash-rich basic and intermediate lava and scoria (Uoive Volcanics) and pyroclastics and lava of mainly dacitic composition (Manna Volcanics).

The active volcanoes Mt. Lamington and Mt. Victory are andesitic strato-volcanoes of late Pleistocene to Recent age (Taylor 1958; Jakeš and Smith 1970). Mt. Lamington last erupted in 1951, when catastrophic nuées ardentes were followed by dome extrusion in the main crater. Similar eruptions took place during the latest volcanic activity on Mt. Victory in the 1890s. Volcanic ash of dacitic composition mantles much of the terrain near Mt. Lamington and occurs as thick deposits forming relatively subdued topography on rocks of the Papuan Ultramafic Belt to the south and west.

The only other recently active volcano on mainland eastern Papua is Waiowa, also known as Goropu (Fisher 1957), which erupted in 1943/44. Waiowa lies south of Mt. Victory and is a small volcano built up mainly of agglomerate containing fragments of both country rocks and potash-rich andesitic lava (phenocrysts of biotite and augite set in a fine-grained groundmass of plagioclase, orthopyroxene, opaque granules, and volcanic glass). Another small and very young volcano, which consists of a scoria cone and an andesitic lava flow (chem. analysis no. 20 in Jakeš and Smith 1970), is situated 11 km north-east of Waiowa.

On the west side of the Owen Stanley Range a group of deeply eroded volcanoes extends from the Brown River north of Port Moresby to the northern edge of the mapped area. They are built up of subaerial lava and pyroclastics of mainly basaltic composition, and mainly conglomeratic derived sediments. The erosional forms of these volcanoes are similar to that of Sesara volcano, and indicate that they are probably of Pliocene age. The Astrolabe Agglomerate (Yates and de Ferranti 1967), which forms the Astrolabe Range and Sogeri Plateau east of Port Moresby, is of similar age. It consists of coarsely stratified agglomerate of mainly basaltic composition with minor intercalated tuff; most of these pyroclastics may be nuée ardente deposits. Volcanics that are probably slightly younger crop out in the Cloudy Bay area on the south coast. These volcanics consist of alkali basalt lava and pyroclastics.

An isolated occurrence of similar rock type near Marshall Lagoon is probably late Pleistocene, as are two small volcanoes 80 km east-north-east and 50 km north-east of Port Moresby. The last volcano, on Naoro Creek, is a cone about 300 m high built up of potash-rich andesitic lava (phenocrysts of olivine, biotite, and clinopyroxene set in a glassy to very fine-grained groundmass).

III. Structure

The metamorphic foliation of the Mesozoic schists is tightly folded in places but is generally uniformly tilted or folded into broad anticlinal structures (Davies and Smith 1971). The Papuan Ultramafic Belt typically dips 10–30° east to north-east, the steepest dips being along the western margin of the belt (Davies 1971). Rocks of Eocene to early Pliocene age are mostly steeply dipping about fold axes trending parallel to the main ranges. Simple anticlinal folds occur in the north-west, affecting Miocene and Pliocene sediments of the Kurai and Palipala Hills. Mid-Pliocene to Recent rocks are generally either not folded or affected by only gentle flexures.

Two structural domes occur in the south-east. The larger dome forms the Goropu Mountains and may still be rising. The other is south of Cape Frere. Both are elongated west-north-west.

Several major faults are present in the area, the most prominent being the Owen Stanley Fault, which with associated faults forms the north-eastern border of the Owen Stanley Range. Many of the faults are still active.

IV. Geological History

The geological history of eastern Papua is interpreted by Davies and Smith (1971) in terms of plate tectonics, involving interaction between Australian and Pacific lithospheric plates and opening of the Coral Sea by rifting.

During the Mesozoic some 10,000–20,000 m of sediments of mainly sialic composition were deposited on or near the north-eastern margin of the Australian continent. At the end of the Cretaceous or somewhat later (Palaeocene or early Eocene) the sialic sediments were overridden by the Mesozoic oceanic crust (the Papuan Ultramafic Belt) from the north-east and were metamorphosed. This movement took place along a low-angle fault (the Owen Stanley Fault). In the Eocene the Coral Sea basin opened by rifting, and large volumes of basalt were extruded onto a deep ocean floor. At about the same time some shallow and deep-water sediments were deposited locally, as for instance in the Port Moresby area. Slow sedimentation probably continued in the area during the Lower and Middle Oligocene.

The eastern Papua land mass began to emerge in the Upper Oligocene–Lower Miocene. Sediments derived from the land mass were deposited in the Aure Trough in the north-west and linear limestone reefs developed in the east. Shallow-water volcanic activity locally accompanied sedimentation near Port Moresby, on Cape Vogel, and near Mullins Harbour.

In the Middle Miocene sedimentation continued in the Aure Trough and began in the Cape Vogel area. Reef limestone developed near Port Moresby and

elsewhere, and some shallow-water volcanic activity took place in the Cape Ward Hunt area. Since the Middle Miocene, emergence accompanied by block faulting has continued, detrital sediments have been deposited on both sides of the main range, and there has been widespread terrestrial volcanic activity. The Pliocene and Quaternary history is discussed in Part V.

V. Correlations between Geology, Land Forms, Soils, and Vegetation

Because land-form types are described in terms of land forms and lithology, most geological boundaries are also land-form type boundaries. However, except in the case of unconsolidated sediments, which are mostly Quaternary, lithology is not related to geological age. For instance, basaltic igneous rocks of Mesozoic, Tertiary, or Quaternary age are not distinguished from one another in defining basaltic land-form types.

The oldest rocks in the area, the Mesozoic schists and the igneous rocks of the Papuan Ultramafic Belt, are crystalline rocks that are relatively resistant to erosion. These give rise to mainly mountainous and high hilly terrain that is characterized by very steep forested slopes (over 30°) and shallow poorly developed soils. The poorest soils, indicated by the poorest smallest-crowned forest, occur on ultramafic rocks.

Terrain developed on the Eocene to early Pliocene rocks ranges in relief from very low (less than 30 m) to mountainous (over 400 m). Slopes are again mostly very steep. On basaltic igneous rocks ridge-and-ravine topography prevails, and the soils and vegetation are generally similar to those on the Mesozoic rocks. Tertiary limestone typically forms steep to excessively steep strike ridges on which soils are mostly very shallow. The vegetation is poorer than on the basaltic igneous rocks and ranges from poor forest to woodland and thicket to low grassland, depending mainly on amount and seasonality of rainfall. The detrital sedimentary rocks form mostly steep to very steep terrain, and soils are shallow except on the gently undulating terrain of USu land-form type which is developed mainly on poorly consolidated sediments and deeply weathered basaltic rocks.

The mid-Pliocene to mid-Pleistocene volcanic rocks are preserved as deeply eroded volcanoes which have little if any of their original constructional surfaces preserved. On these ancient volcanoes narrow ridges with very steep slopes prevail, and soils and vegetation are similar to those on the older volcanic rocks. The younger volcanics, of late Pleistocene to Recent age, form well-preserved to quite deeply eroded but still readily recognizable volcanoes. Volcanic ash emitted from these volcanoes has produced deep fertile soils on adjacent plains, alluvial fans, and slopes not being actively eroded. Such terrain, where slopes are not too steep, forms some of the best areas for agricultural land use in eastern Papua.

The Pleistocene glacial deposits and reef limestone are of very limited extent. The glacial deposits are confined to the highest mountain summits where they occur as well-preserved moraines, and the reef limestone is largely confined to the eastern tip of Cape Vogel where it occurs as an uplifted platform on which karst land forms are beginning to develop.

Pleistocene and Pliocene detrital sediments are poorly consolidated and hence relatively unresistant to erosion. They form dissected alluvial plains and fans that

generally have relatively deep soils. However, in places, as along the north coast east of the Musa River and in the Musa, Keveri, and Bidubi basins, deep dissection has given rise to very steep-sided to precipitous knife-edged ridges (slopes over 40°). These ridges have very shallow soils and support a vegetation of poor forest or, more commonly, low grassland. The younger sediments, consisting of alluvial, colluvial, and littoral deposits, are being laid down at the present time on the extensive plains flanking the mountain ranges and also on more restricted alluvial fans. On these plains and fans the soils and vegetation vary according to drainage conditions which range from swampy to well drained.

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PART V. GEOMORPHOLOGY OF EASTERN PAPUA

By D. H. Blake*

I. Introduction

Eastern Papua can be divided into four main geomorphic units: the central ranges, the north-east coast volcanoes, the coastal hills and undulating terrain, and the low-lying plains (*Fig. 6*).

In this account the geomorphic units are described first, followed by sections on land-forming processes, geomorphic history, and the relationship of geomorphology to land-form types.

The main rivers and their catchments are shown in Figure 7. The largest catchment is that of the Musa River, which covers about 6800 km^2.

II. Geomorphic Units

(*a*) *Central Ranges*

The central ranges comprise the Owen Stanley Range and several flanking ranges. The Owen Stanley Range, the main watershed of mainland eastern Papua, is formed mostly of Mesozoic schist in the north-west and Tertiary basaltic rocks in the south-east. It is taken to include both the Wharton Range in the north-west and the Goropu Mountains in the east. The range consists mainly of mountainous terrain (relief over 400 m) but also includes low to high hilly terrain (relief 30–400 m) and intermontane basins of very low relief (less than 30 m). The hilly terrain occurs as both foothills and remnant summit surfaces.

Flanking ranges are present on both sides of the Owen Stanley Range. On the north-east side they extend from the northern edge of the mapped area south-east to Goodenough Bay. The main ranges here are the Otava Range, formed mostly of pre-Pliocene basaltic igneous rocks; the Guaya, Owalama, Sibium, and Didana Ranges, of mainly ultramafic rocks of the pre-Pliocene Papuan Ultramafic Belt; and the Gwoira Range, which is formed of coarse-grained Plio–Pleistocene sediments. On the south-west side of the Owen Stanley Range the flanking ranges include mountains of Pliocene volcanic rocks north-west of Port Moresby, the Astrolabe Range and Sogeri Plateau, also formed of Pliocene volcanics, east of Port Moresby, and mountain and hill ridges of phyllite and early Tertiary sedimentary and basaltic volcanic rocks to the south-east.

The central ranges consist mainly of denudational land forms of the equilibrium ridge-and-ravine form (Ruxton 1967*a*). The ridges typically have sharp crests and

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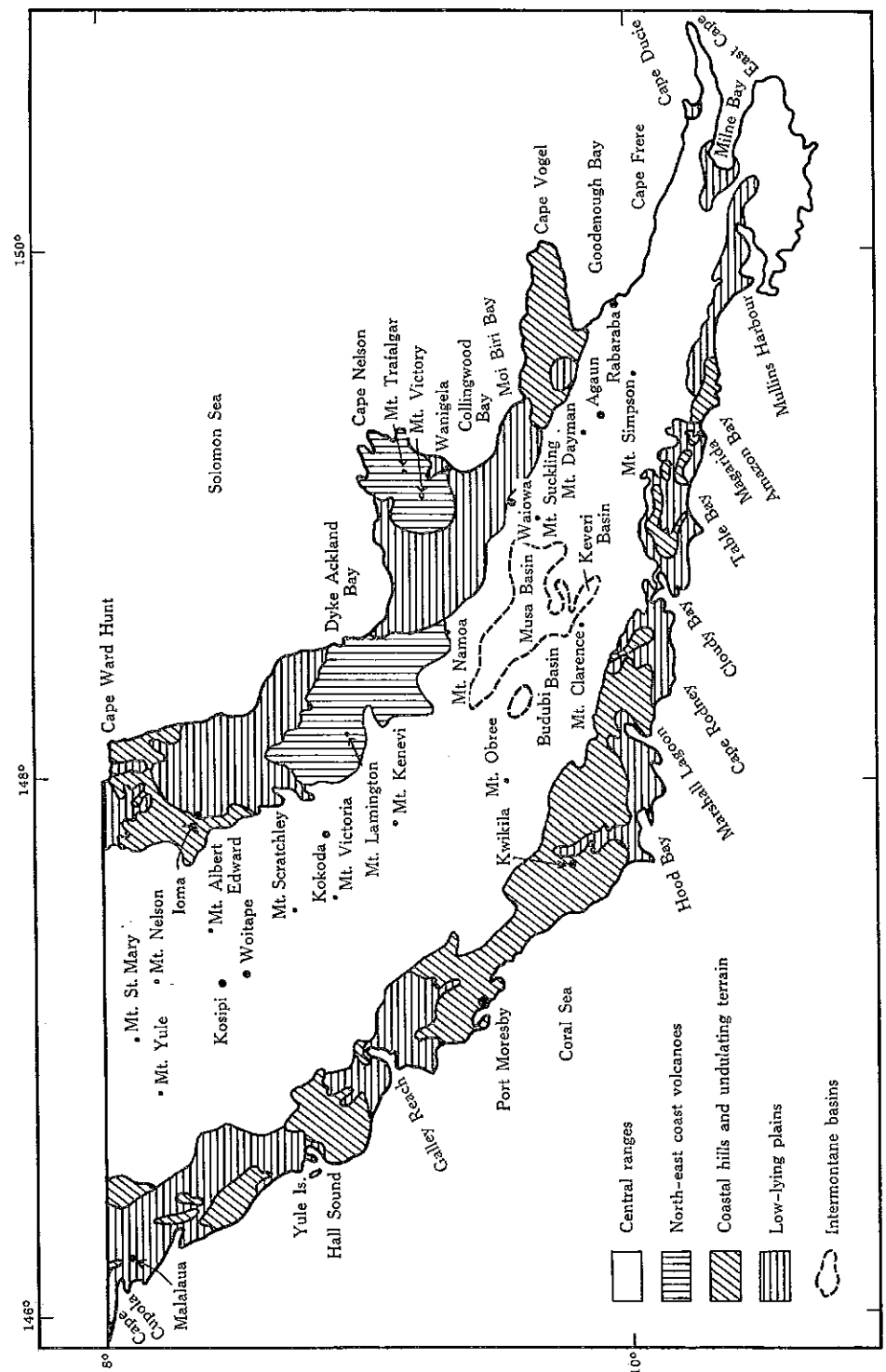

Fig. 6.—Geomorphic units.

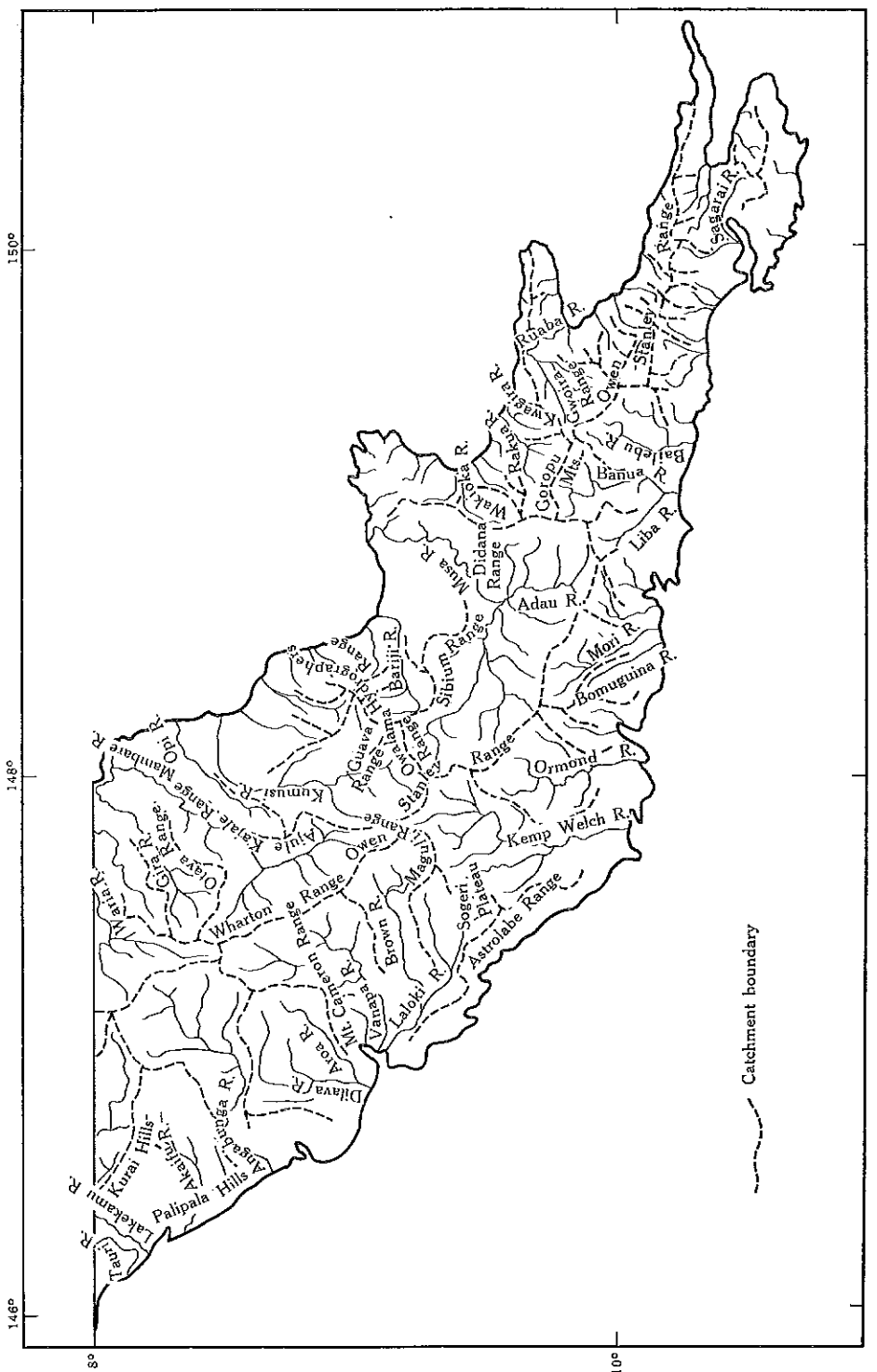

Fig. 7.—Main rivers and their catchments.

straight side slopes, mainly between 30° and 40°, which meet to form very narrow V-shaped valleys (Plate 6). In this type of terrain slope erosion keeps pace with rapid downcutting of valley bottoms. However, in places the terrain has not reached the erosionally graded ridge-and-ravine stage and oversteepened precipitous slopes, cliffs, and landslip scars characterize the landscape (Plate 23, Fig. 1).

Some of the geomorphic features of the central ranges are discussed below.

(i) *Dissected Plateaux and Remnant Surfaces.*—Dissected plateaux and remnant summit surfaces occur along the main watershed of the Owen Stanley Range and are also present on some of the flanking ranges and foothills (PBn, PBy, PMi, PMg, and PMb land-form types). They are surrounded by lower-lying terrain which generally has a greater relief and coarser grain, and they are being slowly reduced in size by the headward erosion of deep valleys around their borders. The dissected plateaux consist of subaccordant steep to very steep-sided ridges with narrow crests and have a generally dense dendritic drainage pattern, with streams in narrow V-shaped valleys. The remnant summit surfaces vary from smooth horizontal surfaces to steeply undulating high hilly terrain with local flat-floored intermontane valleys. Remnant surfaces not forming watersheds include several steep fault plane surfaces, most of which are along the north-east side of the Owen Stanley Range.

In the Milne Bay area, small dissected plateaux of low relief occur at elevations rising from 185 m in the south-east to 1550 m in the north-west, near Cape Frere (Smith 1970; Smith and Simpson 1971). They consist of narrow steep-sided branching ridges generally less than 100 m high. These plateaux probably represent an irregular Plio–Pleistocene erosional surface.

Along the north coast between Cape Frere and East Cape, the main range is bounded by shallowly dissected flat-iron surfaces which dip steeply north. These surfaces represent the plane of a major fault. To the south of Cape Frere a strongly convex surface rises southwards to merge with a roughly horizontal dissected plateau surface. The convex surface (XBp land-form type) is shallowly dissected by closely spaced and mostly parallel streams and is also incised by several amphitheatre-headed gorges over 400 m deep (Plate 14, Fig. 2).

Near Rabaraba flat nearly horizontal surfaces are preserved locally on the summits of extremely steep-sided and mostly knife-edged ridges (ZSv land-form type) that are formed of late Pliocene or Pleistocene coarse-grained alluvial and deltaic sediments (Plate 13, Fig. 1; Plate 22, Fig. 2). The local flat summits occur at various levels up to 500 m above sea level and represent the original depositional surfaces of former alluvial fans.

The Goropu Mountains further west represent a structural dome that is probably still rising. The dome is elongated in a west-north-west direction and its highest point, Mt. Suckling, is 3675 m above sea level. The dome is deeply incised by several rivers flowing in extremely steep-sided valleys, especially in the western part, where little of the dome surface is preserved. In contrast, the convex sides and top of the dome surface are mostly well preserved in the east (YMp land-form type), except for shallow incision by innumerable parallel consequent streams (Plate 16, Fig. 7; Plate 22, Fig. 1). The dome is formed of schist, the foliation of which is parallel to the dome surface. The north side of the dome descends abruptly to a broad low-lying coastal plain, the east side is partly overlapped by Plio–Pleistocene

sediments forming razor-back ridges of the Gwoira Range, the south side is bounded by faults which separate the dome from mountains on pre-Pliocene basaltic igneous rocks, and the west side descends to dissected fans at the east end of the Musa basin. North-dipping flat-iron surfaces on schist south of the Gwoira Range represent a fault plane that joins the Goropu Mountains dome to the west. A similar but smaller dome is probably represented by a convex surface and part of a dissected plateau south of Cape Frere.

A small intermontane basin is situated on the Goropu Mountains dome south of Mt. Suckling, just on the north side of the main divide, and another lies in a similar situation at Agaun, east of the Goropu Mountains. Both basins have relatively flat floors bordered by alluvial fans, and they are drained by streams that drop into deep valleys at the north-east ends of the basins and eventually flow into the Solomon Sea. The basin south of Mt. Suckling is cut off to the south by a scarp face dropping over 1000 m to the valley of the Bonua River. The south-west end of the Agaun basin is deeply incised by streams draining to the Coral Sea. Both basins probably originated during the late Pleistocene.

Small dissected plateaux similar to those of the Milne Bay area are present westwards along the Owen Stanley Range to the Kemp Welch River. A larger dissected plateau lies on the west side of this river; it consists of very steep ridge-and-ravine terrain with locally over 400 m relief.

The Sogeri Plateau east of Port Moresby (Plate 13) is a shallowly dissected remnant of a constructional volcanic surface of Pliocene age (Mabbutt 1965; Yates and de Ferranti 1967). It is mainly 500–800 m above sea level and is bounded by cliffs up to 250 m high. The remnant surface has been warped to form a broad syncline plunging gently north-west. The south-west limb of the fold forms the Astrolabe Range, the highest point of which is 1080 m above sea level.

In the Mt. Kenevi area, 80 km east-north-east of Port Moresby, extensive hilly remnant surfaces form the watershed of the Owen Stanley Range. These surfaces consist mainly of massive ridges with broad rounded summits, some of which have shallow basin-like depressions, and long steep side slopes. The valleys between the massive ridges of the remnant surfaces locally open out to form broad alluvial basins, the two largest of which are occupied by swampy areas known as the Myola lakes (Plate 21, Fig. 1). The basins lie over 1500 m above sea level and consist of narrow flood-plains with highly sinuous meandering streams and flanking terraces and low-angle alluvial fans. On leaving the basins the streams descend abruptly into deep V-shaped valleys. The remnant surfaces in this area are considered to be part of a highly irregular Pleistocene land surface which has been modified by subsequent faulting, flexuring, and tilting, indicated by river captures and diversions as well as erosion.

Dissected plateaux and remnant summit surfaces continue along the Owen Stanley Range to the northern edge of the mapped area. On Mt. Albert Edward and Mt. Scratchley the remnant surfaces have been modified by late Pleistocene glacial erosion (Löffler 1970). The remnant surfaces include two intermontane basins south-west of Mt. Albert Edward. These are the Neon basin (Plate 7) at about 2800 m and Kosipi swamp at about 1800 m above sea level: both consist of central swampy flood-plains flanked by alluvial fans.

On the Ajule Kajale Range south-east of Mt. Albert Edward remnant surfaces may be represented by ash-covered hilly areas of relatively low relief on mountain summits (Paterson 1964).

(ii) *Musa Basin.*—The Musa basin (Plate 10; Fig. 6) is a roughly triangular-shaped hilly area covering about 1400 km^2 along the middle course of the Musa River. It lies between 120 and 620 m above sea level and is surrounded by the Owen Stanley Range to the south, the Sibium–Didana Ranges to the north, and the Goropu Mountains to the east. The Musa basin consists of a narrow east–west alluvial plain, bordered by undissected and dissected fans and a complex of valley benches and steep to very steep-sided ridges, that is formed of terrestrial Plio–Pleistocene sediments (Ruxton 1967*a*). Similar ridge complexes occur in the smaller adjoining Keveri basin to the south and in the isolated small Budubi basin to the south-west. Both these smaller basins are higher than the Musa basin. The three basins were formerly intermontane valleys with thick deposits of Plio–Pleistocene alluvium and they have since been tectonically deformed and deeply eroded so that little, if any, of the original depositional surfaces have been preserved.

(iii) *Yodda–Kumusi Fault Trough.*—Extending north-west from the Musa basin to the edge of the map area is a narrow fault-bounded trough which separates the Owen Stanley Range from flanking ranges to the east (Plate 8; geological map). The west side of the trough is bounded by the Owen Stanley Fault, the plane of which is represented by a dissected surface dipping 30° to 45° north-east. This surface is drained by parallel streams in narrow V-shaped gorges. Within the trough there are undissected alluvial fans and terraces, variably dissected old fans, and hilly and mountainous terrain on pre-Pliocene igneous rocks, mainly basalt. Some of the dissected fans consist of closely spaced, parallel, accordant ridges with narrow crests and a local relief generally less than 200 m; some consist of flat-topped interfluves separated by steep-sided V-shaped valleys generally less than 200 m deep; and some consist of massive ridges up to 500 m high. Terraces and other surfaces not being actively eroded or aggraded within the trough are mantled by several metres of volcanic ash derived from Mt. Lamington.

(iv) *Volcanoes.*—Two young (Pleistocene to Recent) volcanoes occur within the central ranges and two others, not yet confirmed, have been interpreted on air photos. The two known volcanoes are Waiowa volcano and a volcano on Naoro River 55 km north-east of Port Moresby. Waiowa volcano is an asymmetrical pyroclastic cone formed in 1943–44 that rises to about 540 m above sea level on the north flank of the Goropu Mountains (Fisher 1957). It has moderate to gentle concave side slopes and a summit crater containing a small lake (Plate 29, Fig. 2). Naoro volcano is about 300 m high and is a steep-sided lava cone with no summit crater preserved. The two other volcanoes lie 7 km north-west of the Budubi basin and 7 km south-east of the Myola lakes respectively. Both are small asymmetrical low-angle cones that have not been examined on the ground.

Ancient volcanoes, with little or none of their original volcanic surfaces preserved, occur north-west of Port Moresby and in the Cloudy Bay area on the south coast. These volcanoes can be distinguished because, unlike the adjacent mountains and hills, they have not yet reached the erosionally graded stage of

ridge-and-ravine land forms. Instead, cliffs, precipitous slopes, and shallowly dissected volcanic surfaces are characteristic features. A modified radial drainage pattern is preserved locally, especially on lower slopes.

(v) *Glaciation.*—The effects of Pleistocene glaciation in eastern Papua have been described by Löffler (1970, 1972). The most extensive glaciation occurred on Mt. Albert Edward, the top of which is an irregular plateau with two summit ridges. During the maximum glaciation the mountain had an ice cap covering 90 km^2, extending from the summit at 3990 m down to 3400 m. Glacial land forms preserved include cirques, U-shaped glacial valleys, moraines marking the maximum extent of the glaciation, and recessional moraines; many of the cirques contain lakes.

A smaller plateau area, Mt. Scratchley, to the south of Mt. Albert Edward, had an ice cap that covered about 28 km^2. Mt. Scratchley is about 3800 m above sea level and has well-developed moraines and glacial valleys. In addition, several small cirques occur along a ridge to the north.

The highest mountain in eastern Papua, Mt. Victoria, which rises to 4036 m above sea level, was also glaciated during the Pleistocene. However, unlike Mt. Albert Edward and Mt. Scratchley, it is a narrow very steep-sided ridge and only about 15 km^2 was covered by ice. Well-preserved glacial features are confined to the north-west where two cirques lead down to two glacial valleys with moraines.

At the time of maximum glaciation the snowline was at 3600–3650 m on Mt. Albert Edward and Mt. Scratchley and at 3650–3700 m on Mt. Victoria.

(*b*) *North-east Coast Volcanoes*

Two groups of active and extinct volcanoes occur on the north-east side of the Owen Stanley Range between longitudes 148° and 149° 20′E. The more westerly of the two is the Mt. Lamington group which consists of the active Mt. Lamington volcano, the deeply eroded and extinct Hydrographers volcano, several smaller extinct volcanoes forming part of the Managalase Plateau, and the very deeply eroded and long extinct Sesara volcano. To the east, separated from the Mt. Lamington group by the plain of the lower Musa River, is the Cape Nelson group, which comprises the potentially active Mt. Victory volcano and the deeply eroded Mt. Trafalgar volcano.

Mt. Lamington (Taylor 1958; Haantjens *et al.* 1964*a*) is a volcanic cone (Plate 5), rising to 1780 m above sea level, that last erupted in 1951. It has a rugged summit area with several lava domes, lava flows, adventive cones, and debris slopes in various stages of dissection, and a large crater open to the north. This crater contains a lava dome 560 m high which was extruded during the last eruption. The summit area is flanked by extensive, gently concave fans formed mainly of pyroclastics and derived alluvial deposits. Several small adventive cones occur on the flanks. The volcano has a well-developed radial drainage pattern.

The Hydrographers volcano (Haantjens *et al.* 1964*a*; Ruxton and McDougall 1967) rises to 1887 m on the east side of Mt. Lamington. Although it is deeply eroded its general volcanic profile is clearly discernible. The flanks consist of radial razor-back ridges and V-shaped valleys, with some triangular-shaped foot-slope remnants, known as planezes, on the lowest slopes in the east (Plate 19, Fig. 2). The central part is formed of non-accordant mountain ridges and peaks. The ridges are

very steep-sided, and landslip scars are common. The volcano is in a late planeze or early residual mountain stage of dissection. It was formed 650,000–700,000 years ago and has been eroded at rates up to 75 cm per 1000 years (Ruxton and McDougall 1967).

The Managalase Plateau (Ruxton 1966, 1967*a*) to the south of the Hydrographers volcano lies mostly between 460 and 1070 m, although the highest point, Mt. Manna, is 1127 m above sea level. The eastern part of the plateau (Plate 9) is formed of late Pleistocene to Recent lava flows, lava cones, cinder cones, and ash cones, some of which are deeply dissected while some are very well preserved. The western part of the plateau comprises the dissected southern foot slope of the Hydrographers volcano and consists of closely spaced parallel ridges with crests sloping south and south-west at 1–2°.

Sesara volcano, south-east of the Managalase Plateau, is in a near-skeletal stage of dissection and has been dated at 5·4–5·75 million years, or early Pliocene (Ruxton and McDougall 1967). It consists mainly of mountain ridges with very steep to precipitous sides and many cliffs, indicating that the equilibrium ridge-and-ravine stage of erosion has not yet been reached. The highest point on the volcano, Mt. Namoa, is 1340 m above sea level.

Mt. Victory (Fisher 1957; Haantjens *et al.* 1964*b*), one of the two volcanoes of the Cape Nelson group, rises to 1856 m and was last active in the 1890s. Like Mt. Lamington, it has a rugged summit area, consisting of lava domes and flows in various stages of dissection, and broadly concave flanking fans formed mainly of pyroclastic and derived alluvial deposits. There are several adventive cones in the summit area, one of which, in the saddle between Mt. Victory and Mt. Trafalgar, contains the crater lake Ridubidubina. Young well-preserved lava flows at least 50 m thick and two adventive cones occur on the south-west flank. A well-developed radial drainage pattern is present.

Mt. Trafalgar (Haantjens *et al.* 1964*b*), 1706 m, is similar in form and erosional stage to the Hydrographers volcano, consisting largely of long radial valleys separated by mostly razor-back ridges. On the lower north and east slopes, U-shaped valleys form fjord-like inlets up to 6·4 km long and 150 m high separated by narrow planezes. The inlets may have resulted from an initial relative lowering of sea level causing deeply incised valleys to form on the foot slopes, followed by a relative rise in sea level and consequent drowning of the deep valleys. The relative rise in sea level could have been due to local subsidence caused by the loading effect of the thick pile of volcanic rocks forming the two volcanoes (J. G. Best, unpublished report 1950).

(*c*) *Coastal Hills and Undulating Terrain*

A discontinuous zone of coastal hills and undulating terrain is present along the south-west coast from Cape Cupola in the north-west to Mullins Harbour in the south-east. Similar terrain also occurs on the north-east coast near Cape Ward Hunt, on Cape Vogel, and on Cape Dulcie. The coastal hills and undulating terrain have a relief mainly between 10 and 300 m. They are formed of Tertiary detrital sedimentary rocks, limestone, and local associated volcanics, mainly pyroclastics. The rocks range considerably in their resistance to erosion, the most resistant types generally being limestone and chert.

The discontinuous zone along the south-west coast consists of belts of strike ridges and cuestas formed on limestone and chert, branching ridges on mainly sandstone and siltstone, undulating lowlands mainly on mudstone, and narrow valley floors, including some strike valleys, with mostly clayey alluvium. The zone is broken into separate parts by the alluvial plains of the large rivers that drain the south-west side of the Owen Stanley Range. West of longitude 148°30′ ridges of limestone and chert generally have smoothly rounded crests and short to very short spurs (Plate 4; Plate 23, Fig. 1; Plate 24, Fig. 1), whereas ridges on other rock types mostly have very narrow and uneven crests and long branching spurs (Plate 13, Fig. 1). Side slopes are mostly 20–30°, although steeper slopes occur in valley heads and on some scarp faces. Concave foot slopes of up to 5° are typically present, commonly mantled by alluvial and colluvial debris. Small plateaux occur between the Kemp Welch and Ormond Rivers, formed on flat-lying limestone near the coast and on basaltic igneous rocks further inland. Prominent limestone scarps occur near the coast in the same area and to the west towards Port Moresby. In the north-west the Palipala and Kurai Hills represent anticlinal structures (Plate 15, Fig. 2). Near Cape Cupola an intricate pattern of low subaccordant ridges and narrow valleys is formed on Tertiary detrital sedimentary rocks. Raised reefs and marine abrasion platforms occur up to 30 m above sea level near Port Moresby. Very gently undulating terrain between Marshall Lagoon and Cloudy Bay is formed on old alluvium of probably late Pleistocene age (Plate 14, Fig. 1).

The area of relatively low seasonal rainfall between the Lakekamu River in the north-west and the Ormond River in the south-east has a savannah type of morphogenetic regime (Mabbutt 1965; Mabbutt and Scott 1966). Here minor streams are ephemeral and some land forms, surface deposits, and weathering profiles are inherited from an earlier landscape cycle. The undulating terrain is in an advanced stage of planation. Relics of ferruginous duricrust are present locally.

Along the south coast east of longitude 148°30′ the coastal hills consist mainly of strike ridges of limestone (Plate 17, Fig. 2). These ridges have characteristic knobbly crests, indicative of solution weathering, and oversteepened side slopes with many cliff faces and scree slopes.

On the north-east coast a coastal plateau in the Cape Ward Hunt area has been faulted and tilted to form several separate segments, up to 410 m above sea level, which have been shallowly dissected by closely spaced streams. Inland from the plateau, low ridges and gently undulating terrain extend westwards to the foothills of the central ranges (Plate 12). The coastal plateau and the low ridges and undulating terrain are formed of Pliocene sedimentary and volcanic rocks.

The hills on Cape Vogel rise to 450 m above sea level but the relief is generally less than 300 m (Haantjens *et al.* 1964*b*). In the extreme east, limestone of probably late Pleistocene age forms a platform up to 60 m above sea level; this platform is in a very early stage of karst development. To the west are the hill ridges on mainly Tertiary detrital sediments that make up most of the Cape Vogel peninsula. These ridges have narrow uneven crests and long branching spurs and are similar to some of the coastal ridges near Port Moresby. The drainage pattern is dendritic. The westernmost part of the peninsula consists of an intricate pattern of closely spaced accordant ridges and a low, slightly irregular plateau bounded to the north by a

dissected escarpment. Locally the ridges on the peninsula are separated by flat floors of valleys and basins consisting mainly of alluvial clay.

Cape Dulcie, south-east of Cape Vogel, is a shallowly dissected plateau tilted to the south that is formed of Tertiary igneous rocks. The highest part of the plateau is about 200 m above sea level.

(*d*) *Low-lying Plains*

Low-lying alluvial and littoral plains occur on both sides of the central ranges. The main areas on the south-west side are the Lakekamu–Angabunga and Dilava–Laloki plains north-west of Port Moresby, and plains along the south coast from the Kemp Welch River to Marshall Lagoon, from Cape Rodney to Magarida, and in the vicinity of Mullins Harbour. On the east and north sides of the central ranges the main areas are the Kumusi–Mambare lowlands in the north-east, the Musa plain, the coastal plain on the north side of the Goropu Mountains, the alluvial plain of the Ruaba River, and the plain at the western end of Milne Bay. The low-lying plains are developed on young alluvial and littoral deposits and are characterized by general slopes of less than 1° and local relief of less than 10 m.

(i) *Alluvial Plains.*—The major rivers of eastern Papua have extensive alluvial plains along their lower courses. The plains are mainly less than 100 m above sea level and typically have gradients between 1 in 100 and 1 in 1000, although slopes up to 1° occur in places and local bordering fans may have slopes up to 5°. The rivers drain rapidly eroding mountainous terrain and carry large volumes of detritus down to the plains, where frequent flooding by the sediment-laden water causes rapid aggradation. However, not all parts of the plains receive large amounts of sediment, as some are flooded mainly by clear run-on water.

The alluvial plains range from well drained to swampy. Well-drained parts have rapidly to moderately permeable soils, water-table depths generally in excess of 2 m, and mostly infrequent and short-lived flooding. Swamps occur where the water-table is above the ground surface for at least three months a year and are located where there are insufficient slopes and drainage outlets to allow rain-water and run-on water to disperse.

The most extensive alluvial plains occur north-west of Port Moresby and on the north-east coast west of longitude 149°E. These plains consist mainly of present and prior meander tracts and back plains, and are combinations of meander plains and covered plains according to the classification of Melton (1936). The meander tracts form alluvial ridges that are slightly higher and commonly better drained than the flanking back plains, many of which are partly or wholly occupied by swamps. The meander tracts are formed mainly of meander scroll complexes (Blake and Ollier 1971), which consist of intersecting groups of arcuate low ridges representing former point bars. The main rivers are confined to the meander tracts. They have highly sinuous meandering channels that are commonly unstable (Plate 2). This is indicated by numerous ox-bow and serpentine lakes and swamps representing abandoned channels and by concurrent deposition and erosion along the present channels. Low levees are present locally, bordering the less unstable parts of channels.

In their upper inland parts the alluvial plains generally have narrow shallowly incised flood-plains with very unstable and commonly braided channels (Plate 6;

Plate 20, Fig. 1). The flood-plains are flanked by back plains that commonly have a channelled microrelief.

The alluvial plains north-west of Port Moresby occupy a tectonic depression (Mabbutt 1965) bordered to the north-east by foothills of the central ranges and to the south-west by coastal hills. Changes in river courses are common, as shown by the presence of many prior channels. The most recent major change took place at the end of 1954, when the meandering Angabunga River (Speight 1965*a*) overspilled through a crevasse which has since developed into a new channel. The new course of the Angabunga River is 29 km shorter than the former course, and the gradient downstream from the crevasse has increased from 2·5 in 10,000 for the abandoned lower course to 5 in 10,000 for the new course (Speight 1965*b*). Swamps occur between present and prior meander tracts and adjacent hills. In these swamps seasonal fluctuations in water level of up to 2 m are common. During the rainy season the swamps are subject to river flooding while during periods of low river level, in the dry season, they overspill into the main rivers. Most of the swamps are being aggraded by clay deposited from still water and silty alluvium from inflowing streams. Locally, however, the amount of sediment deposition is less than the accumulation of organic matter, and where this occurs peat swamps are formed. In some cases the swamp deposits consist of alternating layers of peat and clay.

Along the south coast, the Kemp Welch River has a mostly well-drained and relatively narrow alluvial plain with a central meander tract and several prior channels. The Ormond River emerges from the coastal hills to form a poorly drained to swampy delta with several distributary channels and prior channels. Further east is the alluvial plain of the Mori River, the inland part of which consists of a narrow incised frequently flooded plain, which contains the present highly unstable and locally braided channels, flanked by mostly well-drained back plains. Downstream the alluvial plain becomes wider and the river channel, no longer incised, follows a meandering course before splitting up seawards into several distributary channels. Most of the alluvial plains to the east are similar to the upper part of the Mori River alluvial plain; meander tracts, if present, are restricted to the seaward margins. The Bonua River, for instance, which rises on the south side of the Goropu Mountains, has a narrow confined upper alluvial plain (Plate 6; Plate 20, Fig. 1) made up of an unstable braided channel and channelled back plains. Downstream the valley opens out and the river flows across a broad coastal plain to the sea, but without developing a highly sinuous meandering channel. The coastal plain here, between Cloudy Bay and Magarida, consists mainly of extensive swamps separated from the sea by a barrier of beach ridges (Plate 17, Fig. 2).

In the north, on the north-east side of the central ranges, the extensive Kumusi–Mambare lowlands (Paterson 1964) consist mainly of narrow meander tracts and flanking swampy back plains. Low levees commonly border the river channels on the meander tracts. Much of the swampy back plains consists of peat. Near the inland margins of the plains the rivers flow in narrow terraced flood-plains incised up to 7 m into well-drained back plains. In the south the alluvial plains merge with the lower flanks of Mt. Lamington volcano. Here the plains have gradients up to 1 in 100, and include some very low-angle fans (slopes less than 1°) drained by numerous unstable braided channels; the fans pass upslope to volcano-alluvial fans with slopes of 1–5° (Plate 5).

The Musa plain (Ruxton 1967*a*) to the south-east has been formed by rapid outgrowth resulting from the deposition of large volumes of sediment transported through the Musa gorge from the central mountain ranges. It is a nearly level depositional plain on which there are slightly higher and generally better-drained meander tracts of present and prior rivers. The plains to the east, on the north side of the Goropu Mountains and the Gwoira Range, are piedmont plains (Haantjens *et al.* 1964*b*) traversed by several subparallel fast-flowing rivers. The rivers are mainly confined to narrow incised flood-plains which are locally as much as 10 m below the flanking back plains, especially near the mountain front. Regular flooding of the back plains appears to be restricted to small areas near the coast. Swamps on the south and west sides of Mt. Victory may possibly be due to sinking of the thick pile of volcanic rocks. North of Mt. Suckling a poorly drained and locally swampy fan-shaped area has been formed where unstable braided rivers flow out from the Goropu Mountains onto the plain.

Small alluvial plains are associated with minor rivers draining coastal hills in savannah areas near Port Moresby and on Cape Vogel. These plains are generally less than 2 km wide and consist of narrow flood-plains flanked by colluvial and alluvial fans. The river channels are typically highly sinuous and are incised up to 7 m into the flood-plains.

(ii) *Littoral Plains.*—These consist mainly of beach-ridge complexes and tidal flats but are also taken to include two small dune fields near Hood Bay. Littoral plains occur on coasts that are being built out seawards, and are best developed along the south-west coast. The tidal range around the coast is generally less than 2 m.

Beach-ridge complexes reach their maximum development between Cloudy Bay and the mouth of the Bonua River on the south coast, where they form a littoral plain up to 6 km wide. Such complexes (Plate 1; Plate 17, Fig. 2) consist of long parallel ridges and swales (depressions) with a local relief up to 3 m but generally less than 2 m. The ridges are most pronounced on the seaward side, and inland they commonly grade into flats which have a local relief of less than 1 m. They are formed of sand transported by long-shore drift, and each beach ridge marks a former shoreline. The swales between the ridges are commonly swampy. Low irregular sand dunes are commonly present on the outermost ridge of beach-ridge complexes near Port Moresby. Near Malalaua in the north-west old beach-ridge complexes occur up to 9 km inland and 8 m above sea level. These are overlain by thin deposits of young alluvium and are largely graded to plains.

Tidal flats occur mainly in protected embayments and in the vicinity of river outlets. They are formed predominantly of clay and silt and are characterized by mangrove vegetation. The outermost parts are subject to daily salt-water or, in river mouths, brackish-water tidal flooding, but the inland parts may be subject to only monthly or seasonal flooding. The main areas of tidal flats are the Lakekamu River delta, Hall Sound, Galley Reach (Plate 1), Hood Bay, Marshall Lagoon, Cloudy Bay, and Mullins Harbour along the south-west coast, and the seaward margin of the Musa plain (Plate 3) and along the south side of Collingwood Bay on the north-east coast. A prominent microrelief of crab mounds is commonly present. The mounds are up to 2 m high and tend to be most abundant bordering tidal channels where they may coalesce to form raised rims. Small inclusions of beach-ridge complexes are present locally within the tidal flats, as in the Galley Reach area. Also the

mangrove vegetation on the tidal flats locally shows a beach-ridge pattern, indicating slight drowning of former beach-ridge complexes. The tidal flats typically have an anastomosing drainage pattern of meandering creeks. The creeks characteristically have funnel-shaped mouths and have both highly sinuous meanders and straight reaches connected by sharp elbow bends.

Two small fields of sand dunes are located near Hood Bay, on the south coast. The larger field is on the north-west side of Hood Bay where it is separated from the sea by a beach-ridge complex. It consists of longitudinal dunes up to 30 m high elongated in a west-north-west direction, oblique to the prevailing south-east winds. The smaller dune field is 25 km to the east and is formed of irregular dunes mostly less than 20 m high.

Coral reefs, including both barrier and fringing reefs, occur along the south-west coast from Hall Sound to Mullins Harbour, but are only sporadically developed elsewhere. Former coral beaches occur up to 10 m above sea level near Cape Ward Hunt in the north-east, and raised coral reefs occur near Port Moresby, on Cape Vogel, and along the north coast between Rabaraba and East Cape (Plate 18, Fig. 2).

III. Land-forming Processes

The main land-forming processes active in eastern Papua are briefly discussed under the headings tectonism, volcanism, weathering, slope processes, fluvial processes, and littoral processes. These processes are the same as those active elsewhere in Papua New Guinea, and are discussed in more detail in other reports in the Land Research Series, especially by Ruxton (1967*a*, 1969) and Speight (1967).

Eastern Papua consists mainly of mountainous and hilly terrain. In such terrain a dynamic balance is commonly reached between the rate of slope denudation and the rate of stream down-cutting, resulting in erosionally graded ridge-and-ravine land forms.

(*a*) *Tectonism*

Tectonism causes folding, warping, tilting, and faulting of the land surface. Folding is clearly evident in the north-west where the Palipala and Kurai Hills have been formed by uplift along anticlinal fold axes. Warping and tilting are shown by raised reefs on the coast, by dome structures such as that forming the Goropu Mountains, and by modified plateau surfaces such as the Sogeri plateau near Port Moresby and the coastal plateau at Cape Ward Hunt.

Land forms resulting from faulting include flat-iron surfaces developed by exposure and dissection of fault planes, mainly on the north-east side of the Owen Stanley Range, and fault line features such as scarps and linear depressions. Faulting has also resulted in remnant plateau surfaces being preserved at different levels and has caused many instances of river diversion and capture.

(*b*) *Volcanism*

Volcanic land-forming processes include the formation of lava flows, lava domes, scoria cones, and craters, mainly on the summit areas of active volcanoes, and the deposition of pyroclastic material, mainly on the flanks of the volcanoes

and on nearby land surfaces. For instance, thick mantles of volcanic ash are preserved in the vicinity of Mt. Lamington on surfaces that are not being actively eroded or aggraded.

Present-day volcanic activity in the area is restricted to fumarolic activity in the summit areas of Mt. Lamington and Mt. Victory, and near the junction of the Awara and Musa Rivers at the western end of the Musa basin (Fisher 1957).

Hot springs, which, however, may not be related to volcanic activity, have been recorded in the Musa basin (Fisher 1957) and on the north side of the Goropu Mountains (Heming 1969).

(*c*) *Weathering*

Weathering in Papua New Guinea has been discussed recently by Haantjens and Bleeker (1970). As it is a tropical high-rainfall area, conditions are generally optimal for chemical weathering. However, because the interaction of climate and high relief also leads to rapid erosion, deep mature weathering is relatively uncommon and most surfaces have shallow immature weathering profiles.

In mature weathering, secondary clay minerals greatly predominate over "weatherable" minerals and rock fragments. In eastern Papua such weathering is mainly confined to remnant surfaces in the central ranges but is also found locally on dissected fan surfaces, as at the eastern end of the Musa basin where some mature weathering profiles are over 7 m deep (P. Bleeker, personal communication). At the other end of the weathering scale comes skeletal weathering in which secondary clay minerals are insignificant. This type of weathering occurs on precipitous slopes and on land forms developed on very young sediments, such as frequently flooded alluvial plains and tidal flats, and on very young volcanic rocks. Fresh rock outcrops are rare, being confined to cliffs and to the beds of actively down-cutting mountain streams. The prevailing steep and very steep slopes in the mountains and hills mainly have shallow immature weathering profiles.

(*d*) *Slope Processes*

The main land-forming processes active on hill slopes are mass movement, slope wash, and gullying. In addition, solifluction, the downslope movement of soil material resulting from frost action, is an important process above 3000 m.

(i) *Mass Movement.*—Large slumps, landslides, and rock falls are characteristic features of oversteepened slopes, especially in the central ranges. Small rotational slumps are common locally; they are probably caused mainly by heavy rain and not by earthquake activity, which is an important factor in several other parts of Papua New Guinea. Terracettes, formed by soil creep, are common on steep and very steep slopes throughout the area as are bent tree trunks, evidence for rapid soil creep. Mud-flow fans in the Musa basin have been formed by slumping of very deep weathering profiles (Ruxton 1967*a*).

(ii) *Slope Wash.*—Slope wash includes the erosive action of rain drops and surface run-off not concentrated as streams. It is probably an important erosional process on many slopes over 5° (Ruxton 1967*b*), as shown by the general paucity of leaf litter and the local occurrence of small-scale earth pillars, scoured surfaces, and lag gravel.

(iii) *Gullying.*—Gullies occur on most hill and mountain slopes and start within 70 m of crests. They increase in size down slope and eventually join streams in valley bottoms. Subsurface erosion, with the development of tunnels connecting gullies, has been recorded in the north-west (Ruxton 1969) and probably occurs locally elsewhere in the area, especially on slopes with clay soils mantled by volcanic ash. On such sites water passes readily through the volcanic ash and erodes the top of the underlying impermeable clay.

(*e*) *Fluvial Processes*

Streams in the mountains and hills are generally poorly graded and torrential and have steep gradients and gravelly or bouldery beds. Such streams are eroding their beds by rapid vertical and lateral corrasion. As a result, incised channels, undercut banks, and oversteepened lower side slopes of valleys are very common. Gorges are developed in extreme cases of vertical down-cutting. As well as eroding, the mountain streams also locally deposit sediment. This occurs where gradients decrease and the valley floors become broader. In such places the valley floors form local covered plains (Melton 1936) with meandering channels, levees, and thick back-plain deposits.

Most of the debris resulting from erosion in the hills and mountains is transported by streams onto the low-lying plains. In some cases, as on the north side of the Goropu Mountains, there is an abrupt transition from mountains to plains; the gradient of the streams decreases sharply and coarse detritus is deposited to form alluvial fans; these fans are commonly terraced (Plate 20, Fig. 1). Where foothills are present, as on the west side of the central mountain ranges, the change in stream gradient is less abrupt and prominent alluvial fans are not normally developed.

On reaching the low-lying plains the streams deposit most of their bed load and suspended load. The coarser detritus is generally laid down as channel deposits in the stream beds or as lateral accretion deposits to form point bars and meander scrolls. The finer detritus is mostly deposited on levees or back plains or is carried out to sea. In several cases, as at the mouth of the Musa River, much of the detritus is being deposited on deltas that are extending the low-lying plains seaward.

(*f*) *Littoral Processes*

Littoral land-forming processes involve long-shore drifting of sand, development of tidal flats, coral growth, and coastal erosion. Long-shore drifting of sand carried down to the sea by the main rivers results in the formation of spits, bars, and active beaches and leads to the development of beach ridge complexes. Tidal flats are developed mainly in embayments protected from strong currents, especially in river outlets where fine sediment carried onto the flats is trapped by mangroves and deposited. Mound-building crabs also contribute to the accretion of tidal flats. Active coral growth takes place on fringing and barrier reefs, mainly along the south-west coast between Hall Sound and Mullins Harbour. Coastal erosion is confined to headlands that are not protected by coral reefs and are not sites of active sedimentation.

IV. Geomorphic History

The Mesozoic and Tertiary history of mainland eastern Papua has been discussed in Part IV. Uplift of the central ranges commenced in the Upper Oligocene–Lower Miocene and has continued to the present day, accompanied by block faulting, folding, warping, and volcanism. Extensive erosion has taken place during the uplift and large volumes of sediment have been transported from the ranges and deposited on adjacent low-lying plains and in offshore areas.

(*a*) *Pliocene and Early Pleistocene*

During the Pliocene large strato-volcanoes were built up on the west side of the Owen Stanley Range north-west of Port Moresby, and the volcanic agglomerate forming the present Sogeri plateau was laid down in a broad valley or basin. Volcanoes were also active south-east of Mt. Lamington and on the south coast near Cloudy Bay. By the end of the Pliocene the volcanoes had become extinct and subsequent erosion has left little of the original constructional surfaces preserved.

Within the central ranges undulating erosional surfaces were developed along watersheds, while coarse detrital sediments of Plio–Pleistocene age were deposited in the Musa basin and the nearby Keveri and Budubi basins and also in the Yodda–Kumusi fault trough to the north-west. Coarse sediments of similar age were also deposited as alluvial fans and deltas along the north side of the Owen Stanley Range east of the Goropu Mountains, and limestone reefs were formed near Cape Frere. Pliocene and older sediments on Cape Vogel were uplifted and subjected to normal erosional processes. In the north-west the Palipala and Kurai Hills were formed by uplift along anticlinal axes.

(*b*) *Mid Pleistocene to Recent*

Volcanic activity since the early Pleistocene has been mainly confined to the north-east coast volcanoes, though small volcanoes have also been active within the central ranges.

The continued development of the central ranges has led to:

(1) deep dissection and local warping of Plio–Pleistocene fan surfaces in intermontane basins along the north coast east of the Goropu Mountains and in the Yodda–Kumusi fault trough;

(2) uplift of the dome forming the Goropu Mountains and the smaller dome south of Cape Frere;

(3) uplift and erosion of Plio–Pleistocene erosional surfaces which are now represented by remnant summit surfaces and dissected plateaux;

(4) formation of flat-iron surfaces, scarps, and other land forms associated with faulting; and

(5) rapid erosion in the mountains and aggradation on the low-lying plains, with most of the mountainous and hilly areas being erosionally graded to the ridge-and-ravine stage.

Other Quaternary geomorphic events include late Pleistocene glaciation on the highest peaks of the Owen Stanley Range, dissection of some Pleistocene alluvial

fans and plains (Plate 20, Fig. 2), growth of coral reefs around the coast, development of beach-ridge complexes and tidal flats, and continued denudation of coastal hills and undulating terrain.

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PART VI. VEGETATION OF EASTERN PAPUA

By K. PAIJMANS*

I. INTRODUCTION

The most important factors which determine the vegetation in Papua New Guinea are site drainage conditions, climatic factors, and man's activities. Soil and rock type are of relatively minor importance. The most widespread climax vegetation type is forest, other climax vegetation types being herbaceous vegetation, palm vegetation, and woodland which mainly occupy swamps. Also present are virtually stable disclimax vegetation types such as savannah and grassland. Successions of vegetation types, gradually reverting back to forest, occur where the original forest has been destroyed, for instance by volcanic eruptions.

Eastern Papua contains all the main vegetation types represented in Papua New Guinea. In the following account these types are described and information is given on their distribution and relationship to the environment.

II. VEGETATION AND MAJOR ENVIRONMENTS

The coast is fringed by mostly discontinuous narrow bands and small patches of mangrove. The largest areas of mangrove occur along the south-west and south coasts; along the north coast it is extensive only where it borders the Musa coastal plain. The mangrove ranges from low herbaceous vegetation on salt flats through scrub, mixed mangrove and nypa palm vegetation, and woodland to mangrove forest, according to the different tidal regimes and climates. Nypa palm covers large areas near the mouths of some of the major rivers and lines tidal creeks in narrow stands that are flooded daily by brackish water.

Freshwater swamp communities occupy large areas on low-lying coastal plains and smaller areas inland. Swamp forest and other predominantly woody vegetation, commonly mixed with sago palm and pandans, are found in shallow and often fluctuating swamps, whereas a herbaceous vegetation of swamp grasses, sedges, and in places aquatics, grows in deeper permanent swamp. Tea-tree or paper bark tree (*Melaleuca*) is the characteristic tree in seasonally dry swamps. The main areas of freshwater swamp vegetation are in the north-west near the Palipala Hills and in the north-east around the lower courses of the Gira, Mambare, and Opi Rivers. Inland, freshwater swamp communities occur in some intermontane basins such as the Kosipi swamp at 1800 m a.s.l.

Grasslands occur from sea level to the highest altitudes. They are very largely man-made and are most widespread in monsoonal coastal areas where the fire danger

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and population density are highest, for instance along the south-west coast, to the west of Cape Vogel, and in the Musa basin. However, extensive areas of grassland also occur in non-monsoonal mountain regions, especially in the central north. Here, where they are below the upper limit of agriculture, they are mainly the result of clearing, intensive shifting cultivation, and repeated burning. Above this limit they largely replace forest destroyed by hunters' fires. Above the tree line the natural vegetation consists of tussock grassland with patches of shrubbery.

Savannah is a fire-disclimax vegetation consisting of scattered trees over a ground layer of grasses. It occurs on various land forms in regions with a strongly seasonal climate, mainly near the south-west coast but also inland in intermontane rain-shadow areas such as the Musa and Keveri basins.

Forest, the main vegetation type, covers about 75% of the area. Most forest trees are evergreen but as the rainfall becomes lower and more seasonally distributed the forest canopy becomes richer in deciduous trees. Large-crowned tall very mixed forest is predominant on plains and gently sloping fans with fine-textured soils, mainly in the coastal lowlands but also in the hills and mountains. The forest is tallest and best closed on well-drained terrain and becomes increasingly irregular and open on less stable and more frequently flooded sites. On back plains subject to seasonal inundation the forest is less tall and smaller crowned. Very small-crowned dense forest mixed with medium-crowned forest occurs locally on gently undulating gravelly alluvial plains and fans. This last type is most extensive on plains bordering foothills near Marshall Lagoon.

In the forest of the hills and mountains changes in composition and structure are largely related to altitude. At low altitudes the forest is normally very mixed and does not contain a predominance of any one tree species. Above about 500 m a.s.l. oaks and laurels form a large proportion of the canopy trees and above about 1400 m are joined by Cunoniaceae and Elaeocarpaceae. As the altitude increases the forest becomes smaller crowned and lower, and the trees have smaller and thicker leaves; the forest is commonly dark toned on air photos. Above about 1800 m various species of southern beech (*Nothofagus*) become prominent. The beech trees are often mixed with oaks but they also form almost pure stands which when mature have a much higher canopy than adjacent mixed forest. Above about 2000 m conifers usually become frequent trees and in many places dominate in the forest canopy; they register in very dark tones on air photos.

Above 2000 m, especially on exposed ridges and upper slopes, the forest is low, thin stemmed, and crooked, and abundant epiphytic and ground mosses give it a distinctly mossy aspect. At about 3400 m the forest occurs in patches surrounded by tussock grassland and near its altitudinal limit, at about 3900 m, it has commonly degenerated to scrub, although in places it retains true forest stature.

III. Classification of Vegetation Types

The vegetation has been divided into seven main structural groups that can be readily recognized on air photos. These groups have been subdivided into vegetation types based on structure, floristics, and environmental affinities. Each of these types has been named according to the feature which is considered to characterize the

type best. As such this classification method is not systematic, nor is it strictly vegetational, because non-vegetation attributes such as swamp, plain, and lower montane are used to define many vegetation types. However, the method provides names that are meaningful and descriptive and it facilitates the identification of many vegetation types (Küchler and Montoya Maquin 1971). Each of the major groups is defined below, with notes on the manner in which it has been subdivided into vegetation types.

(*a*) *Mixed Herbaceous Vegetation*

This group comprises those vegetation types in which non-graminoid herbs, sedges, and ferns determine the aspect. Grasses are usually present but are subordinate, and woody plants are uncommon. Four types have been distinguished within the group, three based on habitat and one on the dominance of ferns.

(*b*) *Grassland*

As the name implies, grassland is a vegetation type that is dominated by grasses. Scattered shrubs and trees are usually present and as the density of the trees increases, grassland grades into savannah. Grasslands are subdivided into seven types, firstly according to height and secondly according to habitat. Height categories used are low grassland, less than 0·5 m high; mid-height grassland, between 0·5 and 1·5 m high; and tall grassland, over 1·5 m high.

(*c*) *Palm and Pandan Vegetation*

Three vegetation types belong to this group, dominated respectively by sago palm, nypa palm, and pandans. These, except for one variety of pandan vegetation, are confined to swampy environments.

(*d*) *Scrub and Thicket*

Scrub consists of either dense shrubs excluding palms and pandans or very low dense trees or both. Thicket is similar but has an emergent layer of very scattered low trees. As the tree density increases, thicket grades into woodland. Four types have been distinguished within the group, based on habitat.

(*e*) *Savannah*

Savannah consists of a ground cover of grasses overtopped by an open tree layer. Savannah has been subdivided into seven vegetation types based on the dominant genus or species in the tree layer.

(*f*) *Woodland*

Woodland consists of an open upper storey of trees and an undergrowth of usually dense shrubs on dry land and of coarse sedges in swamp. It is intermediate between forest and scrub on dry land, and between forest and mixed herbaceous vegetation in swamp. Six types have been distinguished based on habitat, climate, or dominant tree.

(*g*) *Forest*

In forest the canopy trees have crowns that touch or overlap. Twelve types of forest have been distinguished: littoral forest, mangrove forest, and freshwater swamp forest which are distinguished according to habitat; three types of forest on plains and fans, named according to the structure of the canopy, which is strongly correlated with environmental features such as flooding, drainage conditions, and soil properties; three types of hill forest in the lowlands, which are distinguished according to crown size, a feature determined by climate, tree species, land form, soil depth, and rock type; and three types of forest in the mountains, based on altitudinal zones with boundaries at approximately 1400, 2400, and 3400 m. The mountain forest types cannot be precisely defined, because firstly they grade into one another and secondly the boundaries between types vary in altitude from one place to another due to local variations in topography and climate.

Crown size categories used in the descriptions of forest types are: small crowned, average crown size of canopy trees less than 8 m; medium crowned, between 8 and 15 m; and large crowned, over 15 m. Tree height has not been used in subdividing the forests as it is not sufficiently diagnostic and in tropical forest it cannot normally be measured from air photos. However, some height categories are given in the descriptions of forest types: these are low forest which has a canopy less than 20 m high; mid-height forest with a canopy between 20 and 30 m; and tall forest which has a canopy over 30 m high.

The trees that are most common in forest regrowth stages are mentioned in the description of the relevant forest type.

(*h*) *Seral Vegetation*

Seral vegetation types are those that pioneer on terrain that has hitherto been bare or where the original vegetation has been destroyed, usually as a result of volcanic activity. Four types of succession are distinguished, based on habitat. They comprise communities ranging from mixed herbaceous vegetation to forest. Transitions that are less distinctly seral, for instance grassland or savannah reverting to woodland or forest and the transitions from brackish to freshwater environment, are not included under seral vegetation.

IV. Vegetation Map

The vegetation map accompanying this report is at a scale of 1 : 1,000,000 and is based on air-photo interpretation. Correlations between the air-photo image and ground observations of vegetation as well as of other environmental attributes such as topography, drainage, and altitude have been used to define mapping categories and to establish their boundaries. Hence the map and its reference combine structural, floristic, and environmental attributes.

Boundaries between mapping categories differ in precision, for instance a boundary between forest and grassland is usually sharp and precise, whereas a boundary between merging forest types is poorly defined and hence is more or less arbitrary.

The number of mapping categories is smaller than the number of vegetation types described in the text. This is because some vegetation types such as gallery woodland and most types of mixed herbaceous and seral vegetation occupy areas too small or narrow to be shown on the map and because some vegetation types, such as low, mid-height, and tall grassland, and various types of savannah, cannot be reliably separated on air photos.

Mangrove vegetation has been mapped as a single category that includes mixed herbaceous vegetation on salt flats as well as mangrove scrub, woodland, and forest, and also nypa palm vegetation; this is because these major groups are too intricately mixed to be mapped separately. For the same reason patches of freshwater swamp forest and *Melaleuca* swamp savannah have been mapped together with swamp woodland as a single category. Brackish-water swamp woodland has been mapped as mangrove vegetation where nypa palm is clearly visible on the air photos, and as swamp woodland where patches of sago palm are prominent.

Scrub usually covers areas too small to be mapped separately, although areas of scrub have been mapped in the high mountains and along the south and south-west coasts.

In many places forest, woodland, or scrub are intricately mixed with grassland or savannah. Areas of such mixtures are shown on the map with a circle overprint and a dot overprint respectively.

Except for mangrove, the vegetation types are arranged in the map reference in the order in which they are described in the text.

V. Description and Ecology of Vegetation Types

The following descriptions are based on observations made in the field during 1969 and on the published reports of the previously surveyed parts of the area (Heyligers 1965; Paijmans 1967, 1969; Taylor 1964*a*, 1964*b*). Table 10 correlates the vegetation types used in this report with those of the earlier reports. The descriptions include notes on habitat, main occurrence, and relationships with other vegetation types. In lists of plant names the most common plants are given first unless stated otherwise.

(*a*) *Mixed Herbaceous Vegetation*

(i) *Mixed Herbaceous Vegetation on Salt Flats.*—A low vegetation of *Sesuvium portulacastrum* and *Tecticornia cinerea* forms a patchy cover on salt flats on the inland side of mangroves in strongly monsoonal areas. Soil salinity is very high due to continuous evaporation and salt accumulation during the dry season. The type occupies the transition zones between the centres of the salt flats, which are bare, and the surrounding slightly lower-lying margins, which have mangrove scrub. Grasses and sedges such as *Sporobolus* and *Fimbristylis* appear towards the border with the mangrove scrub.

(ii) *Mixed Herbaceous Swamp Vegetation.*—This vegetation type consists of a dense mixture of herbs, sedges, ferns, and grasses rooted in a mat of floating or water-logged organic debris. It is confined to permanent swamps, forming a more or less stable edaphic climax. *Hanguana malayana*, in places up to 2·5 m high, is

TABLE 10

CORRELATIONS BETWEEN VEGETATION TYPES OF THIS REPORT AND VEGETATION TYPES OF PREVIOUSLY SURVEYED PARTS OF EASTERN PAPUA

Eastern Papua	Buna–Kokoda	Wanigela–Cape Vogel	Safia–Pongani	Port Moresby–Kairuku	Kerema–Vailala
Mixed herbaceous vegetation					
Mixed herbaceous vegetation on salt flats				*Sesuvium–Tecticornia* mixed herbaceous vegetation	
Mixed herbaceous swamp vegetation	*Thoracostachyum sumatranum–Hanguana malayana* alliance	Herbaceous swamp (sedge)	*Leersia–Hanguana* mixed herbaceous vegetation. Fern mixed herbaceous vegetation. Fern scrub	*Leersia–Hanguana* mixed herbaceous vegetation	*Thoracostachyum–Hanguana* mixed herbaceous vegetation *Hanguana* mixed herbaceous vegetation
Mixed herbaceous aquatic vegetation			Aquatic mixed herbaceous vegetation	*Nymphaea–Azolla* mixed herbaceous vegetation	*Leersia–Nymphaea* mixed herbaceous vegetation
Mixed herbaceous fern vegetation					
Grasslands					
Low grassland in saline environment				*Sporobolus–Eriochloa* low grassland	
Low grassland on beach plains					Low grassland
Low grassland of high altitudes			Alpine grassland		
Mid-height grassland of the lowlands	*Themeda australis–Imperata cylindrica–Coelorachis rottboellioides* alliance. *Imperata cylindrica–Apluda mutica* alliance	*Imperata cylindrica–Ischaemum barbatum* suballiance. *Themeda australis–Alloteropsis semialata* alliance	Mid-height grassland. Short grassland (impoverished). *Timonius–Commersonia* scrub (regenerating grassland)	*Ophiuros–Imperata* mid-height grassland. *Ophiuros–Themeda australis* mid-height grassland. *Imperata–Themeda australis* mid-height grassland. *Hyptis–Imperata* mixed herbaceous vegetation	Mid-height grassland

Mid-height grassland of the mountains					
Tall swamp grassland		Herbaceous swamp (tall grass)	*Phragmites* tall grass vegetation	*Phragmites–Saccharum robustum* tall grassland. *Saccharum robustum* tall grassland*	*Saccharum* tall grassland.* *Phragmites* tall grassland*
Tall grassland of the lowlands	*Saccharum spontaneum–Imperata cylindrica* alliance	*Saccharum spontaneum–Imperata cylindrica–Ophiuros exaltatus* suballiance. *Saccharum spontaneum–Imperata cylindrica–Coelorachis rottboellioides* suballiance. *Saccharum spontaneum–Imperata cylindrica–Cymbopogon procerus* suballiance. Regenerating grassland	Tall grassland	*Saccharum spontaneum–Imperata* tall grassland	*Imperata–Phragmites* tall grassland
Palm and pandan vegetation					
Nypa palm vegetation		*Nypa fruticans* association	Nypa palm vegetation	Nypa palm vegetation	Nypa palm vegetation
Sago palm vegetation	*Metroxylon sagu* association	*Metroxylon sagu* association		*Metroxylon–Artocarpus* palm vegetation	Sago palm vegetation
Pandan vegetation		*Pandanus* sp. association		*Pandanus* vegetation	Pandan vegetation
Scrub and thicket					
Scrub on beach ridges				*Premna–Scaevola* scrub. *Pluchea–Flagellaria* scrub. *Clerodendron–Flagellaria* evergreen thicket	*Hibiscus–Desmodium* scrub
Mangrove scrub			Mangrove scrub	*Lumnitzera* scrub. *Avicennia–Ceriops* low evergreen forest*	*Avicennia* scrub. *Lumnitzera* scrub

TABLE 10 (*Continued*)

Eastern Papua	Buna–Kokoda	Wanigela–Cape Vogel	Safia–Pongani	Port Moresby–Kairuku	Kerema–Vailala
Scrub in brackish environment Scrub of high altitudes				*Hibiscus–Flagellaria* evergreen thicket	
Savannah					
Eucalypt savannah			Eucalypt savannah	*Themeda australis–Eucalyptus* savannah. *Ophiuros–E. alba* savannah. *Ophiuros–E. papuana* savannah. *Ophiuros–E. tereticornis* savannah. *Themeda novoguineensis–Eucalyptus* savannah. *Imperata–Eucalyptus* savannah	
Melaleuca swamp savannah					*Melaleuca leucadendron* savannah
Melaleuca savannah					Low *Melaleuca argentea* savannah. Mid-height *Melaleuca argentea* savannah
Tree fern savannah					
Nauclea–Antidesma savannah		*Saccharum spontaneum–Neonauclea* association	*Nauclea–Antidesma* savannah	*Ophiuros–Timonius* savannah	
Albizia procera savannah				*Themeda australis–Timonius* savannah	
Woodland					
Woodland on beach ridges		*Ipomoea pes-caprae–Barringtonia asiatica* succession*	Beach forest*		Littoral woodland

Avicennia woodland	*Avicennia marina* association	*Avicennia marina* association	*Avicennia* mangrove	*Avicennia–Ceriops* low evergreen forest*	*Avicennia* low forest
Brackish-water swamp woodland	*Heritiera littoralis* association	*Heritiera littoralis* association. *Avicennia marina–Bruguiera gymnorrhiza* association. *Acrostichum speciosum–Parinari corymbosum* association. *Acrostichum speciosum–Avicennia marina* association	Mixed swamp woodland	*Acacia–Myoporum* evergreen thicket. *Avicennia–Excoecaria* low evergreen forest. *Heritiera–Bruguiera* mid-height evergreen forest. *Excoecaria–Hibiscus* mid-height evergreen forest. *Melaleuca–Excoecaria* mid-height evergreen forest	Mixed mangrove swamp woodland
Freshwater swamp woodland	*Campnosperma auriculata–Metroxylon sagu* alliance. *Campnosperma auriculata–Thoracostachyum sumatranum* alliance	*Metroxylon sagu* association	Sago swamp woodland. *Pandanus* swamp woodland	*Metroxylon–Macaranga* palm vegetation	Freshwater swamp woodland
Monsoonal woodland				*Gyrocarpus–Harpullia* semi-deciduous thicket. *Garuga–Rhodomyrtus* semi-deciduous thicket. *Adenanthera–Colona* semi-deciduous thicket. *Eucalyptus–Acacia* semi-deciduous thicket	
Gallery woodland					
Forest					
Littoral forest	*Barringtonia asiatica–Pterocarpus indicus* association		Beach forest*		

TABLE 10 (*Continued*)

Eastern Papua	Buna–Kokoda	Wanigela–Cape Vogel	Safia–Pongani	Port Moresby–Kairuku	Kerema–Vailala
Mangrove forest	*Bruguiera gymnorrhiza* association. *Rhizophora mucronata* association	*Bruguiera gymnorrhiza* association. *Rhizophora mucronata* association	*Rhizophora* mangrove forest. *Bruguiera* mangrove forest	*Rhizophora–Bruguiera* mid-height forest	*Avicennia* low forest.* *Rhizophora–Bruguiera* mid-height forest
Freshwater swamp forest	*Campnosperma auriculata–Syzygium* sp. alliance. *Planchonia timorensis–Metroxylon sagu* association	*Bischofia javanica–Metroxylon sagu* association. *Bischoffia javanica–Pandanus* sp. association		*Ficus–Myristica* mid-height evergreen forest*	Medium- to large-crowned mixed swamp forest
Large- to medium-crowned forest on plains and fans	*Anisoptera kostermansiana–Pometia pinnata* association. *Pometia pinnata–Chisocheton* sp. association	*Pometia pinnata–Tetrameles nudiflora–Alstonia scholaris* association. *Planchonia timorensis–Pterocarpus indicus–Terminalia microcarpa* association. *Pometia pinnata–Tristiropsis subangula–Cryptocarya* sp. association. *Pometia pinnata–Tristiropsis subangula–Anisoptera kostermansiana* association. *Anisoptera kostermansiana–Pometia pinnata* association	Tall alluvium forest. Tall evergreen fan forest. Tall mixed deciduous fan forest	*Octomeles–Artocarpus* tall evergreen forest. *Cananga–Pometia* tall evergreen forest. *Pometia–Celtis* tall evergreen forest. *Alstonia–Kleinhovia* tall evergreen forest. *Pometia–Artocarpus* tall evergreen forest. *Althoffia–Endospermum* low evergreen forest (regrowth). *Planchonia–Adenanthera* slightly deciduous forest. *Spondias–Celtis* slightly deciduous forest. *Bombax–Terminalia* strongly deciduous forest.* *Albizia–Maniltoa* strongly deciduous forest	Large-crowned tall forest. Small- to medium-crowned basin forest*

Open forest on plains	*Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association. *Pometia pinnata–Dillenia quercifolia–Palaquium* sp. alliance	*Terminalia canaliculata–Bischofia javanica* association	Irregular tall alluvium forest	*Melaleuca–Nauclea* mid-height evergreen forest. *Nauclea–Kleinhovia* mid-height evergreen forest. *Ficus–Myristica* mid-height evergreen forest.* *Cerbera–Alstonia* tall evergreen forest	Open large-crowned forest. Mid-height semi-deciduous forest. Small- to medium-crowned basin forest*
Small-crowned forest on plains and fans			Low fan forest		
Medium-crowned lowland hill forest	*Anisoptera kostermansiana–Intsia bijuga* association. *Anisoptera kostermansiana–Eucalyptopsis papuana–Dillenia nalagi* association. *Syzygium* sp.–*Flindersia* spp. association. *Lithocarpus molucca–Castanopsis acuminatissima* association	*Anisoptera kostermansiana–Alstonia scholaris–Rhus taitensis* association. *Anisoptera kostermansiana–Intsia bijuga–Garcinia* sp. association. *Anisoptera kostermansiana–Intsia bijuga–Terminalia* spp. association. *Rhus taitensis–Canarium salomonense–Intsia bijuga* association. *Lithocarpus* sp.–*Cryptocarya* spp. alliance	Mid-height fan forest. Mid-slope forest. Mixed deciduous hill forest. Mixed *Araucaria* hill forest	*Intsia–Spondias* slightly deciduous forest. *Albizia–Canarium* slightly deciduous forest. *Casuarina–Dysoxylum* tall evergreen forest. *Pometia–Canarium* tall evergreen forest. *Castanopsis–Elaeocarpus* tall evergreen forest. *Lithocarpus–Elaeocarpus* tall evergreen forest	Small- to medium-crowned hill forest. Upland forest
Large-crowned lowland hill forest			Plateau forest. Foothill forest		Medium- to large-crowned hill forest
Small-crowned lowland hill forest		Dry evergreen forest formation. Lower montane rain forest formation*	Very small-crowned hill forest. Small-crowned hill forest. *Castanopsis* forest. Mixed *Casuarina* hill forest	*Bombax–Terminalia* strongly deciduous forest.* *Bombax–Celtis* strongly deciduous forest. *Garuga–Brachychiton* slightly deciduous forest. *Intsia–Celtis* slightly deciduous forest	Very small-crowned hill forest. Lower montane forest.* Mixed *Casuarina* forest

TABLE 10 (*Continued*)

Eastern Papua	Buna–Kokoda	Wanigela–Cape Vogel	Safia–Pongani	Port Moresby–Kairuku	Kerema–Vailala
Lower montane forest		Lower montane rain forest formation*	Lower montane forest. Stunted lower montane forest		Lower montane forest*
Coniferous lower montane forest Montane forest			Montane forest		
Seral vegetation					
(1) Coastal successions					
Mixed herbaceous beach vegetation		*Ipomoea pes-caprae–Barringtonia asiatica* succession*	*Ipomoea–Canavalia* mixed herbaceous vegetation	*Spinifex–Canavalia* mixed herbaceous vegetation	*Ipomoea–Canavalia* mixed herbaceous vegetation
Casuarina		*Casuarina equisetifolia* succession	*Casuarina equisetifolia* forest		
Mangrove	*Ceriops tagal* association	*Ceriops tagal* association	*Sonneratia* mangrove. *Avicennia* mangrove*	*Sonneratia acida* low evergreen forest. *Avicennia–Sonneratia* low evergreen forest. *Ceriops* low evergreen forest	*Sonneratia* low forest. *Avicennia* low forest*
(2) River bank successions		*Octomeles sumatrana* succession. Mixed successions of low-level distributaries*	*Saccharum* tall grass vegetation	*Saccharum robustum* tall grassland.* *Artocarpus–Ficus* low evergreen forest	*Saccharum* tall grassland.* *Phragmites* tall grassland.* *Octomeles–Artocarpus* mid-height forest
(3) Stream bed successions					
Saccharum		Mixed successions of low-level distributaries.* Stream-bed successions			

Casuarina		*Casuarina* sp. successions	*Casuarina* fan forest. Mixed *Casuarina* fan forest
(4) Volcanic blast area successions	Herbaceous seral communities. *Trema orientalis* associes. *Euroschinus papuanus* communities. "Lamington banjir" sere	Waiowa blast successions. Mt. Victory blast successions	

* Partial correlation.

characteristic of the vegetation type and is commonly associated with coarse sedges such as *Thoracostachyum sumatranum* and *Scleria*, the swamp grasses *Leersia hexandra*, *Hymenachne acutigluma*, and *Echinochloa stagnina*, and scattered herbs such as *Polygonum* and *Ludwigia*. The plants grow in mixture or form a mosaic in which one or more of the species locally dominate. Towards deeper swamp the type grades into mixed herbaceous aquatic vegetation (see below). Towards less permanent swamp, pandans, shrubs, low sago palms, and a few trees appear, such as *Melaleuca*, *Nauclea*, *Campnosperma*, *Intsia*, and *Neuburgia*, and the type grades into swamp woodland. The widely scattered trees are usually overgrown with herbaceous climbers such as *Nepenthes* and Convolvulaceae and climbing ferns such as *Stenochlaena*. The main areas are in the north-west, and south of Dyke Ackland Bay where they flank the Musa coastal plain to the east and west.

(iii) *Mixed Herbaceous Aquatic Vegetation.*—This type consists predominantly of water plants such as submerged *Ceratophyllum*, partly submerged and partly floating *Nymphaea* and *Nymphoides*, and floating *Lemna*, *Azolla imbricata*, *Pistia stratiotes*, and *Utricularia*, often growing in a mosaic of locally dominating species. It occurs in standing or slowly flowing water of deep swamps, lakes, lagoons, and ox-bows. Towards land the aquatics become mixed with swamp grasses and sedges.

(iv) *Mixed Herbaceous Fern Vegetation.*—This is a very dense vegetation up to 1·5 m high that consists of one of the ferns *Gleichenia*, *Dicranopteris*, or *Pteridium*, almost pure or mixed with grasses such as *Eulalia leptostachys* and *Imperata cylindrica*. Herbs are very scarce or absent. *Lycopodium* is usually present at ground level and scattered pandans locally emerge above the fern layer (Plate 24, Fig. 2). The type is restricted to small patches within forest of the hills and mountains and is most common in the east, where it locally covers areas of up to 10 ha. It is a fire-disclimax which is probably maintained by recurring fires and because forest species have difficulty in invading the dense fern cover.

(*b*) *Grasslands*

(i) *Low Grassland in Saline Environment.*—This grassland consists mainly of *Sporobolus virginicus*. Scarce associates are a few other grasses, the herbs *Sesuvium portulacastrum* and *Tecticornia cinerea*, and the shrub *Pluchea indica*. The type is restricted to areas with a strongly monsoonal climate, where it occurs on alkaline heavy clay at the back of mangrove, in a zone between mangrove scrub on the seaward side and mid-height grassland or savannah on the landward side (Plate 4). The habitat is probably seasonally flooded by fresh water but is only rarely reached by the tidal salt water. The grassland is up to 0·3 m high, dense and lush on the lower part bordering mangrove, open and lower on the landward side.

(ii) *Low Grassland on Beach Plains.*—This is a dense grassland consisting mainly of *Paspalum vaginatum* and a sedge *Fimbristylis* sp., associated with scarce herbs and shrubs of the mixed herbaceous beach vegetation type (see subsection (*h*)). The type occurs on low-lying sandy beach flats seasonally inundated by fresh water.

(iii) *Low Grassland of High Altitudes.*—This is a low tussock grassland rich in sedges, mosses, herbs, and ferns and occurring mainly above 3900 m altitude. The main grasses are *Deschampsia klossii*, *Anthoxanthum angustum*, *Dichelachne novoguineensis*, *Agrostis reinwardtii*, and species of *Deyeuxia*, *Poa*, *Festuca*, and

Danthonia. Cushion plants and carpet-forming low herbs such as *Eriocaulon, Potentilla, Astelia, Plantago, Ranunculus, Haloragis, Sphagnum,* and *Gleichenia* grow between the grass tussocks and locally replace the grasses altogether. Sedges such as *Machaerina rubiginosa* may form almost pure stands on very boggy sites. Shrubs are sparse and are mainly in the Ericaceae and Epacridaceae; in addition, *Hypericum macgregorii* and *Coprosma divergens* are usually present. The shrubs are commonly dwarfed and appressed to the ground or to rocks and many have small leathery leaves. These features, which give the shrubs a markedly xerophytic character, may enable them to withstand the extremes of temperature and humidity.

This type of grassland is the natural vegetation on high mountain tops above the tree line which is generally at about 3900 m. It is also present below the tree line, probably as both a primary and a derived type, on flat poorly drained summit areas (Plate 23, Fig. 2), on slopes with shallow waterlogged soils, and in high-lying intermontane basins such as the Myola "lakes" near Mt. Kenevi at 2000 m a.s.l. (Plate 1, Fig. 1) and the Neon basin at 2800 m a.s.l. Although the ground is permanently waterlogged and the vegetation is wet most of the time, the grass dries out during dry spells and is then set alight by native hunters and travellers.

(iv) *Mid-height Grassland of the Lowlands.*—This grassland occurs between sea level and about 2000 m altitude and is most common on hilly terrain. *Themeda australis, Imperata cylindrica, Eulalia leptostachys,* and *Ophiuros tongcalingii* are the grasses that most often reach dominance. *Themeda australis* (kangaroo grass) is the major dominant. *Imperata cylindrica* (kunai) ranks second and is dominant only in areas with a long history of cultivation. *Eulalia leptostachys* has a more regional distribution and is dominant or codominant in many places along the north coast in the east (Plate 22, Fig. 1), and in the hills around the Musa basin and the headwaters of the Adau River. *Ophiuros tongcalingii* is a widespread and normally common tall component of mid-height grassland but is the dominant grass over large parts of the fluvial plains in the Port Moresby–Kairuku area (Heyligers 1965).

Other grasses that are usually present but are only locally dominant or codominant are *Sorghum nitidum, Arundinella setosa, Heteropogon contortus,* and *Saccharum spontaneum.* The most widespread of a host of other grasses of minor importance are *Capillipedium parviflorum, Apluda mutica, Themeda novoguineensis, Cymbopogon procerus, Pseudopogonatherum irritans, Panicum* spp., and, in coastal areas, *Ischaemum muticum.*

Herbs are commonly present but are nearly always sparse. Some of the most widespread species are *Euphorbia serrulata, Tridax procumbens, Buchnera tomentosa, Pouzolzia hirta, Polygala* spp., *Spathoglottis* sp., and the legumes *Indigofera trifoliata, Crotalaria* spp., *Desmodium* spp., *Cassia mimosoides, Tephrosia* spp., *Atylosia* spp., and *Pueraria* spp. Frequent creepers, twiners, and climbers are *Cissus, Passiflora foetida,* the fern *Lygodium,* and the legumes *Glycine tomentella, Phaseolus sublobatus,* and *Vigna vexillata.* The proportion of legumes is very variable though generally they are scarce and often absent. Very low herbs such as *Pygmaeopremna sessilifolia* and *Curculigo orchiodes* flower and fruit during the brief period of reduced grass cover that occurs after burning.

Associated shrubs and trees are limited to those that are fire-tolerant. Some of the most frequent shrubs are *Albizia procera, Grewia* cf. *retusifolia, Melastoma malabathricum, Clerodendrum* cf. *floribundum, Glochidion* sp., *Pandanus* sp., and

Grevillea papuana. Trees include *Timonius*, *Cycas media*, *Pandanus*, *Antidesma ghaesembilla*, *Nauclea orientalis*, and *Deplanchea tetraphylla*. *Nauclea*, *Antidesma*, and *Pandanus* not uncommonly mark drainage lines; *Deplanchea* is characteristic in monsoonal areas. Some of the species mentioned under shrubs, such as *Albizia procera* and *Grevillea papuana*, may grow into low trees.

Grasses that are more common near forest borders than in open grassland are *Apluda mutica*, *Polytoca macrophylla*, *Coelorachis rottboellioides*, *Themeda novoguineensis*, and *Saccharum spontaneum*. These are moisture-loving grasses that are also more common along drainage lines and near seepages on slopes. Most of them grow to a height of over 1·5 m and form tall grassland where they dominate.

Themeda australis and *Heteropogon contortus* (black spear grass) favour dry sites and tolerate shallow stony soils. The seeds of both species are so shaped that they become readily buried in the topsoil where conditions for germination are more favourable than on the surface (Tothill 1969).

Almost all mid-height grassland of the lowlands is the result of intensive native gardening and frequent burning, and is maintained as a fire-disclimax by regular burning. It is most widespread in hilly areas that have a marked dry season such as Cape Vogel peninsula, the hills surrounding the Musa basin, and areas near Hood Bay. Locally, however, the type is extensive in populated mountainous areas with a relatively high rainfall, for instance around Woitape and to the south along the upper Vanapa River and its tributaries.

After *Themeda australis* grassland has been burnt it may become dominated by *Capillipedium parviflorum* or *Eulalia trispicata* or, as on the hills along the north-east coast, it may be replaced on the crests by *Heteropogon contortus*. This is because fires often run along crests; such fires do not kill established plants of *Heteropogon*, they favour the germination of its seed and reduce the ground cover of other species (Isbell 1969).

When burning is discontinued the scattered shrubs and trees within the grassland increase in density, and genera such as *Alphitonia*, *Rhus*, *Commersonia*, and *Garuga* may appear. Provided fire does not recur, the trees gradually suppress the grass layer, which is replaced by ferns and gingers, and the grassland reverts to forest via savannah or scrub and thicket. Such regenerating grassland is found for instance on the south-western foot slopes of Mt. Victory (Taylor 1964*b*). This process takes considerably longer than the conversion from woody garden regrowth to forest.

(v) *Mid-height Grassland of the Mountains.*—This grassland occurs mainly between 2000 and 3900 m a.s.l. The major dominants are *Danthonia archboldii* on relatively well-drained terrain and *Deschampsia klossii* on sites that are poorly drained. However, many other grasses are locally codominant, for instance *Agrostis reinwardtii*, other species of *Danthonia*, *Dichelachne novoguineensis*, *Imperata*, *?conferta*, *Poa* spp., *Deyeuxia* spp., *Anthoxanthum angustum*, and *Arundinella furva*. Many other mid-height and low grasses are widespread but inconspicuous. Sedges are common; a species of *Gahnia* forms large tussocks, and *Machaerina rubiginosa* locally forms small almost pure stands on wet sites.

Only a few observations have been made near the lower altitude limit of the vegetation type. *Eulalia leptostachys* is the dominant grass in places and *Imperata* is common on some disturbed sites.

Herbs are more common than in the grasslands of the lowlands. They include *Potentilla*, *Anaphalis*, *Gentiana*, *Hebe*, *Tetramolopium*, and *Trachymene*. On wetter sites, *Eriocaulon*, *Trigonotis*, *Geranium*, and *Astelia papuana* are particularly common. One or more of various species of *Gleichenia* fern are always present. A characteristic feature is the absence of legumes.

Low shrubs such as *Styphelia suaveolens* and other Epacridaceae, *Hypericum macgregorii*, *Eurya brassii*, Ericaceae, and *Cyathea* tree ferns are common on relatively well-drained sites. Locally, *Styphelia* and *Hypericum* form patches of dense heath-like vegetation which replaces the grasses.

Structurally mid-height grassland of the mountains differs from lowland mid-height grassland in that it is more tussocky and generally little over 0·5 m high. On shallow permanently waterlogged soils the tussocks are wider apart, low herbs, ferns, and mosses fill the spaces between the tussocks, and the type grades into low grassland of high altitudes. Floristically mid-height grassland of the mountains appears to be more related to the natural low grassland above the tree line, probably because of down spread of a number of "alpine" grasses, an upward thrust of lowland grasses being prevented by a more or less continuous forest belt.

Most of the mid-height grassland of the mountains, like the lowland grasslands, is secondary after destruction of the original forest by fire, and below the upper limit of agriculture also by shifting cultivation. At higher altitudes the proportion of natural grassland becomes higher as edaphic and climatic conditions become more adverse to tree growth.

Mid-height grassland of the mountains is most extensive in the central ranges to the north-west of Mt. Albert Edward. It often occurs in mosaic with gardens or lower montane and coniferous lower montane forest.

(vi) *Tall Swamp Grassland.*—The main grasses in tall swamp grassland are *Saccharum robustum* which grows to a height of 5 m and *Phragmites karka* which may reach 4 m. Both species occur in pure stands or in mixture with *Coix lachryma-jobi* as a frequent tall grass associate. Other grasses, and herbs, shrubs, and trees, are normally very sparse. Pure *Phragmites* occupies an often wide zone of fluctuating freshwater swamp bordering mixed herbaceous vegetation in permanent swamp and also occurs in areas subject to brackish flooding such as swales between beach ridges. Both *Saccharum* and *Phragmites* border old river courses in permanent freshwater swamp, where they form a more or less stable edaphic climax. On low river banks, including scrolls, they usually form the first stage of a seral succession (see subsection (*h*)).

(vii) *Tall Grassland of the Lowlands.*—This vegetation type most commonly consists of a mixture of codominant *Saccharum spontaneum* and *Imperata cylindrica*, in which *Saccharum* grows to a height of 3·5 m and *Imperata* to over 1·5 m. Associated tall and mid-height grasses are *Ophiuros tongcalingii*, *Sorghum nitidum*, *Apluda mutica*, *Coelorachis rottboellioides*, and *Phragmites karka*. After burning, *Imperata* is the first to sprout and may temporarily dominate the new sward. Sedges are moderately common.

The most widespread herbs are those that are frequent in mid-height grassland of the lowlands but they are much scarcer in the tall grassland vegetation type.

Frequent shrubs are *Albizia procera, Leea rubra, Ficus* spp., *Melastoma malabathricum,* and *Glochidion;* trees include *Nauclea orientalis, Antidesma ghaesembilla, Pandanus, Timonius timon,* and *Melaleuca.*

The distribution of tall grassland is determined mainly by the availability of soil moisture. The main habitat is plains that are inundated for a short period during the wet season but the type also occurs on fans and undulating terrain and extends into the hills on foot slopes, along drainage lines and depressions, and occasionally on crests. Large continuous areas of the type occur in the Musa basin and on the Angabunga River plain. Both *Imperata cylindrica* and *Saccharum spontaneum* are moisture-loving, and Whyte (1968) notes that the distribution of *Saccharum spontaneum* is not so much restricted by climate as by the need for a constant soil-water level. The presence of mid-height or low grassland on plains usually indicates adverse edaphic conditions, more rarely prolonged periods of gardening and intensive burning.

The correlation with soil moisture is shown by the commonly occurring sequence where grass-covered hills pass down into swamps. In this sequence low to mid-height *Themeda* grassland on crests and slopes grades into tall grassland on foot slopes which is first dominated by *Imperata* and then slightly lower down by *Saccharum.* Lower still, *Saccharum* grassland containing an admixture of *Phragmites* grades into pure *Phragmites* swamp grassland.

(c) *Palm and Pandan Vegetation*

(i) *Nypa Palm Vegetation.*—*Nypa fruticans* covers extensive low-lying areas in river estuaries subject to daily brackish flooding, and also lines tidal creeks where fresh and salt water mix. At the lowest sites nypa palm forms pure stands in which the canopy of palm fronds is up to 9 m high. Where this canopy is closed there is no undergrowth except for a few nypa palm seedlings, tufts of *Acrostichum* fern, and a liliaceous plant *?Crinum.* On slightly higher ground scattered trees emerge above the nypa; these include various mangrove species, *Heritiera littoralis, Dolichandrone spathacea, Xylocarpus moluccana,* and stilt-rooted *Myristica ?hollrungii.* The main areas are near the mouths of the Vanapa, Laloki, Biaru, Kapuri, Lakekamu, and Tauri Rivers.

Crabs favouring the *Nypa* environment build their mounds to well above high-water mark. Some of the mounds become interconnected to form small islands that are separated from one another by tidal channels. *Acrostichum* fern and *Acanthus* invade the islands, followed later by freshwater vegetation. In places the islands are cleared by the local population and used for gardening, while nypa palm and various mangrove species persist in the channels.

(ii) *Sago Palm Vegetation.*—This type where well developed consists of dense stands of *Metroxylon sagu,* the fronds of which form a closed canopy 10–12 m high, with flowering stems reaching 20 m; there are no lower shrub or herb layers. Where the canopy is more open there is an understorey consisting of tall coarse sedges, pandans, *Hanguana,* and *Phragmites* in near-permanent swamp and of ferns, grasses, and gingers on higher ground where the water-table is below the surface for much of the year. Climbers, particularly climbing ferns, are also a feature of open stands. Trees comprising many species that occur in swamp forest and dry-land alluvium

forest are usually present and widely scattered. Gradations occur from pure sago palm virtually without trees to swamp woodland and open swamp forest with an understorey of sago palm.

The habitat is seasonal to permanent swamp, and the main areas are in the large coastal swamps in the north-west (Plate 2) and along the Gira, Mambare, and Opi Rivers in the north-east. Sago palm is best developed in shallow swamp where there is a regular influx of fresh water. Deep, more or less stagnant swamp and brackish sites form a less favourable habitat. Where they border deep herbaceous swamp the palms tend to grow in low rounded clumps. On slightly brackish sites sago usually occurs scattered together with nypa but may also form dense low stands less than 3 m tall. In the hills and mountains sago occurs on flat valley floors, in basins and seepage areas, and along streams, and either in groups or as single individuals which may be natural or may have been planted.

(iii) *Pandan Vegetation.*—In the lowlands the type consists of *Pandanus* forming dense, usually small stands up to about 8 m high. Scattered trees, with their trunks often covered by climbers, sometimes emerge above the pandan canopy. A ground layer may be absent or may consist of coarse sedges, *Hanguana*, tall gingers, ferns, and grasses.

The type occurs in fresh to slightly brackish environments in localities that are nearly permanently swampy or subject to frequent flooding, such as depressions on back plains, scrolls and low river banks, prior river courses, and blocked valley swamps.

In the mountains above about 1800 m the type consists of groups of tall pandan trees as high as the forest canopy and scattered within the forest. Such groups are protected and probably extended by the local population which eats the fruits and uses the leaves for thatching and mat-making (Schweinfurth 1970).

(*d*) *Scrub and Thicket*

(i) *Scrub on Beach Ridges.*—This type consists of usually dense tall shrubs up to 6 m high. The most common shrubs are *Hibiscus tiliaceus*, *Thespesia populnea*, *Desmodium umbellatum*, *Scaevola frutescens*, *Clerodendrum inerme*, and *Premna corymbosa*. The scrub becomes a thicket where low trees such as *Acacia auriculiformis*, *Gyrocarpus americanus*, and *Pittosporum ferrugineum* form an open layer above the shrubs. Climbers, particularly *Flagellaria indica*, are often common. Scattered herbs, sedges, and grasses occur where the scrub is less dense.

The type is found on beach ridges in regions with a strongly monsoonal climate and normally occupies a zone between pioneering mixed herbaceous vegetation to seaward and mangrove to landward. On both sides of Galley Reach it occurs together with grassland and grades into woodland with *Melaleuca* (Plate 1).

(ii) *Mangrove Scrub.*—The mangrove species that most commonly form scrub are *Avicennia marina*, *Ceriops tagal*, and *Lumnitzera racemosa* (Plate 1). They occur either as a pure scrub of even height or as mixed thickets in which *Avicennia* forms an upper layer of 6–8 m high. Pure *Avicennia* scrub without ground vegetation is found at about high-water mark where tidal flooding is relatively frequent. Mixtures of *Avicennia* with *Ceriops* or *Lumnitzera* on slightly higher and less frequently flooded ground commonly have a herb layer of *Sesuvium portulacastrum* and some sedges.

Almost pure *Lumnitzera*, with or without some *Hibiscus tiliaceus*, occurs as a fringing scrub 2–3 m high between pure *Avicennia* mangrove and mixed herbaceous *Sesuvium–Tecticornia* vegetation on slightly higher ground.

Saline peaty or clayey inner tidal flats and low inner beach ridges at or just above high-water mark are the habitat of *Avicennia–Ceriops–Lumnitzera* scrub, mainly in regions with a strongly monsoonal climate. *Avicennia marina* is the mangrove species that is most tolerant of high salinity (Macnae 1966). In non-monsoonal areas *Rhizophora* scrub may occupy the poorly drained centres of tidal flats furthest away from the tidal creeks.

(iii) *Scrub in Brackish Environment.*—This scrub consists mainly of *Hibiscus tiliaceus* and *Pluchea indica.* Low trees such as *Excoecaria agallocha* and *Acacia auriculiformis* may emerge above it. Climbers, especially *Flagellaria indica*, are common.

The type occurs under monsoonal climatic conditions on innermost tidal flats and on back plains that have alkaline soils. Such terrain is seasonally swampy because of inundation by rain water or flooding by river water in the wet season and may be occasionally flooded by brackish water during the dry season. South-east of Galley Reach it occurs between mangrove and freshwater swamp grassland or swamp woodland with *Melaleuca.*

(iv) *Scrub of High Altitudes.*—This is a tall dense scrub consisting of close-branched shrubs and low trees with usually small coriaceous leaves. Common constituents are *Coprosma divergens, Pittosporum pullifolium*, Ericaceae, Epacridaceae, *Xanthomyrtus*, and *Papuacedrus papuanus.* The type occurs in mosaic with grassland above the forest line and is also present below this limit from about 3000 m on very steep slopes having shallow stony soils. It is extensive only on the upper slopes of Mt. Suckling and the Goropu Mountains.

(*e*) *Savannah*

(i) *Eucalypt Savannah.*—In eucalypt savannah the tree layer consists of one or more of the species *Eucalyptus alba, E. confertiflora, E. papuana*, and *E. tereticornis. Melaleuca* is a rare associate in the canopy. The trees usually have crooked stems of small to moderate girth and very rarely reach a girth of 1·5 m. Tree height usually varies between 9 and 20 m, and is most commonly between 10 and 15 m. However, *E. tereticornis* often has a straight bole and may reach a height of over 30 m. The ground layer consists of mid-height grasses similar to those of open grassland, and the composition and frequency of associated herbs, shrubs, and low trees are also similar. *Themeda australis* is the major dominant grass and next in importance is *Imperata cylindrica*, especially in previously gardened areas. Most of the other grasses, including those that are locally codominant and those that are rarer, are the same as those of mid-height grassland of the lowlands. *Sehima nervosum* is a codominant in savannah around Port Moresby (Heyligers 1965).

Herbs are scarce to moderately common generally and are mainly leguminous. *Dianella* appears to be more frequent in savannah than in open grassland, in contrast to *Spathoglottis.*

Shrubs and low trees are scarce. *Desmodium umbellatum* is moderately common in savannah and was not seen in open grassland. *Grevillea papuana*, *Banksia dentata*, *Cycas media*, and *Casuarina papuana* are locally common in eucalypt savannah of hilly areas.

Climbers and epiphytes are rare, except in hilly areas where *Usnea*, *Dischidia*, and epiphytic ferns are locally common.

Eucalypt savannah occurs from sea level to about 1000 m, but only in areas that have a marked dry season. The type is found mainly in the coastal hills and the foothills of the central range along the south-west coast (Plate 4) but also inland in some intermontane rain-shadow areas. In areas of very low rainfall and a severe dry season eucalypt savannah also occurs on undulating terrain and plains, whereas under less severe conditions it is mainly confined to hill crests and upper slopes, the lower slopes and valley bottoms remaining under forest. Eucalypts appear to be absent from the dry region of the Cape Vogel peninsula and the coastal hills to the south-east of it, and to the north-west do not appear to extend beyond the Palipala Hills.

There appears to be little correlation between eucalypt species and habitat, and in many places two or three species grow on one site (Heyligers 1966). *E. papuana* is widespread and is the most common eucalypt in eastern Papua. *E. alba* is more frequent on sites with gravelly soils, it usually has a poor stem form. *E. tereticornis* is common where conditions of climate and soil are more favourable, for instance on the Sogeri plateau, on the eastern and south-eastern lower slopes of the Hydrographers Range, and inland in the Musa basin (Plate 10) and the Keveri valleys. It reaches a higher altitude than the other species and is reported to occur up to 1500 m a.s.l. (Lane-Poole 1925, p. 35).

Most eucalypt savannah is man-made and grows on formerly forest-covered terrain. Small patches of natural savannah may have always existed on sites unfavourable to forest growth or may have developed after lightning damage in dry forest. The savannah has reached its present-day extent through fires lit for hunting rather than through shifting cultivation. Although the present-day savannah–forest boundary appears to be fairly stable, grass fires in savannah often penetrate into and damage or destroy marginal forest.

Mature eucalypt trees are fire-tolerant but young trees, often occurring in groups, may be badly damaged or killed by grass fires. Normally a few individuals of a group survive to maintain the community, but the savannah is replaced by grassland where fires are very frequent and fierce. Regression of savannah to grassland may also be caused by tree-felling and ring barking. In rare cases eucalypt savannah reverts to forest through a thicket stage of emergent eucalypts and a lower tree and shrub layer of savannah and forest species. A mixed forest with scattered tall emergent eucalypts seen at some localities is probably a late stage in the succession to the climax without eucalypts.

(ii) Melaleuca *Swamp Savannah*.—In this vegetation type *Melaleuca* trees form an upper layer of variable density but generally even height over a ground layer of mainly *Phragmites* and tall sedges. The tree density may approach that of forest. The trees may reach a height of 30 m and a girth of 1·2 m. Various species of

Melaleuca are present, the commonest probably being *M. cajuputi* and *M. leucadendra*, but individual stands usually consist predominantly of one species.

Sparse associated trees are *Nauclea*, *Cordia*, *Pandanus*, and *Livistona* palm. Sago palm occurs in the understorey in many places. *Stenochlaena* fern and other climbers are usually common, and epiphytic *Myrmecodia* and *Dischidia* are often present. Where the type is transitional to mixed herbaceous swamp vegetation the trees are low and widely scattered, and *Hanguana* and *Scleria* are prominent in the ground layer.

Melaleuca swamp savannah occurs in areas that have a markedly seasonal climate. It grows in fluctuating swamps, usually near the coast, that dry out for a short period during the dry season. The type is found along the south and south-west coasts, especially in swamps in the north-west, where it is commonly mixed with swamp woodland or grades into herbaceous swamp vegetation.

Melaleuca, like the eucalypts, is fire-tolerant. The type is secondary after the destruction of littoral forest or swamp woodland, and is maintained by burning.

(iii) Melaleuca *Savannah.*—In this vegetation type usually thin-stemmed low and crooked *Melaleuca* trees form an open layer over dense mid-height grassland. *Melaleuca cajuputi* and *M. dealbata* are two of several species of *Melaleuca* present. Associated trees, shrubs, and herbs are those that occur in open grassland; trees of *Eucalyptus alba*, *E. papuana*, and *E. tereticornis* are also occasionally present. *Themeda novoguineensis* is the dominant grass in many places, often with *Imperata cylindrica* as codominant. *Sorghum nitidum*, *Ophiuros tongcalingii*, *Ischaemum fragile*, and many other grasses are normally present.

Melaleuca savannah is confined to areas with a marked dry season and is a disclimax vegetation which has replaced forest. It occurs on plains, fans, and occasionally on hills, predominantly on sites that are temporarily waterlogged, in many cases due to perched water-tables. Small areas are found along the south coast eastwards from Marshall Lagoon, and in the north-west near Malalaua.

(iv) *Tree Fern Savannah.*—Tree ferns of the genus *Cyathea* in combination with mid-height grassland of the mountains form a type of savannah that covers large areas above 2700 m altitude on the southern and south-western slopes of Mt. Albert Edward (Plate 7). The genus *Cyathea* is characteristically a forest dweller but some species are able to withstand occasional dryness, frost, and fire in open grassland (Paijmans and Löffler 1972). The tree ferns are usually densest near the boundary with lower montane forest and are also very common in scrub that forms the transition between grassland and forest. On Mt. Albert Edward they appear to be remnants from a former forest cover.

(v) Nauclea–Antidesma *Savannah.*—In this type of savannah the tree cover is formed by *Nauclea orientalis* and *Antidesma ghaesembilla*, a low gnarled tree that normally occurs widely scattered in eucalypt savannah. The type is commonly associated with tall *Saccharum–Imperata* grassland and is characteristic on temporarily waterlogged flat areas or depressions. Accompanying trees are *Timonius timon*, *Pandanus*, and *Neonauclea*.

(vi) Albizia procera *Savannah.*—*Albizia procera*, a common shrub in eucalypt savannah, may grow into a low tree and locally dominates the tree layer where

eucalypts are absent, as along the north-east coast. Trees of *Timonius timon* and *Rhus taitensis* are usually also present. The ground cover consists of mid-height grasses.

(vii) Casuarina papuana *Savannah.*—In this savannah *Casuarina papuana* forms the tree storey over low to mid-height grasses. The type occurs inland in a relatively dry region between Mt. Suckling and Mt. Clarence.

(*f*) *Woodland*

(i) *Woodland on Beach Ridges.*—This pantropical vegetation type has a characteristic floristic composition, invariably containing several of the tree species *Calophyllum inophyllum, Barringtonia asiatica, Hernandia peltata, Terminalia catappa, Erythrina variegata, Hibiscus tiliaceus, Thespesia populnea, Cordia subcordata, Cerbera manghas,* and *Pandanus tectorius. Premna, Desmodium,* and *Clerodendrum* are common shrub genera, palms and climbers are very common, and *Crinum asiaticum* features in the herb layer.

This type of woodland occurs on beach ridges in a zone between mixed herbaceous vegetation or scrub to seaward and forest or monsoonal woodland to landward. It is usually strongly disturbed or secondary.

(ii) Avicennia *Woodland.*—Various mangrove species, either pure or in mixture, form variably dense woodland 8–15 m high. The commonest variety is formed of thick, low, gnarled, and wide-crowned trees of *Avicennia marina.* Such stands have no shrub and herb layers on the lowest sites, whereas on higher ground an undergrowth of low trees of *Ceriops, Aegiceras, Bruguiera, Excoecaria,* and rare *Rhizophora,* and a ground cover of *Sesuvium portulacastrum* and some *Sporobolus* are commonly present.

The vegetation type occurs at the back of mangrove forest in areas that are fairly frequently to only occasionally subject to tidal flooding. Local strips of dead and dying trees probably indicate a change in habitat caused by a change in soil salinity or flooding regime.

(iii) *Brackish Water Swamp Woodland.*—This type of woodland is a mixture of plants of saline, brackish, and fresh water environment. The composition of the mixture depends on the degree of salinity. Just inland from pure mangrove the tree layer still consists predominantly of various mangrove species, but common associates are *Xylocarpus moluccensis* and *Heritiera littoralis;* the ground layer is made up mainly of *Acrostichum speciosum* and some *Acanthus ilicifolius.* Further inland, with decreasing salinity, many other tree species appear such as *Myristica ?hollrungii, Diospyros ferrea, Sapium indicum, Inocarpus papuanus,* and *Intsia bijuga.* A dense layer of tall shrubs and low trees includes *Brownlowia argentata, Hibiscus tiliaceus, Barringtonia, Dolichandrone spathacea,* tree ferns, and pandans, while in the ground layer tall sedges are conspicuous. Palms are common, and in addition to nypa and sago palm include *Areca, Arenga,* and *Caryota.* Climbers are very common, particularly in open stands, and comprise *Stenochlaena, Flagellaria,* and many others. Epiphytes, mainly ferns but also myrmecophytes, are usually present. Various forms of breathing roots, such as short straight pointed aerial roots and knee roots, and also surface roots and stilt roots are often abundant. Further inland still, sago

palm becomes more frequent and *Rhizophora* and *Bruguiera* are present only as tall emergent trees which no longer regenerate.

The habitat is a brackish permanently swampy transition zone between mangrove and freshwater swamp woodland. It is subject to tidal inundation by brackish river water that is backed up by the incoming tide. The main occurrence is near the mouths of the Tauri and Lakekamu Rivers where the type may be up to half a kilometre wide. In other instances the transition is rather abrupt, forming a narrow zone of swamp grassland or open woodland between mangrove and freshwater swamp forest or woodland.

A poorer variety of brackish-water swamp woodland consists of an upper layer of *Excoecaria agallocha*, with or without a lower storey of *Hibiscus* and *Clerodendrum*, and a ground cover of *Acrostichum* with lesser *Acanthus*. With decreasing brackish influence *Excoecaria* becomes mixed with *Melaleuca, Acacia,* and *Myoporum* and the ground cover locally consists of grasses and sedges. Bunches of adventitious roots at the base of *Melaleuca* and *Excoecaria* trunks are a characteristic feature. This variety of mixed mangrove swamp woodland grows on seasonally inundated brackish coastal back plains under strongly monsoonal climatic conditions.

(iv) *Freshwater Swamp Woodland.*—Freshwater swamp woodland has an open upper storey formed by trees such as *Campnosperma, Nauclea, Mitragyna,* and many others. In the understorey sago palm and pandans are common; *Hanguana* and tall sedges (*Thoracostachyum, Mapania,* and *Scirpodendron*) form the ground layer. Climbers are usually abundant. The type grades into open swamp forest towards higher ground and into swamp grassland or mixed herbaceous swamp vegetation towards deeper swamp. The habitat is permanent or near-permanent shallow swamp (Plate 3; Plate 17, Fig. 2).

In areas with a marked dry season and hence a strongly fluctuating water-table the habitat may be dry for part of the year. On such sites *Carallia brachiata* and a species of *Syzygium* are common trees. The ground cover is usually low and patchy and adventitious roots are characteristic.

Freshwater swamp woodland is extensive around the lower courses of the Lakekamu, Tauri, Gira, Mambare, and Opi Rivers and flanks the Musa coastal plain to the west, north, and east.

(v) *Monsoonal Woodland.*—Monsoonal woodland is rich in tree species, many of which are deciduous. Frequent tree genera are *Gyrocarpus, Harpullia, Garuga, Bombax, Brachychiton, Erythrina, Terminalia, Alstonia,* and *Intsia* but there are also many other almost equally frequent trees. Scattered eucalypts occur in places and *Acacia* and *Myoporum* are common on low inland beach ridges. The height of the trees ranges from 6 to 20 m. The shrub layer is variable in density; some of the shrubs are thorny. Thin woody climbers, some of them with spines, are very common. Grasses, ferns, and sedges form the ground cover.

The type is extensive in monsoonal areas near the south-west coast where it occurs on a variety of land forms such as inner beach ridges, valley floors, alluvial plains, and hill slopes (Plate 4). It grades into small-crowned lowland hill forest with higher rainfall and into scrub with lower rainfall and less favourable soil conditions.

(vi) *Gallery Woodland.*—Gallery woodland is confined to the vicinity of streams. It is generally similar to monsoonal woodland, having a very mixed floristic

composition and a large proportion of deciduous higher trees. Frequent trees are *Intsia, Pterocarpus, Alstonia brassii, Terminalia, Garuga, Protium, Antidesma, Semecarpus, Horsfieldia, Rhus, Barringtonia, Maniltoa,* and *Litsea.* In the shrub layer *Maniltoa, Syzygium,* and *Codiaeum* are often present. Thin woody climbers are common and bamboo occurs occasionally. Small tree palms and pandans are very common closest to the stream channels. Most gallery woodland has been disturbed by fire or selective felling.

Gallery woodland is found in both coastal and inland localities that have a marked dry season. It occurs mainly in narrow bands along small streams within areas of savannah or grassland (Plate 4) and forms the impoverished remnants of a former more extensive forest or woodland cover. Under similar climatic conditions the proportion of deciduous trees is higher in gallery woodland than in forest.

(*g*) *Forest*

(i) *Littoral Forest.*—This is a medium-crowned mid-height forest that is characterized by an abundance of palms in the shrub and lower tree layers. Common trees in the canopy are *Pterocarpus, Terminalia, Planchonia, Nauclea, Syzygium, Pongamia,* and *Melaleuca.* The stem form is often poor. Climbers are usually plentiful but rattan is uncommon. In places all trunks are covered with *Stenochlaena.* Gingers and ferns feature in the herb layer.

Beach plains and beach ridges are the habitat (Plate 17, Fig. 2). Such sites often have a water-table at or near the surface and are seasonally inundated. Forest dominated by *Melaleuca* is a small-crowned and rather dense variety of littoral forest occurring on the south coast between Cloudy Bay and Amazon Bay.

(ii) *Mangrove Forest.*—The main trees that form mangrove forest are *Rhizophora* and *Bruguiera.* They are discussed at genus level as the growing conditions of the different species are insufficiently known.

The seaward fringe of mangrove forest is often formed of *Rhizophora* in low, almost pure, well-closed, one-layered stands. Widely scattered old emergent *Avicennia* trees may also be present. A sparse undergrowth consists almost solely of *Rhizophora* seedlings and saplings and occasional tufts of *Acrostichum.* Climbers and epiphytes are virtually absent. Circular openings of about 0·5 ha in the forest are a common feature in *Rhizophora* stands. These openings are clearly visible on air photos (Paijmans 1966). On the ground one finds that the trees in them are either dead or dying, possibly because of lightning strikes (Komarek 1968, quoting J. A. R. Anderson). Each opening commonly has a dense group of mangrove seedlings and saplings of mainly *Rhizophora* in its centre.

Rhizophora forest occurs on tidal flats that are flooded daily for long periods. It is best developed fringing tidal creeks, and tree height decreases rapidly away from the creeks. It occurs on clay, peat, sand, and coral detritus, but the forest is lower on sandy soils and stunted or scrubby on coral.

Bruguiera may also form almost pure stands but more commonly occurs in mixture with *Rhizophora* on slightly higher sites than pure *Rhizophora* forest. *Acrostichum* ferns and mangrove seedlings form a variably dense ground cover.

In mature mangrove forest the trees are well over 30 m tall and have girths over 1·5 m and the canopy is relatively open. The *Rhizophora* trees have very high

and wide, arched and multi-branched stilt roots and the *Bruguiera* trees have pneumatophores and buttresses. Associated trees are *Camptostemon schultzii*, *Xylocarpus moluccensis*, and *Heritiera littoralis*. The shrub and herb layers consist of saplings and seedlings of mangroves, *Acanthus*, *Acrostichum*, nypa palm, and *?Crinum*. Climbers and epiphytes are common in places and comprise *Hoya*, *Dischidia*, myrmecophytes, orchids, and ferns.

Such mature forest is found inland from aggrading coasts in areas of high rainfall and low seasonality, on sites subject to slightly brackish tidal flooding. Crab mounds, which are common especially along tidal creeks, are densely overgrown with *Acanthus* and *Acrostichum* where sufficient light reaches the ground. The local population uses the mounds for gardens after killing the surrounding mangrove trees by ring-barking to admit more light.

(iii) *Freshwater Swamp Forest.*—This forest type usually has a fairly even and open canopy but dense stands also occur, especially where one tree species predominates. The canopy is 20–30 m high and rare emergents reach 40 m. Frequent canopy trees are *Campnosperma brevipetiolata*, *C. auriculata*, *Bischofia javanica*, *Nauclea orientalis*, *Mitragyna speciosa*, *Terminalia canaliculata*, *Alstonia scholaris*, *Calophyllum* sp., *Syzygium* spp., *Planchonia papuana*, *Palaquium* sp., *Dillenia* sp., *Pterocarpus indicus*, *Intsia bijuga*, and *Melaleuca* spp. They may occur in mixture but often one or two species predominate.

The lower tree strata are very open as most trees have their crowns in the canopy. Sago palm and/or pandans often form a second stratum. Sparse but characteristic lower trees are *Alstonia spatulata* and, in regions with a marked seasonal climate, *Carallia brachiata* and *Acacia* spp. The shrub and herb layers are usually sparse but dense patches of *Hanguana* and tall sedges occur locally.

Thin lianes, fleshy climbers, and climbing ferns often thickly cover the tree trunks. Epiphytes may be plentiful in open stands. Buttresses are not conspicuous but stilt roots, pneumatophores, and surface roots are common, and adventitious roots are often prominent in swamps with a strongly fluctuating water-table. There is often a considerable accumulation of organic debris, especially where *Campnosperma* and sago palm are abundant.

Shallow permanent swamp is the habitat. Swamp forest grades into swamp woodland towards deeper swamp and into open forest on plains towards less swampy terrain. Some of the trees that are frequent in swamp forest also occur in forest on hills, such as *Bischofia javanica*, *Alstonia scholaris*, *Pterocarpus indicus*, and *Intsia bijuga*.

A rare occurrence of the type in the mountains is the swamp forest that fringes an intermontane basin near Kusipi at 2600 m a.s.l. Here the most common trees are *Syzygium* spp., *Dacrycarpus steupii*, *Podocarpus neriifolius*, and *Nothofagus perryi*.

(iv) *Large- to Medium-crowned Forest on Plains and Fans.*—This forest type has an irregular structure throughout all layers. The canopy is rather open and has many gaps (Plate 2); it is also irregular in height but is mainly 30–35 m. Emergents reach a height of 50 m or more, rarely 60 m (*Octomeles*), and some trees attain a girth well over 2·5 m. Boles are straight, except in trees of notoriously poor stem form such as *Pterocarpus* and *Vitex* and to a lesser extent *Pometia*. Many trees have buttresses and those of canopy and emergent trees are often very high and wide.

The floristic composition is very mixed. Some tree species that are invariably present in the upper storey are *Pometia pinnata, Octomeles sumatrana, Ficus* spp., *Alstonia scholaris*, and *Terminalia* spp. Other genera commonly represented are *Pterocarpus, Artocarpus, Planchonella, Planchonia, Canarium, Elaeocarpus, Cryptocarya, Celtis, Dracontomelum, Dysoxylum, Syzygium, Vitex*, and *Intsia.*

The lower tree strata, like the canopy, are irregular in structure and are commonly rather open. The shrub layer is very variable in cover and density, varying with the amount of light penetrating through the canopy, and the types of shrubs present. Small tree palms, true shrub palms, and young rattan palms are common in the shrub layer and tall gingers and Marantaceae locally form a dense cover. Pandans are rarely common.

The herb layer is very patchy; it has an average cover of 5–10% but may be absent, for instance where shrub palms are abundant, or quite dense, as in places where it is formed by *Selaginella, Elatostema*, Marantaceae, or Commelinaceae. Otherwise the herb layer consists mainly of ferns, tree seedlings, and rattan seedlings.

Thin and thick woody lianes, fleshy climbers, and climbing ferns are usually common. Climbing rattan is invariably present, but is dense only in openings. Epiphytes are common only in the crowns of canopy trees.

The type occurs on well to imperfectly drained alluvial plains and on gently sloping fans that have deep soils. The habitat is either not or only rarely flooded but pools of standing water commonly form during heavy rains and may remain for several days. The type is extensive in lowland areas and also occurs on alluvial plains and fans in the hills and mountains. The largest areas are found north of Mt. Lamington, on the Musa coastal plain, on the fans and plains between the Goropu Mountains and the north coast, and along the south coast. The forest is richer in species and more mixed than swamp forest, although some trees show patterned distribution. This is either because they are early colonizers or because of later disturbance to the forest. *Octomeles, Anthocephalus*, and *Artocarpus* are colonizing trees. They produce abundant seeds which in the case of *Octomeles* and *Anthocephalus* are very light and widely dispersed by wind. *Cananga, Endospermum, Canarium, Euodia, Laportea, Sterculia*, and *Pimelodendron* are locally predominant in old secondary forest and *Kleinhovia, Macaranga*, and *Althoffia* may dominate early regrowth stages. A forest dominated by *Pometia* has a flatter and denser canopy than is usual for forest on alluvial plains and hence can often be recognized on air photos, for instance on the plain between the Brown and Vanapa Rivers and between Cloudy Bay and Amazon Bay along the middle and lower courses of the Liba, Bonua, and Bailebu Rivers.

On well-drained sites the forest is tall and emergents and most canopy trees have large crowns. On back plains the average crown size of the canopy trees is smaller (Plate 2), the average tree height is slightly lower, and emergents are more widely spaced because of seasonal inundation and the prevalence of heavier-textured less permeable soils. Otherwise the forest structure is similar to that on more favourable sites. The floristic composition does not change a great deal either, but some trees such as *Octomeles* and *Pometia* are less common and others such as *Bischofia javanica, Planchonia papuana, Nauclea orientalis, Anthocephalus cadamba, Maniltoa* sp., *Alstonia scholaris, Intsia bijuga*, and *Vitex cofassus* are more common. Charac-

teristic and locally prominent lower trees are *Carallia*, *Barringtonia*, stilt-rooted *Myristica*, and *Pisonia*.

In areas which have a marked dry season the forest is similar in structure but contains a higher than usual proportion of deciduous and semi-deciduous trees in the canopy. Such trees include *Bombax ceiba*, *Anisoptera kostermansiana*, *Garuga floribunda*, *Terminalia* spp., *Manilloa schefferi*, *Alstonia brassii*, *Gmelina moluccana*, *Albizia* sp., and *Intsia bijuga*. Other trees that are more common in monsoonal than in non-monsoonal regions are *Celtis*, *Dracaena*, *Semecarpus*, *Serianthes*, *Protium*, and *Flindersia*. The main areas of such forest occur on fan slopes in the Musa basin and on flats on Cape Vogel peninsula.

(v) *Open Forest on Plains.*—In this type of forest the canopy is very irregular in height and closure and there are many large gaps in the canopy. In places the forest is broken up into groups of trees alternating with patches of thicket which are overgrown by rattan, *Flagellaria*, and other climbers. Tall sedges and pandans are locally prominent in the undergrowth. The herb layer is normally very sparse.

The forest type occurs on alluvial plains that are frequently flooded by river water and on back plains that are subject to prolonged wet-season inundation (Plate 2). It grades into and is often found between coastal swamp woodland or swamp forest, and large- to medium-crowned forest on plains and fans. Forest on very young alluvium is often characterized by emergent large-crowned *Octomeles* and by *Kleinhovia* in the lower storeys. In such forest the shrub and herb layers are commonly very open, indicating frequent short-lived flooding.

In areas with a severe dry season causing temporary water stress deciduous tree species occur together with trees indicating poor drainage, such as *Planchonia* and *Bischofia*.

(vi) *Small-crowned Forest on Plains and Fans.*—This is a small- to very small-crowned, dense, mid-height to tall, generally thin-stemmed type of forest. On air photos very small-crowned forest is generally seen to alternate with patches or lines of small- to medium-crowned forest (Plate 14, Fig. 1). Locally predominating trees are *Hopea*, *Anisoptera*, *Intsia*, *Casuarina*, and, in the east, *Vatica* and *Eucalyptopsis*.

The type occurs on gently undulating lowland plains with commonly gravelly soils, for instance those bordering foothills in the south between Marshall Lagoon and Cloudy Bay, and on gravelly and/or poorly drained basin slopes as in the hills south of Milne Bay and west of the Musa coastal plain. Where the forest type occurs on lowland plains it often includes patches of swamp woodland and swamp grassland.

(vii) *Medium-crowned Lowland Hill Forest.*—Medium-crowned lowland hill forest is variable in structure and composition since it grows on many different land forms and rock types and in a variety of climatic conditions. It is the main forest type in the area and occurs from sea level to about 1400 m altitude. In general the forest canopy is evergreen and fairly regular in height (25–30 m), closure (70–80%), and crown size. Emergents reach 40 m, rarely 50 m. Emergents and canopy trees have straight boles. Girths over 2·5 m are rare. The lower tree storeys are moderately dense and a great number of trees are in the pole stage. Many trees have small buttresses but stilt roots are uncommon.

The shrub layer is composed of a great number of individuals but mainly consists of slender saplings, hence the total cover is relatively low (20–30%), visibility within the forest relatively good, and passage through the forest relatively easy.

The herb layer is very patchy. It has a variable cover, generally 5–20% but locally either much denser or almost nil. It consists mainly of ferns and seedlings but is locally dominated by *Selaginella* and, particularly at higher altitude, *Elatostema*. Sedges and grasses occur consistently but are very sparse.

Climbers are moderately common and mainly consist of thin woody lianes. Thick woody lianes, fleshy climbers, and climbing rattan palm are invariably present but are not conspicuous, although rattan is common in patches. In some areas, especially on ridge crests, scrambling bamboo is locally common. Tree palms are locally present, especially at low altitudes; these are usually scattered and have their crowns in the lower tree layers and in the canopy but rarely above the canopy. Shrub palms are moderately common, often consisting mainly of young rattan. Pandans occur in the lower tree and shrub layers but are rarely common. Tree ferns are scarce. Gingers and Marantaceae are usually present but inconspicuous. Vascular epiphytes are plentiful in tree crowns, particularly in old trees that have thick branches. Epiphytic mosses become common on tree trunks with increasing altitude and are also generally common down in narrow valley bottoms.

Medium-crowned lowland hill forest differs in structure from the forest on plains as follows. Canopy and emergent trees are slightly lower; the canopy is more regular in height, closure, and crown sizes; trees with very large girths are less common and timber volume is lower; large buttresses are less common; the total number of trees with a girth of 30 cm and over is greater and there are more trees in the pole and sapling stages; the shrub layer, consisting mainly of slender saplings, has a lower cover; tall gingers occur but do not normally grow densely; the ground layer is somewhat denser; thick woody lianes, rattan, and palms are less common; fleshy climbers and climbing ferns on tree trunks are less common.

Medium-crowned lowland hill forest is very mixed floristically. Frequent tree genera of canopy and emergent layers are *Pometia*, *Canarium*, *Hopea*, *Anisoptera*, *Cryptocarya*, *Terminalia*, *Syzygium*, *Ficus*, *Celtis*, *Dysoxylum*, and *Buchanania*, but many more have a frequency similar to *Buchanania*. Above 500 m *Castanopsis*, *Sloanea*, and *Elaeocarpus* become prominent. Characteristic genera of the lower tree storeys are *Syzygium*, *Garcinia*, *Myristica*, *Gnetum*, *Diospyros*, and *Dracaena*.

Scattered *Araucaria* trees occur in many localities in lowland hill forest and in some places the tree forms fairly dense stands, as locally in the mountains around the Musa basin. Full-grown *Araucaria* reaches a height of over 70 m, towering 20–30 m above the associated mixed broad-leaved forest, and may have a girth well over 3 m. The total basal area is up to twice that of broad-leaved forest without *Araucaria* and the timber volume is up to tenfold (Paijmans 1970). *A. hunsteinii* (klinki pine) is more common than *A. cunninghamii* (hoop pine) in lowland hill forest, but hoop pine has a wider altitudinal range (Havel 1971), reaching well into the lower montane forest. Both species regenerate well and grow on a variety of land forms and soils, although they commonly grow gregariously on ridge crests and tend to be associated with poor forest growing on shallow soils.

In areas with an annual rainfall below about 1800 mm and a marked dry season the forest canopy has many deciduous and semi-deciduous trees such as *Terminalia* spp., *Intsia bijuga*, *Anisoptera kostermansiana*, *Erythrina* sp., *Sterculia* spp., *Pterygota horsfieldii*, *Alstonia spectabilis*, *Rhus taitensis*, *Ficus* sp., *Maniltoa schefferi*, and *Pterocarpus indicus*. The lower tree storeys are evergreen. In the lower tree storey *Dracaena*, and in the shrub layer *Maniltoa*, *Croton*, *Lunasia amara*, *Acalypha*, and *Cycas*, are more common than in evergreen hill forest. The forest is similar in structure to its evergreen counterpart except that it has a somewhat more open canopy and commonly contains scrambling bamboo. The forest often forms a "fern-leaf" pattern with savannah or grassland, the forest occupying the lower slopes and valley bottoms and the savannah or grassland covering crests and upper slopes, as in the Musa basin and on Cape Vogel peninsula (Plate 10; Plate 13, Fig. 1).

On steep and unstable slopes with skeletal soils the canopy of lowland hill forest is open, irregular, and smaller crowned (Plate 6) and many trunks are leaning or are bent at the base. Soil erosion causes roots to become exposed, and some trees develop adventitious roots.

In regions with a long history of shifting agriculture much of the forest is old secondary forest. The overall crown size of such mixtures is below average and on air photos they may resemble primary small-crowned forest. Trees that are characteristically more common in old secondary forest are *Albizia falcataria*, *Euodia*, *Endospermum*, *Sterculia*, *Tristiropsis*, and *Terminalia kaernbachii*. Various Euphorbiaceae such as *Macaranga*, *Mallotus*, *Glochidion*, and *Bridelia* are prominent in early stages of forest regrowth, as are *Ficus*, *Timonius*, *Alphitonia*, *Leucosyke*, *Euroschinus*, and *Trema*. *Albizia falcataria* occurs in undisturbed forest scattered along streams and in small groups on landslide scars, but otherwise is indicative of human interference. Emergent *Albizia* trees have wide flat crowns that show up as light-toned on the air photos. *Terminalia kaernbachii* also occurs in undisturbed forest; its proportion in secondary forest is higher because the indigenes propagate the tree for its edible nuts. Abundant bamboo is also indicative of secondary forest.

(viii) *Large-crowned Lowland Hill Forest.*—On plateaux and gentle slopes, provided drainage and moisture conditions are favourable, lowland hill forest has an above-average crown size, height, girth, and timber volume and its structure approaches that of large-crowned forest on plains and fans (Plate 9). Such large-crowned lowland hill forest occurs for instance on the lower slopes of Mt. Lamington and Mt. Victory. Similarly, lowland hill forest on foot slopes in V-shaped valleys resembles large-crowned forest on plains and fans because on such sites the canopy is more irregular in height and density than in average lowland hill forest, the number of trees with large girth and large buttresses is greater, and rattan and other climbers are more prominent. *Pometia* is a common tree on such sites.

(ix) *Small-crowned Lowland Hill Forest.*—Trees such as *Casuarina*, *Castanopsis*, and *Hopea* have small crowns, and hence lowland hill forest in which any of these trees predominates is small-crowned (Plate 14, Fig. 2).

Casuarina papuana in many places forms an emergent layer over broad-leaved forest and, although this layer is usually open, on air photos the forest appears small-crowned and dark-toned. The species tolerates dry conditions and is most

common on shallow stony soils, especially on ultramafic rock and limestone, extending from sea level into lower montane forest. It is probably a pioneer in places where the original forest has been damaged or destroyed, and apparently only regenerates in open forest. *C. papuana* forest is common in the mountains west of Mt. Suckling near the headwaters of the Adau River and on the range north of Milne Bay.

Castanopsis acuminatissima commonly forms dense almost pure stands on ridge crests and upper slopes above about 500 m a.s.l. Forest dominated by *Castanopsis* has a dense even canopy showing smooth and dark grey on air photos. *Castanopsis* is common over large areas of forest on closely dissected plateau surfaces east of Sogeri plateau around the headwaters of Kemp Welch River.

Forest dominated by *Hopea* is tall, slender, and dense and the basal area is above average. The timber volume, however, is not necessarily high as *Hopea* trees rarely reach a girth over 2 m. *Hopea* is predominant in many places in the foothills on the south side of the central range and in the eastern end of Papua (Plate 15, Fig. 1), occurring from about sea level to 450 m. Its regeneration is commonly plentiful and a dense layer of seedlings and saplings often covers the ground. At the time of survey many *Hopea* trees were in flower, having light yellowish crowns that are easily distinguishable from the air. However, when *Hopea* is not in flower its crown is not distinctive.

In areas with a marked dry season some of the canopy trees are deciduous. A belt of such small-crowned slightly deciduous forest is present inland from the south and south-west coasts, occurring between coastal savannah and grassland to seaward and medium-crowned evergreen forest inland: this belt is probably due to a combination of seasonal drought stress, human influence, and shallow soils.

In regions with an annual rainfall less than about 1200 mm and a severe dry season the forest canopy is dominated by deciduous trees which, in addition to those already mentioned under medium-crowned lowland hill forest, include *Bombax ceiba*, *Gyrocarpus papuanus*, *Brachychiton carruthersii*, *Adenanthera pavonina*, *Garuga floribunda*, and *Protium macgregorii*. The canopy is low (18–25 m) and open and in places the forest grades into woodland or thicket. The lower tree storeys consist of deciduous, semi-deciduous, and evergreen trees. Many shrubs in the undergrowth are spiny and scrambling. Thin woody lianes and *Flagellaria* are very common, but epiphytes are scarce. Small-crowned deciduous lowland hill forest occurs in the coastal hill and foothill zones near Port Moresby mainly on limestone (Heyligers 1965). The boundary between deciduous and evergreen forest is gradual and because of variations in topography and moisture conditions it is also commonly irregular. For instance, on dry ridge crests slightly deciduous forest may extend into the zone of evergreen forest, while on relatively moist valley floors and plains it may extend into areas of strongly deciduous forest (Heyligers 1965).

The predominance of very small-crowned thin-stemmed forest in the Sibium and Didana Ranges and in the Otava and Ajule Kajale Ranges is related to steep slopes and shallow stony soils developed on ultramafic rocks. In the Sibium and Didana Ranges, *Neonauclea* sp. and *Intsia bijuga* are more common than normal in the lowland hill forest and climbing and scrambling bamboo (*Nastus ?obtusus*) is prominent in many places. Forest on ultramafic rocks north-west of the Sibium Range

is medium-crowned and less poor, possibly because of an admixture of Lamington ash to the soils. Small-crowned lowland hill forest in the Otava Range is sharply bounded to the west by medium-crowned lowland hill forest on mainly basaltic rocks.

(x) *Lower Montane Forest.*—In this forest type the evergreen canopy is generally between 20 and 30 m high and is smaller-crowned and more even in height than in average lowland hill forest. The closure of the canopy is also greater and more regular. Leaves are mainly simple, often leathery and shiny, and have entire or serrated margins. The average leaf size is smaller than in lowland hill forest. The trees are of small to medium girth and many trunks are low-branched and crooked or leaning. Tree density is often very high. Old trees have thick, crooked, and often dead branches, many stumps of dead trees remain standing, and fallen logs and branches cover the ground. Near the higher altitudinal limit of the forest type trees are festooned with abundant epiphytic mosses and epiphytic ferns and orchids are usually also quite common. Stilt roots and adventitious roots are usually present and in places are common, but buttresses are inconspicuous.

Frequent canopy trees are *Nothofagus*, Lauraceae, Cunoniaceae, *Elaeocarpus*, *Sloanea*, *Lithocarpus*, *Castanopsis*, *Syzygium*, *Planchonella*, *Ilex*, *Dryadodaphne*, *Calophyllum*, and the conifers *Podocarpus*, *Papuacedrus*, *Phyllocladus*, and *Araucaria*. *Decaspermum* and *Xanthomyrtus* are particularly common in lower montane forest bordering grassland. *Garcinia*, *Polyosma*, *Symplocos*, *Sericolea*, *Drimys*, *Prunus*, and Araliaceae are found in the lower tree storeys. Notably absent are the families Meliaceae, Burseraceae, Annonaceae, and Papilionaceae.

The shrub layer varies in density with its composition, and with height and density of the tree layers. In many places it consists of a great number of slender shrubs, in other places tall ferns or giant gingers are more common than woody vegetation. Various species of *Psychotria*, *Amaracarpus*, *Rapanea*, *Eurya*, *Cyrtandra*, and *Saurauia* are nearly always present.

The herb layer is also variable in density and is very patchy. In places mosses almost completely cover the ground and also the fallen logs and branches, in other places ferns or *Elatostema* form a dense layer. *Dawsonia* is a conspicuous moss and locally, near forest edges and in open places, *Sphagnum* cushions occur. Sedges are usually present.

Woody lianes are rare but a thin climbing bamboo, *Nastus ?productus*, forms a dense tangle in many places, particularly where the forest canopy is open. Other climbers include Gesneriaceae, *Piper*, *Freycinetia*, *Lycopodium*, ferns, and, near forest edges, scrambling *Rubus*. Climbing rattan and palms in general are rare or absent. Tree ferns are often common and stilt-rooted pandans, sometimes very tall and reaching into the canopy, may occur singly or in groups. Mosses become more abundant with increasing altitude.

A thick springy layer of leaves, mosses, and fallen branches covers the ground. Access through the forest is hampered by fallen logs and thick branches, and in many places also by a dense shrub layer or scrambling bamboo. The visibility is often greatly reduced by tall ferns, gingers, bamboo, and abundant epiphytic mosses. The forest is moist and quiet and appears to harbour few insects and animals.

As in the lowlands, the forest structure is influenced by climate, topography, and species composition. According to Brass (1956), the physiognomy of lower

montane forest and its lower altitudinal limit are correlated with the duration and lower limit of daily cloud cover. He notes (pp. 148–9) that in the vicinity of Mt. Dayman the demarcation line between his mixed rain forest below and mid-mountain forest of oaks and *Castanopsis* above generally "corresponds with the lower edge of the cloud bank which, with a high degree of regularity in both time and local altitude, settles on the mountain slopes early in the afternoon". This could explain the occurrence of a lower montane forest seen at 335 m a.s.l. on a plateau south of Milne Bay, an area known for its cloudiness.

Generally, the higher the altitude of the forest, the longer it is enveloped in cloud, and the greater the abundance of epiphytic and ground mosses. At the highest altitudes such forest has given rise to the apt names "cloud forest" and "mossy forest". On exposed high crests and upper slopes the lower montane forest is dwarfed, thin-stemmed, and often very dense and the trunks are crooked and gnarled. Such forest has become known as "elfin woodland". In contrast, on sites such as gentle slopes and plateau areas lower montane forest grows to a height of 40 m and many trees have a girth over 1·5 m.

Nothofagus spp. and *Araucaria cunninghamii* (hoop pine) are common trees which tend to grow gregariously. Where *Nothofagus* predominates the lower montane forest is often medium-crowned and irregular in height and may be much taller than forest without *Nothofagus* (Plate 7; Plate 17, Fig. 1). In some localities *Nothofagus* appears to regenerate and die in large groups (Plate 7; Plate 16, Fig. 2), in others regeneration of all age classes is present under scattered mature trees. *Nothofagus* is particularly common between the Goropu Mountains and Mt. Dayman and in the north between Mt. Yule and Mt. Nelson.

Araucaria cunninghamii is another tree that often emerges above the forest canopy, reaching a height of over 40 m. Extensive, rather dense stands occur up to about 2500 m altitude on the slopes of the Goropu Mountains, Mt. Suckling, and Mt. Dayman. However, many of the tall emergent *Araucaria* trees on Mt. Suckling appear to be overmature and dying and stands on Mt. Dayman are being damaged by grass fires spreading into the forest.

Lower montane forest has been distinguished from lowland hill forest by its darker tone and generally small-crowned even canopy on air photos. It occurs above about 1400 m altitude in the central range and forms a continuous cover except for a gap to the west and east of Mt. Clarence. Very small-crowned lower montane forest occurs on ultramafic rock in the Otava Range and south of Mt. Suckling. In the area south of Mt. Suckling the forest canopy is dominated by *Casuarina papuana*.

In young regrowth stages, tree ferns, *Alphitonia incana*, *Dodonaea viscosa*, *Weinmannia*, and *Olearia*, are in many places conspicuous, whereas *Castanopsis*, *Lithocarpus*, *Euodia*, and *Elaeocarpus* are often prominent in older regrowth stages.

(xi) *Coniferous Lower Montane Forest.*—With increasing altitude, coniferous trees, mainly *Dacrycarpus*, *Podocarpus*, *Phyllocladus*, *Papuacedrus*, and *Araucaria*, become more abundant in lower montane forest and may reach dominance to form coniferous lower montane forest. This type of forest is similar in structure to mainly broad-leaved lower montane forest, except that many coniferous trees reach a girth

well over 1·5 m even at altitudes over 3000 m and their stem form is generally better than that of the associated broad-leaved species.

Coniferous lower montane forest occurs above about 2400 m altitude throughout the central range, except between Mt. Obree and Mt. Suckling. On air photos it can generally be distinguished by its very dark tones (Plate 7; Plate 18, Fig. 1).

Near its upper limit the forest often borders grassland, with a zone of shrubs and low trees commonly forming the transition between grassland and forest. The forest–grassland boundary is relatively stable, although the grassland gradually encroaches upon the forest as grass fires destroy the forest edges.

(xii) *Montane Forest.*—Montane forest occurs in mosaic with grassland above about 3400 m altitude on the tops of Mt. Albert Edward (Plate 7) and Mt. Victoria and between these two mountains on several high tops of the Wharton Range. At about 3900 m altitude it grades into scrub. Montane forest was examined by the author only on Mt. Albert Edward. Here it differs from the lower montane forest below by having a higher and denser canopy and a more open shrub layer. Also epiphytic mosses and orchids are less common, probably because here the forest is above the zone of longest cloud cover and has more frequent periods of low humidity. The canopy is dominated by *Dacrycarpus compactus* which has an umbrella-shaped crown and even at an altitude of 3800 m reaches a height of 15–20 m (Paijmans and Löffler 1972). The edges of montane forest are often damaged by fire.

(*h*) *Seral Vegetation*

Seral vegetation comprises the vegetation types that pioneer on terrain that has not been vegetated before or where the original vegetation has been destroyed by volcanic eruptions. The various seres have been divided into coastal, river bank, stream bed, and volcanic blast area successions.

(i) *Coastal Successions*

(1) *Mixed herbaceous beach vegetation.*—Sand-binding herbs with long trailing stems, and low grasses and sedges cover the first beach ridge behind the beach from just above high-water mark. On the seaward slope the creepers *Ipomoea pes-caprae* and *Canavalia maritima* are dominant, whereas on the crest grasses such as *Ischaemum muticum* and *Imperata cylindrica* and sedges, e.g. *Fimbristylis* and *Remirea maritima*, are more prominent. Landward, *Vigna marina*, *Passiflora*, and other creepers of the families Convolvulaceae and Cucurbitaceae, seedlings of *Hibiscus tiliaceus*, and low shrubs of *Desmodium*, *Crotalaria*, and *Premna* appear. The parasite *Cassytha filiformis* in places densely overgrows a variety of host plants.

(2) Casuarina.—*C. equisetifolia* forms dense low to mid-height stands on offshore sand bars and on aggrading sandy coasts on sites above high-water mark. It also occurs on sandy strips along river mouths. Tall stands are rare as development is usually prevented by native gardening.

(3) *Mangrove.*—*Avicennia marina*, *Sonneratia caseolaris*, and *Ceriops tagal* form dense, low, often pure, scrubby stands in tidal lagoons and near river mouths where the coast is protected by offshore bars. Young *Avicennia* and *Sonneratia* occur well below high-water mark and the outermost seedlings are submerged for most of the time. At a later stage such scrub becomes mixed with other mangrove species

and eventually develops into mangrove forest via a stage with scattered old emergent *Avicennia.*

A *Sonneratia* which has fruits shaped like those of *S. caseolaris* but has lanceolate instead of broad roundish leaves forms small low pure stands on low river banks, scrolls, and islets in and near the mouths of major rivers. The habitat is daily or periodically flooded by brackish water. This *Sonneratia* is commonly associated with *Acrostichum, Acanthus,* and nypa palm. Inland there may be a ground cover of sedges and grasses, and climbers such as *Stenochlaena* and *Flagellaria* are present.

(ii) *River Bank Successions.*—*Pandanus* and *Phragmites* are the first plants to appear on low silty river banks including scrolls that are frequently flooded by slightly brackish to fresh water. They form small pure stands often occurring together with stands of *Sonneratia.* Upstream, tall *Saccharum robustum* commonly comes next in succession. *Artocarpus altilis* is one of the first trees to appear on the tops of low banks and as flood frequency decreases upstream is joined by *Octomeles sumatrana.* Together the two species are the dominants in a pioneering mid-height to tall forest on sites flooded by fresh water. Early associates are *Ficus, Laportea, Timonius, Kleinhovia,* and *Terminalia.* Climbers are very common, often smothering the *Octomeles* trees, and ferns and gingers are prominent in the ground layer. As the succession becomes more mature the quick-growing *Octomeles* tops *Artocarpus* and the other tree species. In a late stage the forest consists of an open upper storey of huge *Octomeles* trees some 60 m high over a mixture of tree species that are characteristic of forest on plains. *Kleinhovia* is usually very common. The lower tree storeys are open and tree density is low. Normally the shrub layer is also open and the forest is easy to walk through. There is no regeneration of *Octomeles.* Such forest with abundant old emergent *Octomeles* is found along the middle courses of the Tauri, Akaifu, Dilava, Vanapa, Brown, and Rakua Rivers and on fans on the south and south-east sides of Mt. Victory. Normal development of *Octomeles–Artocarpus* forest is commonly interrupted and disturbed by gardening. The usual crop is banana which tolerates frequent short-lived flooding.

Changes of river course alter the succession, e.g. decreasing swampiness along the lower course of the Angabunga River which was abandoned during 1956–57 has resulted in *Saccharum robustum* being succeeded by *S. spontaneum* (Heyligers 1965).

(iii) *Stream Bed Successions*

(1) Saccharum.—*S. spontaneum* forms scattered tussocks (Plate 27) or small pure stands, some over 4 m high, on sand and gravel river banks and bars subject to frequent short-lived flooding. Associated grasses are *Pennisetum macrostachyum* and species of *Paspalum* and *Digitaria.* As flooding becomes less frequent the stands of *Saccharum* are invaded by shrubs, such as *Ficus* spp., *Cassia alata,* and *Crotalaria mucronata* and a variety of tree species, such as *Ficus* spp., *Leucosyke* sp., *Pipturus argenteus, Albizia falcataria, Octomeles sumatrana, Trema orientalis,* and *Omalanthus* sp. Relatively large areas occur on the northern and south-eastern slopes of Mt. Victory and the western and north-western slopes of Mt. Lamington.

(2) Casuarina.—*C. cunninghamiana* is the pioneer further upstream where the gradient is higher and the deposits are mainly very coarse and bouldery, as in the upper course of the Bonua River (Plate 6; Plate 20, Fig. 1). It forms dense pure

stands above the level of frequent flooding. The trees are tall, slender, of medium girth, and up to 40 m high. A herb and shrub layer of ferns (*Selaginella*, *Elatostema*) and pandans develops as litter and sand become trapped between the trees. When the stream changes course away from such stands the flood waters move more slowly and more sand and silt are trapped. Broad-leaved species appear as the habitat becomes more stable, and *Casuarina* no longer regenerates. The forest eventually reaches its mixed broad-leaved climax, large- to medium-crowned forest on plains and fans, via a stage of mixed forest with emergent *Casuarina*. *C. cunninghamiana* also colonizes outwash fans which are either bouldery or gravelly, as at the eastern end of the Musa basin, or are sandy but very poorly drained to swampy, as between the Goropu Mountains and Mt. Victory.

(iv) *Volcanic Blast Area Successions.*—Mosses, *Lycopodium cernuum*, and *Gleichenia* fern are the first to colonize eruption deposits and sites where the original vegetation has been destroyed by volcanic activity. Scattered tufts and stands of *Saccharum spontaneum*, often with *Imperata cylindrica*, generally appear next (Taylor 1957). Shrubs and trees of the type found in stream bed successions invade the grasses, and a monospecific or mixed woodland which often includes species of Musaceae develops.

Trees that colonize blocky lava flows and crater walls are *Casuarina cunninghamiana*, *Rhus taitensis*, *Timonius timon*, and *Neonauclea* sp. (Plate 9; Plate 22, Fig. 1). There is usually a dense ground layer of many species of ferns and also, in open stands, orchids. Despite an initial absence of soil the colonizing trees are fast-growing. Other tree species to invade include *Octomeles sumatrana*, *Albizia falcataria*, and *Trema orientalis*. Eventually the pioneers are replaced by mixed forest. Such successions occur on the cones and craters of Mt. Lamington and Mt. Victory and on Waiowa volcano.

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PART VII. FOREST RESOURCES OF EASTERN PAPUA

By J. C. SAUNDERS*

I. INTRODUCTION

The aim of this Part is to indicate the general location and extent of the forest in eastern Papua and assign estimated stocking rates to each forest type. The land has also been classified into categories giving indexes of accessibility. A summary of the forest resources appears in Table 11.

TABLE 11

SUMMARY OF THE FOREST RESOURCES

Estimated stocking rate class	Area (km^2)	Estimated stocking rate (m^3/ha)	Estimated stocking rate (super ft/ac)
Very high	140	>70	>12,000
High	3700	53–70	9000–12,000
Moderate	22,500	30–52	5000– 9000
Low	16,500	17–29	3000– 5000

Only commercial forests are described. These contain at least 17 m^3/ha of standing timber from trees having a minimum girth of 1·5 m at breast height (or above the buttresses). The same nomenclature is used for these forests as was used in Part VI, to facilitate cross-reference with general descriptions. They may often be smaller in areal extent.

Commercial forest (hereinafter referred to as forest) covers about 70% of the area, occuring from sea level to approximately 3400 m in a wide range of environments. Much of the forest is confined to rugged mountainous country along the central ranges, whereas on the coastal hills and undulating terrain a large proportion of the land has been cleared of forest. Relatively low and markedly seasonal rainfall in large parts of these latter areas result in lower forest resources. The main areas of accessible forest occur along the northern coastal plains and hinterlands from Moi Biri Bay westwards. Despite the relatively large area of forested country, the forest potential of eastern Papua is considered to be moderate to low, because much of the forest is inaccessible.

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

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The potential for minor forest products is moderate. Possible products include extractives from mangrove stands and also from the dipterocarp forests and rattan from forest on poorly drained alluvium.

Present exploitation and milling operations are virtually confined to the Central District. Most of the mills are linked to Port Moresby by road and are designed to supply local markets. The largest mill, located at Cape Rodney, produces sawn timber for shipment to local markets in Port Moresby and also for export overseas. Other operations are located in the Northern and Milne Bay Districts.*

Five areas, listed in Part I, have previously been surveyed by CSIRO Division of Land Research resources survey teams, and almost all of the accessible land along the south coast between Marshall Lagoon and Milne Bay has been surveyed by the Department of Forests, PNG, in much greater detail than was possible during the present survey (Director of Forests, personal communication). The same department has also carried out forest surveys in the Vanapa River, Collingwood Bay, and Ioma areas and in smaller scattered areas near Port Moresby, Popondetta, and Mt. Suckling.

No separate forest resources map is supplied and all references in the text pertain to the vegetation or land-form type maps.

Only existing forest resources have been studied and no attempt has been made to assess the potential for reafforestation, although much of the information embodied in the whole report may be useful in such a study.

II. Assessment Methods

The large area involved (about five times the average area of previous surveys) and the small scale of the final map necessitated some modifications to assessment techniques used in previous surveys such as that of the Aitape-Ambunti area. Preliminary photo interpretation was carried out in association with the plant ecologist, and recognizable photo patterns were delineated. These patterns were distinguished on the basis of structural features of the forest, recognizable species, and topographic position.

All field measurements and estimations were in British units to conform with and allow comparison with previous data; however, metric units have been used in the text where possible. Circular sample plots of 0·1349 ha were used at team observation sites.

Data recorded for all trees of 1·5 m girth or more included girth over bark at breast height (or above buttresses), merchantable length, botanical name, and local name in Amele (Madang) language. Each tree was also classed, on form and external symptoms of defects, as suitable or likely to be unsuitable for milling. In cases where a tree was found on the edge of a plot, the position of the geometric centre of the bole at breast height was the reference point for total acceptance into or rejection from the plot. Girth measurements were made by girth tape in 1-ft classes and merchantable length in 5-ft classes by estimation and by checking every tenth tree with a Blume Leiss altimeter. Where the botanical name of a tree was in doubt a wood sample was taken and later compared with wood samples supported by herbarium specimens.

* "An Atlas of Papua and New Guinea." (Dep. Geogr. Univ. of Papua New Guinea, and Collins Longman.)

Notes were also made on forest and site quality, including evidence of human interference and fallen trees, while other site factors such as slope, soil, etc. were observed by other team members. The site information was augmented by visual observations made while flying over forests at low altitude and by the observations of the plant ecologist.

To conform with data collected by the Department of Forests, PNG, timber volumes calculated for each plot were based on the following formula and no allowance for internal defect was made. The bark allowance was 3 in. off girth.

$$V = 80{\cdot}31549 + 2{\cdot}18592G^2 - 1{\cdot}15235H + 0{\cdot}64224G^2H,$$

where

V = log volume under bark in super ft true measure,
G = girth over bark above buttresses in ft (calculated on girth class mid-point),
H = log length in ft (calculated on the mid-point of 5-ft classes).

From the qualitative and quantitative information collected on each plot, together with data from prior CSIRO and Department of Forests surveys, an appraisal of each plot's value as a representative sample of the forest type was made using air photos and estimated stocking rates were assigned to each type. The assigned stocking rates are a very approximate indication of timber volume and must be used with extreme caution as the sampling percentage was less than 0·001 %. They should be regarded as an indication of which forest types warrant more detailed investigation to assess accurate volume figures. All other parameters except area were estimated in a similar fashion, but with a greater emphasis on recorded data and less on visual appraisal.

III. Classification and Mapping of Forests

In the classification used the forests are divided into six major groups based on environment; these groups are forest on plains and fans, lowland hill forest, lower montane forest, seral forest, littoral forest, and mangrove. The first three groups are subdivided into forest types using structural differences mainly associated with canopy characteristics. The first group includes large- to medium-crowned forest, small-crowned forest, and open forest. The second and largest group comprises large-crowned forest, medium-crowned forest, and small-crowned forest. The third group, lower montane forest, is not subdivided except for the recognition of coniferous lower montane forest, this being a structural manifestation of the floristic difference. These eight forest types, together with the three undifferentiated groups of seral, littoral, and mangrove forest, are the 11 forest types that appear on the accompanying vegetation map as either discrete entities or complexes that include other non-forest vegetation types.

The mapped forest types are by no means homogeneous, and at the map scale of 1 : 1,000,000 no further subdivision is feasible. However, some components within them are recognizable on the air photos. These are single-species stands, semi-deciduous forest or secondary forest, that occur within the matrix of mixed-species forest. Trees that form pure stands and can be recognized on the air photos are *Hopea*, *Castanopsis*, *Nothofagus*, *Araucaria*, *Melaleuca*, *Octomeles*, and *Casuarina*. Their

general location is indicated on a 1 : 500,000 map by symbols. Limited copies of this black and white unpublished map are available on request.

Areas for each mapped forest type were calculated using a dot-grid (1 dot = 1·61290 km²) on a 1 : 500,000 vegetation map. The figures obtained were adjusted after estimating the approximate areas of included forest types and non-forest on each air photo mosaic (approx. scale 1 : 63,360).

IV. Description of Forest Types

(*a*) *General*

To avoid repetition these general descriptions are restricted to points of forestry interest and are designed to complement the more detailed descriptions given in Part VI. In each description only the most frequently occurring trees are named. Each forest type has been placed into a class based on estimated stocking rate (Table 11), and this is used in describing the forest potential of each land-form type.

Secondary forest is generally composed of species that have a wide range of tolerance and, therefore, it is less dependent on environmental factors other than light; for this reason it is described as a composite type for each major group in which it occurs.

(*b*) *Forest on Plains and Fans*

(i) *Large- to Medium-crowned Forest*

(1) *Mixed forest.*—This forest has a high stocking rate and covers 2900 km². The main timber species are *Pometia pinnata*, *Octomeles sumatrana*, *Terminalia* spp., *Pterocarpus indicus*, *Ficus* spp., and *Alstonia scholaris*, none of which normally contribute more than 10% of the total timber volume. However, in certain areas, particularly between the Vanapa and Brown Rivers, between Cloudy Bay and Amazon Bay, and along the Liba, Bonua, and Bailebu Rivers, *Pometia* exceeds this value and is often subdominant to occasionally dominant. Girths are generally moderate to large, ranging up to 4·0 m with 35–40% of trees in the 2·1+ m class. Boles are generally straight and long, ranging up to 21 m except for certain trees which normally have a poor stem form, e.g. *Pterocarpus*, *Vitex*, and to a lesser degree *Pometia pinnata*. Timber volumes per hectare vary greatly but the estimated average stocking rate is 60 m³/ha.

The forest grows on well to imperfectly drained alluvial plains and gently sloping fans on which there is little or no flooding, and thus there are few access hazards except perhaps the need to cross the larger rivers.

The main areas of this forest type are plains and fans north of Mt. Lamington, on the Musa coastal plain, on the fans and plains between the Goropu Mountains and the north coast, and on plains associated with the major rivers along the south coast. The forest is mainly associated with the land-form types AWs, AWv, AWu, FSn, VPn, and DSw.

(2) Octomeles *forest.*—This forest has a very high stocking rate and covers 100 km². It grades from almost pure stands to mixed forest with some emergent *Octomeles*. Girths are large and generally 60% or more of trees fall in the 2·1+ m

girth classes. Boles are straight and long, ranging up to 35 m, and volumes often exceed 117 m^3/ha. The estimated stocking rate is 85 m^3/ha.

Octomeles forest is found on similar sites to the mixed forest but is most widespread near present and prior stream channels, especially along the Tauri, Akaifu, Dilawa, Vanapa, and Brown Rivers of the southern coast and along the Wakioka and Rakua Rivers SE. of Mt. Victory on the northern coast. Access is similar to that of mixed forest. It is mainly confined to the APf and AWs land-form types.

(ii) *Small-crowned Forest.*—This forest has a moderate stocking rate and covers 1200 km^2. The main timber trees include *Syzygium*, *Intsia*, *Anisoptera*, *Hopea*, and in the east *Vatica* and *Eucalyptopsis*. Generally the composition is mixed but locally Dipterocarpaceae become subdominant. Girths are generally small to moderate (up to 2·1 m) and boles are generally straight and long (up to 24 m). The estimated stocking rate is 50 m^3/ha.

The type grows on gently undulating plains and basin areas, very often on gravelly lateritic soils and in areas of poor drainage. Access is good to locally moderate.

The forest is found adjacent to foothills mainly between Marshall Lagoon and Cloudy Bay in the south, west of the Mambare River in the north, and also in upland basins south of Milne Bay and west of the Musa coastal plain. It is almost entirely confined to USu and UHr land-form types.

(iii) *Open Forest.*—This forest has a moderate stocking rate and covers 1500 km^2. The most commonly occurring trees are *Ficus* spp., *Pterocarpus indicus*, *Syzygium* spp., *Neonauclea*, *Nauclea*, *Planchonia*, *Terminalia* spp., *Artocarpus*, and Lauraceae. No species contributes more than 10% of the timber volume except locally where *Laportea* and *Kleinhovia* are dominant. Girths are generally moderate to large, ranging up to 4·0 m, and boles range up to 21 m. Stem form is for the most part straight although some trees including *Pterocarpus*, *Laportea*, and *Kleinhovia* have crooked stems. The estimated stocking rate for the type is 40 m^3/ha.

The forest is found on plains that are subject to frequent short-lived flooding and on back plains subject to moderately long periods of inundation during the wet season. Access, therefore, is considered to be generally moderate.

As it is associated with all major rivers, the forest is found throughout the alluvial plains of eastern Papua but is most prevalent on APf land-form type.

(iv) *Semi-deciduous Forest.*—This forest has a moderate stocking rate and covers 140 km^2. Species composition in general is similar to that of the large- to medium-crowned forest but there is a higher proportion of deciduous and semi-deciduous trees such as *Bombax*, *Anisoptera*, *Intsia*, *Garuga*, *Terminalia* spp., *Gmelina*, *Albizia*, *Flindersia*, and *Sterculia* spp. In other respects such as girth, bole, and stem form this forest type is also similar to the large- to medium-crowned forest but the estimated stocking rate is slightly lower, about 50 m^3/ha, due to a lower tree density.

The access hazards are similar to those of the large- to medium-crowned forest. The type occurs only in two monsoonal areas, the Musa basin and adjacent fans, and the alluvial plains in the Cape Vogel area, in APf, AWs, and USu land-form types.

(v) *Secondary Forest.*—Secondary forest has a low stocking rate and covers 800 km². Species composition is extremely variable and is related to the successional stage attained. The most commonly occurring trees include *Pometia pinnata, Althoffia, Endospermum, Euodia, Macaranga, Sterculia, Cerbera, Pimelodendron,* and *Canarium* spp. Apart from a higher reject percentage, mainly due to over-maturity of the earlier colonizers, the forest attributes are generally similar to those of the mixed forests in which the secondary forest is found. However, estimated stocking rates are generally lower, averaging about 30 m³/ha. Secondary forest also has a lower proportion of valuable timber species.

As secondary forest results from interference by man, it may occur in any situation but is generally confined to the better-drained sites which are best suited to indigenous agriculture.

(c) Lowland Hill Forests

(i) *Large-crowned Forest*

(1) *Mixed forest.*—This forest has a high stocking rate and covers 500 km². The most commonly occurring trees include *Pometia* spp., *Canarium* spp., *Anisoptera, Cryptocarya* spp., *Terminalia* spp., *Syzygium* spp., *Ficus* spp., *Celtis* spp., *Dysoxylum* spp., and *Sloanea* spp., but none contributes more than 10% of the timber volume. Girths are moderately large, ranging up to 3·0 m generally, and boles are straight and long, up to 30 m. The estimated stocking rate is about 70 m³/ha.

The forest is found on gentle to moderate slopes, especially on volcanic land forms, and access is generally moderate to good depending on the steepness of adjacent land.

The main occurrences are on the slopes of Mt. Lamington and Mt. Victory but isolated pockets of this forest are found along the northern slopes of the central ranges. It occurs in VAv, VBm, VPd, VPn, DSf, DSw, and EAf land-form types.

(2) Octomeles *forest.*—This forest has a very high stocking rate and occurs on the slopes of Mt. Victory where it covers 13 km². *Octomeles* is dominant and usually emergent over species of the mixed forest. Girths are large and generally 60% or more fall in the 2·1+ m class. Boles are straight and long, ranging up to 35 m, and volumes often exceed 117 m³/ha. The estimated stocking rate is 85 m³/ha.

The forest is a remnant of a stage in the seral succession on the volcano and will gradually be replaced by mixed forest. Access is similar to that of the mixed forest.

(3) Araucaria *forest.*—This is a very high stocking rate forest that covers 8 km². It is virtually a mixed forest with *Araucaria hunsteinii* emergents of highly variable density. The estimated average stocking rate is 85 m³/ha but in the dense stands the stocking rate may be much higher. Girths are very large, often exceeding 3 m, and boles are very long (up to 50 m) and straight.

The main stand is in the upper reaches of the Bariji River. Access is similar to that of the mixed forest.

(ii) *Medium-crowned Forest*

(1) *Mixed forest.*—This moderate stocking rate forest is the major type of eastern Papua and covers 14,000 km². Species composition is similar to that of the large-crowned forest but girths are somewhat smaller (up to 2·5 m) and boles

shorter (up to 18 m). Stem form is straight. The estimated stocking rate for this type is about 40 m^3/ha.

The forest is developed below 1400 m altitude along the central ranges and on Mt. Trafalgar and Mt. Victory on a variety of land-form types. Access is generally poor to very poor due to very steep slopes but may be moderate in areas adjacent to lower and more accessible terrain.

(2) Hopea *forest.*—A moderate stocking rate forest covering 160 km^2, it is composed of species of the mixed forest but is dominated by *Hopea.* Girths are generally smaller, up to 2·1 m, but the number of stems per unit area is larger than in the mixed forest. Boles are generally moderately long (up to 21 m) and straight. The estimated stocking rate is 45 m^3/ha.

Hopea forest is scattered throughout the area, growing on various land-form types in zones of monsoonal influence, but occurs mainly in the east. Access is similar to that of mixed forest.

(3) Araucaria *forest.*—This is a very high stocking rate forest covering 8 km^2. It is similar in all respects to the *Araucaria* forest occurring in large-crowned hill forest.

It occurs in two small areas, along the upper reaches of the Bariji and Ormond Rivers respectively. Access is similar to that of the mixed forest.

(4) Castanopsis *forest.*—This is a low stocking rate forest covering 260 km^2. The predominant tree is *Castanopsis,* although some *Lithocarpus* is also present. Girths are generally small, up to 2 m, and trees with larger girths are usually defective. Boles are short, usually less than 15 m. The estimated stocking rate is 17 m^3/ha.

Most *Castanopsis* forest is confined to ridge tops and upper slopes and occurs throughout the area on a variety of land-form types. Access is similar to that of the mixed forest.

(iii) *Medium-crowned Semi-deciduous Forest.*—This is a moderate stocking rate forest that covers 420 km^2. Species composition is similar to that of medium-crowned forest except for a large proportional representation by deciduous and semi-deciduous species. These include *Terminalia* spp., *Intsia bijuga, Anisoptera kostermansiana, Sterculia* spp., *Pterygota horsfieldii, Bombax ceiba,* and *Garuga floribunda.* In other respects it is similar to the medium-crowned mixed forest. It has an estimated stocking rate of 35 m^3/ha.

Semi-deciduous forest is confined to the hills around the Musa basin on several land-form types. It is generally more accessible than the other forests in the same group.

(iv) *Small-crowned Forest*

(1) *Mixed forest.*—This is a low stocking rate forest covering 4000 km^2. Species composition is similar to the other mixed lowland hill forests but girths are smaller (up to 2·1 m) and boles shorter (up to 15 m). The estimated stocking rate is 25 m^3/ha.

The forest is found on many land-form types throughout the area. Generally access is poor to very poor owing to very steep slopes.

(2) Hopea *forest.*—This is a moderate stocking rate forest covering 46 km² mainly in the eastern part of the area. It is similar in most respects to the medium-crowned *Hopea* forest but girths and boles are smaller. The estimated stocking rate is approximately 35 m³/ha.

(3) Araucaria *forest.*—This is a very high stocking rate forest covering 30 km². Although similar in most respects to the previously described *Araucaria* forests, the estimated average stocking rate is slightly lower (80 m³/ha) because of the lower volume contribution by associated species. The forest forms small scattered stands along the central ranges.

(4) Castanopsis *forest.*—This is a low stocking rate forest which covers 460 km². The forest is similar in all respects to *Castanopsis* forest occurring in medium-crowned forest. It occurs throughout the area but mainly south of lat. 9°00'S.

(v) *Small-crowned Semi-deciduous Forest*

(1) *Mixed forest.*—This low stocking rate forest covers 1400 km². Species composition is similar to that of the medium-crowned semi-deciduous forest but girths and boles are somewhat smaller and the estimated stocking rate is lower (25 m³/ha).

The forest is located mainly in the south, west of Cloudy Bay, in areas of monsoonal influence. It occurs in a variety of land-form types. Access is generally poor to very poor due to steep slopes.

(2) Castanopsis *forest.*—This low stocking rate forest is similar to the equivalent type described under small-crowned forest. The estimated stocking rate is 17 m³/ha.

Situated on ridge crests and upper slopes, it is found throughout the area mapped as small-crowned semi-deciduous forest.

(vi) *Secondary Forest.*—Secondary forest in the lowland hill forest group is a low stocking rate forest covering approximately 4000 km². In the smaller girth classes the species are similar to those of the equivalent mixed forest type; however, in the larger girth classes trees commonly occurring are *Albizia falcataria, Euodia* spp., *Endospermum* spp., *Macaranga* spp., *Artocarpus* spp., *Tristiropsis* sp., and *Terminalia kaernbachii.* Many of these species are mature trees of earlier seral stages but the last two may often be remnants of previous forest retained as food trees during garden clearing. Girths, bole lengths, and stocking rates vary widely. The estimated average stocking rate is 17 m³/ha.

It occurs throughout the area in varying proportions dependent upon present and prior location and density of population.

(*d*) *Lower Montane Forests*

(i) *Lower Montane Forest*

(1) *Mixed forest.*—This is a moderate stocking rate forest which covers 5100 km². Timber trees present include Cunoniaceae, Lauraceae, *Elaeocarpus, Sloanea, Lithocarpus, Castanopsis, Syzygium, Planchonella, Ilex, Calophyllum,* and the conifers *Podocarpus, Dacrycarpus, Phyllocladus,* and *Papuacedrus.*

Individual species rarely attain subdominance. Girths are mainly small (up to 2·1 m but more often less than 1·8 m) and boles are short, usually not more than 12 m. Stem form is variable and often crooked but the tree density is generally high. The estimated stocking rate is 35 m^3/ha.

The forest is found mainly above 1400 m altitude along the Owen Stanley Range on several land-form types. Because of its topographic position and in many cases its rugged habitat, access is classed as very poor.

(2) Nothofagus *forest.*—This is a moderate stocking rate forest covering 1150 km^2. Although most of the mixed forest species are present the forest is composed predominantly of *Nothofagus* spp. Girths are small to moderate in size (up to 2·7 m) and boles are straight and range up to 24 m long. The estimated stocking rate is 45 m^3/ha, although individual stands may rate much higher than this.

Nothofagus forest is found throughout the lower montane mixed forest area along the central ranges but is more common in the areas between Mt. Kenevi and Mt. Nelson and between the Goropu Mountains and Mt. Yule.

(3) Araucaria *forest.*—This is a moderate stocking rate forest covering 50 km^2. *Araucaria cunninghamii* (hoop pine) is emergent in varying densities over a mixed forest. Girths are generally large and often exceed 2·5 m, while boles are straight and long (up to 35 m). In a continuous strip study on Mt. Suckling carried out by the Department of Forests, the average stocking rate was 117 m^3/ha. Because of the extreme variability in stand density the estimated area has been extended to include large areas of low-density *Araucaria.* Therefore, the estimated average stocking rate for this type (35 m^3/ha) is a rather low figure when compared with individual small dense stands, but probably is a realistic figure for the overall estimated area.

The forest is generally found along the central ranges east of Mt. Obree, mainly on the slopes of Mt. Dayman, Mt. Suckling, and the Goropu Mountains.

Many of the hoop pines in the forest are overmature and in some cases, particularly on Mt. Dayman, they have suffered from fire damage.

(ii) *Coniferous Lower Montane Forest*

(1) *Mixed coniferous forest.*—This is a low stocking rate forest covering 1600 km^2. The species composition is dominated by Podocarpaceae, with occasional *Papuacedrus.* The remaining species are similar to those of the mixed lower montane forest. Girths and boles vary widely between stands but the better stands have girths up to 2·4 m and boles up to 15 m long. Tree density is generally moderate to high and the estimated stocking rate is 30 m^3/ha, but this also varies considerably between stands.

The forest is found on various land-form types usually above 2400 m altitude along the central ranges. Access, as in the lower montane forest, is very poor.

(2) Araucaria *forest.*—This is moderate stocking rate forest which covers 50 km^2. It is similar to the *Araucaria* forest described under the lower montane forest and has the same estimated stocking rate, 35 m^3/ha.

(iii) *Secondary forest.*—Secondary forest covers 290 km^2. The estimated stocking rate is 17 m^3/ha. It is found only at the lower-altitude levels within the lower montane zone and is not associated with the coniferous lower montane forest.

(*e*) *Seral Forests*

(i) Casuarina *Forest.*—This forest has a low stocking rate and covers an area of 80 km². It consists almost entirely of *Casuarina cunninghamiana.* Girths are small, rarely exceeding 1·8 m, and boles are long (up to 30 m) and often slightly fluted. The stands vary widely in their stage of development and hence also in stocking rate, the estimated average of which is 17 m³/ha.

The forest is found mainly on gravelly and bouldery outwash plains and on coarse bouldery deposits along stream channels. The main areas are along the upper courses of the Wakioka River and its tributaries. Access is generally good but flooding may be a hazard. APf and FSn are the main land-form types on which the forest occurs.

(ii) Octomeles *Forest.*—This is a very high stocking rate forest which covers 15 km². The forest has an estimated stocking rate of 85 m³/ha and is similar in all respects to its synonym described under forests on plains and fans. It occurs along the lower parts of the Wakioka River and is associated with volcano–alluvial fans.

(*f*) *Littoral Forests*

(i) *Mixed Forest.*—This forest has a moderate stocking rate and covers 80 km². The most commonly occurring trees are *Pterocarpus indicus, Terminalia* spp., *Planchonia, Nauclea, Syzygium,* and *Melaleuca.* Girths are variable, ranging from small, particularly in *Melaleuca,* to moderately large (3·0 m). Boles are generally short to moderate in length but may reach 20 m. Stem form is often crooked. The estimated stocking rate is 30 m³/ha.

The forest is found on beach plains and beach ridges of LW land-form type, preferring less waterlogged sites than pure *Melaleuca* forest. Access is poor to moderate generally, but good on beach ridges.

(ii) Melaleuca *Forest.*—This forest has a low stocking rate and covers 100 km². It consists of almost pure stands of *Melaleuca* interspersed within areas of mixed forest or swamp vegetation. Girths are small, rarely exceeding 1·5 m, and boles range up to 20 m. A large proportion of the trees falls into the 0·9–1·2 m girth size class and, although too small for milling, could form a source of round timber for wharf piles. The estimated stocking rate is 25 m³/ha.

The forest is virtually restricted to two areas, the low-lying beach plains between Marshall Lagoon and Amazon Bay on LW land-form type and the low-lying back plains of the Akaifu River on AS land-form type. Access is poor due to the moderately long periods of inundation and subsequent poor drainage conditions of the habitat, but this is alleviated by good access on adjacent land, particularly on beach ridges.

(*g*) *Mangrove Forests*

Mangrove vegetation covers approximately 1200 km². Only a very small percentage of this area has millable timber and, therefore, mangrove forest has not been placed in a stocking rate class. Its potential value as a source of minor forest products has, however, prompted its inclusion as a forest type. In some stands of old mangrove forest, as near Mullins Harbour, girths may exceed 1·5 m and boles 15 m. Elsewhere, girths are generally small and trees are suitable only for use in the round.

Except around Dyke Ackland Bay, the main areas of mangrove are along the south coast. All are on LS land-form type. Access is very poor because of tidal flooding.

V. Access

(*a*) *General*

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

(i) *Soil Drainage/Inundation (DI) and Flooding (F) Indexes.*—These indexes indicate the limiting effect of soil wetness and overflow.

It is assumed that due to precipitation alone almost all land will be inaccessible for a certain length of time each year, even under optimum drainage conditions. The time of inaccessibility is estimated from the period during which soil moisture rises above field capacity and is calculated from the results of the application of the water balance model discussed in Part III. Above field capacity conditions are assumed to occur in those weeks when soil moisture storage has reached the maximum level (10 cm) and in which more than 7·5 cm of run-off occurs. The length of the period (Table 12) ranges from 11 days per year at Port Moresby in climatic zone I to 87 days per year at Kokoda in climatic zone IV. These periods, assumed to be typical for each climatic zone, are used in assessing the DI index, after subjective adjustment for interaction with soil drainage/inundation factors.

Table 12

Number of days soil water storage equals 10 cm and run-off is more than 7·5 cm*

	Dogura	Kokoda	Popondetta	Port Moresby	Kwikila	Samarai	Wanigela
Jan.–Mar.	11	29	20	7	4	6	15
Apr.–June	1	17	6	3	4	22	14
July–Sept.	0	13	2	0	4	13	3
Oct.–Dec.	1	28	15	1	1	6	10
Year	13	87	43	11	13	47	42

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

The DI index is calculated for each land-form type using the descriptions in Part II. It is the sum of the products of percentage area of the land-form type affected by a particular hazard and a weighting factor for the maximum expected number of days per year the particular hazard could render the land inaccessible, as set out in Table 13.

Thus:

$$DI = (0{\cdot}0+C)\times \% \text{ area in W0} + (0{\cdot}12+C)\times \% \text{ area in W1} + (0{\cdot}33+C)\times \% \text{ area}$$

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

in W2+(0·5+C)× % area in W3+(0·75+C)× % area in W4+1·00× % area in W5 where W0, W1, . . . W5 are the drainage/inundation hazard classes (Table 13) and C is the adjusted weighting factor for the climatic zone in which the land-form type occurs.

TABLE 13

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

Nature and class of hazard		Estimated max. duration of inaccessibility (days/yr)	Weight factor for calculating soil drainage/inundation or flooding index
Precipitation			
Climatic zone I		13	0·04
Climatic zone II		25	0·07
Climatic zone III		44	0·12
Climatic zones IV–VI		>87	0·24
Soil drainage/inundation			
Well drained	(W0)	0	0
Imperfectly drained or short inundation	(W1)	45	0·12
Poorly drained or moderate inundation	(W2)	120	0·33
Very poorly drained or long inundation	(W3)	180	0·50
Swampy or very long inundation	(W4)	270	0·75
Permanently inundated	(W5)	365	1·00
River flooding			
Nil	(F0)		
Once in 6–10 yr	(F1)	3	0·01
Once in 2–5 yr	(F2)	8	0·02
Once every yr	(F3)	15	0·04
More than once every yr	(F4)	>30	0·08

The F index is derived in a similar way (excluding the factors already used in the DI index), but if flooding occurs at least two times per year a minimum figure of 30 days per year (0·08) is used. F = 0·0× % area in F0+0·01× % area in F1 + . . . +0·08.

(ii) *Slope Indexes.*—This index is calculated for each land-form type from 0·0 (% slopes >10°)+0·33 (% slopes 10–16°)+0·66 (% slopes 17–29°)+1·0 (% slopes >29°).

(iii) *Access* (*A*) *Indexes.*—Although all the environmental factors interact, their effects are often additive; for example, imperfectly drained soils on moderately steep slopes. For this reason, the access index is calculated as the sum of the slope index, soil drainage/inundation index, and flooding index for each land-form type subtracted from 100. A = 100−(S+DI+F).

Access index classes are: nil, 0–5; very poor, 6–20; poor, 21–40; moderate, 41–60; good, 61–80; very good, 81–100.

The access index shows the accessibility of any land-form type relative to other land-form types and has no absolute value.

(b) Terrain Access Categories

On the basis of the indexes described above, the land-form types are grouped into ten broad access categories described below and listed in Part II in the land-form type descriptions.

The land-form types are first divided into four groups on the basis of the slope index (S0, 0–20; S1, 21–40; S2, 41–70; S3, >70), which gives an assessment of the proportion of accessible slope in one land-form type relative to another. Some of the steeper land-form types are placed in a better access category where very low or low relief may increase their accessibility.

Land-form types with soil drainage and/or inundation hazards are subdivided on their drainage/inundation indexes (W1, 22–30; W2, 31–70; W3, 71–100), presenting increasingly difficult access.

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

Access category S0W3 consists of swamps, both freshwater and saline. It comprises the land-form types that are inundated or very poorly drained for 5 months or longer per year, although, in these, some small areas may be accessible for brief periods during the dry season. This category covers substantial areas of the coastal plain and large parts of the alluvial plains of the major rivers.

Access category S0W2 consists of poorly drained plains and fans. Slope and relief are negligible. Because of inundation and poor drainage, large areas may be inaccessible for up to 5 months per year, and minor areas for longer periods. However, by carefully selecting road routes and building causeways where necessary, access may be possible to large areas for most of the year. This category is distributed throughout the coastal and alluvial plains and also includes areas in intermontane basins.

Access category S0W2F is similar to the above but may be subject to flooding, often destructive, at least once per year. It is associated with recently active volcanoes.

Access category S0W1 land consists of alluvial fans and beach ridge complexes. Much of the land is well to imperfectly drained but some parts may be poorly to very poorly drained, and minor areas may be inundated for up to 5 months per year. As a whole the category provides good access. It is distributed mainly in the southern part of the area with smaller areas along the northern coast and inland.

Access category S0W1F consists of alluvial plains and is generally similar in drainage characteristics to category S0W1. However, it is subject to flooding, sometimes serious, at least once a year. Access is classed as good.

Access category S0F consists of flood-plains and terraces which receive damaging floods at least once per year. Except for this hazard it is comparable with access category S0 described below. It occurs extensively throughout the alluvial plains and also along larger streams in intermontane valleys.

Access category S0 land consists mainly of well-drained areas, on alluvial and coastal plains, and fans and undulating surfaces that have characteristic slopes less than 10% and have nil to low relief. It presents no internal access problems except

for minor areas of imperfect to poor drainage and minor areas of steep slopes. It is distributed throughout lowland areas and also occurs in some intermontane basins.

Access category S1 land consists mainly of low hilly terrain and summit plateaux. Slopes are generally moderate and relief varies from very low to moderate. Some areas of steep slopes and minor areas of imperfect to poor drainage occur but are easily avoided. Small patches of land in this category are present throughout the area.

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

Access category S3 land consists mainly of very high hilly and mountainous terrain with very steep slopes, and relief ranging from low to very high. Generally slopes are too steep for road-building, and forested areas are best left as watershed protection. This category is almost entirely confined to the central ranges and north-east coast volcanoes but scattered occurrences are found elsewhere.

(*c*) *General Conclusions*

Accessible land in the area is generally confined to two zones, one along the north coast and one along the south coast. Both consist of foothills, fans, and alluvial and littoral plains and are bounded inland by the central ranges. Interspersed among areas of good access are alluvial and littoral swamps. In the south, the main forested areas of good access are found in the vicinity of the Vanapa and Brown Rivers, and between Kupiano and Sagarai River. The forest types include moderate to high stocking rate forests, generally of mixed composition, but with a high content of *Pometia*. Towards the east, *Hopea* and *Anisoptera* become more common.

Along the north coast, the main forested areas of good access stretch from Moi Biri Bay westwards to Cape Ward Hunt. Here also are forests of moderate to high stocking rate, the main areas being the Wanigela–Rakua River area, the lower Musa River plain, and the fans and plains north of Mt. Lamington.

Two areas of relatively easy access allow some penetration into the main range. These are the Musa basin and the Kokoda valley. A third possible access route is via the alluvial plain of the Bonua River, which flows into Table Bay in the south.

Existing road access is limited to discrete networks centred on Port Moresby, Cape Rodney, Alotau, and Popondetta.

Because of their depth, rivers in the area appear to be unsuitable for floating or raftings logs in any quantity, except perhaps in the lower reaches.

The south coast is well served by sheltered anchorages and so to a lesser extent is the north.

VI. Forest Potential of Land-form Types

Two parameters have been used to determine the forest potential of each land-form type relative to other land-form types. The first parameter used is the stocking rate index. This is calculated by assigning an index of 1·0 to the forest with the highest estimated stocking rate. Other types receive lower indexes proportionate to their estimated stocking rates.

The second parameter is the forest resources index, which is calculated for each land-form type and is the sum of the products of percentage area and the stocking rate index for each forest type present. The forest resource classes are: nil, 0–5; very low, 6–20; low, 21–40; moderate, 41–60; high, 61–80; very high, 81–100.

The forest resources index (FRI) and the access index (AI) are both used to form a subjective estimate of the overall forest productivity of each land-form type in Part II.

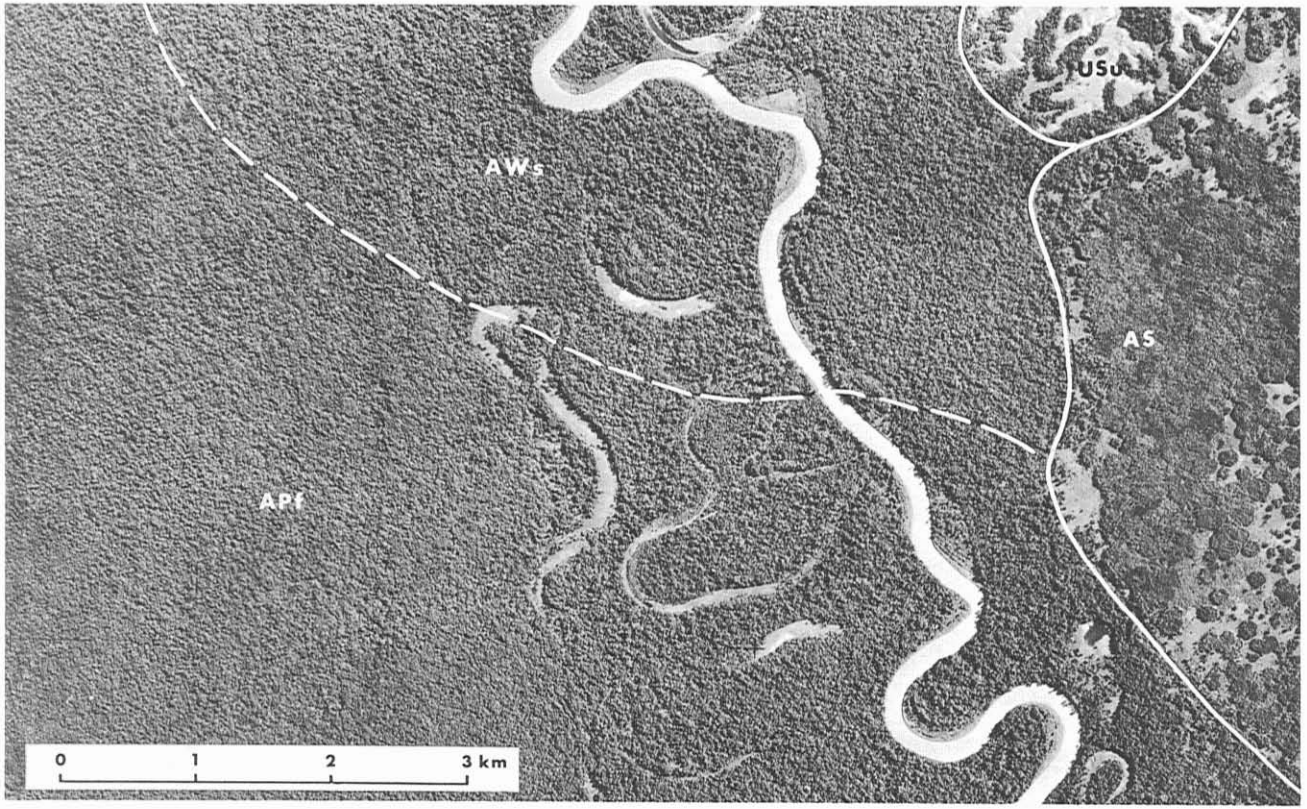
Generally the land-form types with the highest forest resources are those that are more inaccessible. Along the more accessible coast and hinterland the forests have to a large extent been cleared for agriculture and the present vegetation is either a mosaic of remnant forest, gardens, and various stages of secondary growth, or vast areas of grassland and/or savannah, sometimes with inclusions of remnant forest, and tongues of gallery forest along watercourses. The latter pattern is generally confined to monsoonal areas and occurs mainly along the southern coast, west of Marshall Lagoon, and along the northern coast east of Moi Biri Bay.

Land-form types: LS, LW, AWs. Climatic zone: I.

LW land-form type, consisting of beach ridges and flats and swales, shows up as a pattern of gently curving parallel lines. It has a vegetation mainly of monsoonal woodland and scrub (grey tones) and grassland (pale grey). Some patches of open water (black) occur in swales.

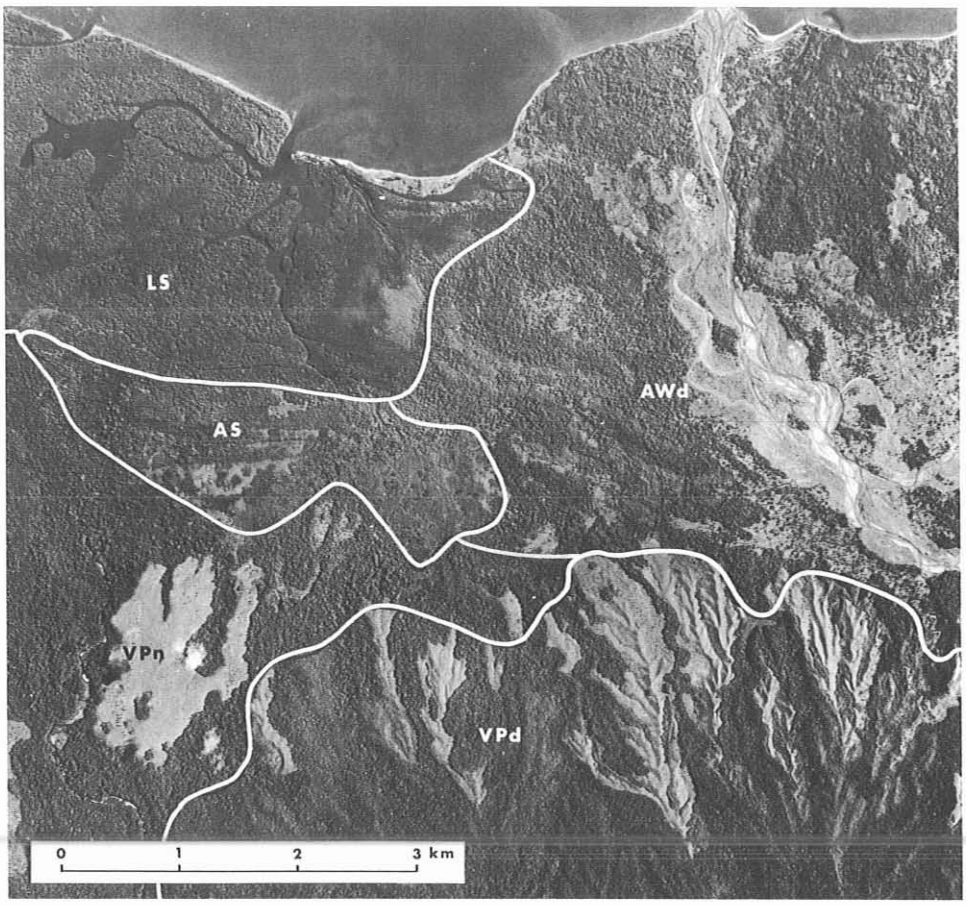
Tidal swamps of LS land-form type are covered by various types of mangrove. The lower-lying areas have dark-toned *Rhizophora–Bruguiera* forest where they are subject to daily tidal flooding (1) and light-toned *Avicennia* woodland on inner margins less frequently reached by the tide (2). Higher-lying terrain, present as unmapped inclusions of LW land-form type (3) and on inland fringes (4), has woodland, thicket, and scrub in which milkwood (*Excoecaria agallocha*) and *Hibiscus tiliaceus* are characteristic, and white-toned salt flats that are bare or have low mixed herbaceous vegetation or low sedge–grassland.

AWs land-form type here consists of moderately well to imperfectly drained alluvial plains which partly overlie beach ridges and have alkaline soils. They are largely covered with man-induced grassland of mainly *Ophiuros*, *Themeda australis*, and *Imperata*. The different grey tones of the grassland are due to burning.



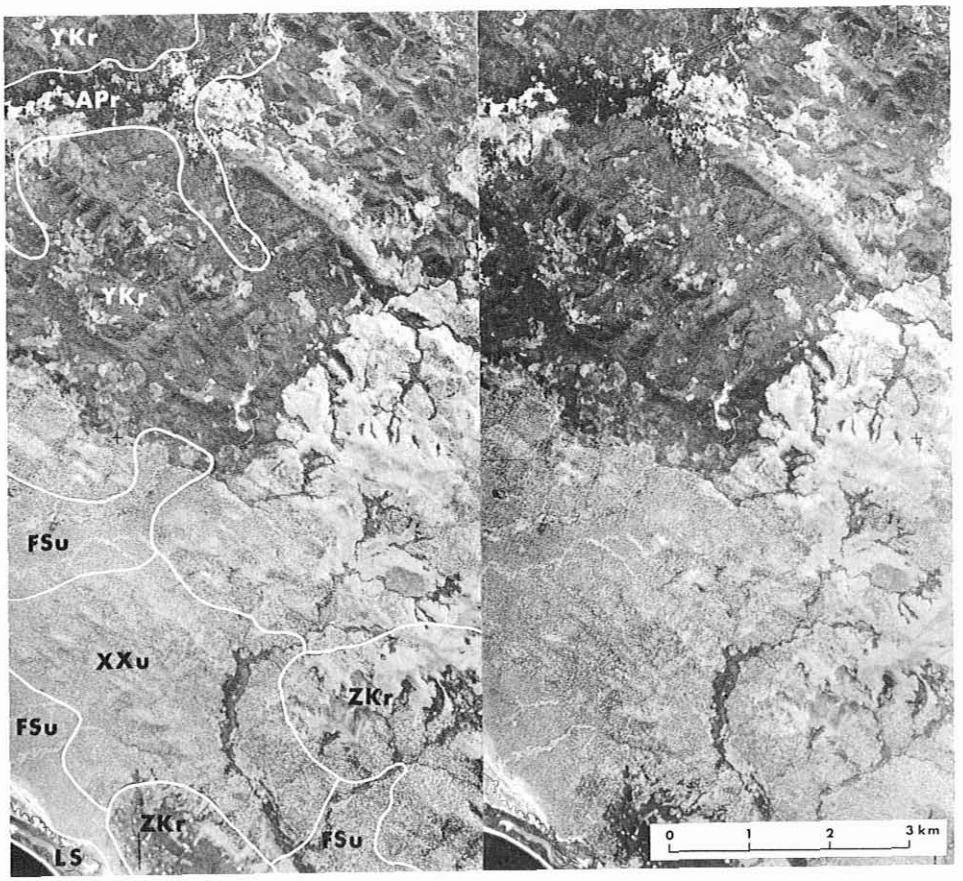
Land-form types: AS, APf, AWs, USu. Climatic zone: II.

The air photo shows part of the flood-plain of the meandering and frequently shifting lower course of the Tauri River. The unstable, frequently flooded, and poorly drained meander tract of APf land-form type in the south merges upstream into the more stable, less frequently flooded, and better-drained meander tract of AWs land-form type. As drainage conditions improve northwards the vegetation changes from large-crowned open forest into large-crowned more closed forest. The meander tracts are flanked by back plains that are subject to seasonal inundation. To the west the back plains are covered with relatively small-crowned dense forest, whereas to the east they consist of permanent swamp (AS land-form type) with sago palms (grey tone) and mixed herbaceous swamp vegetation (pale grey tone). In the north-east gently undulating terrain of USu land-form type consists of very pale grass-covered interfluves and dark forested depressions.



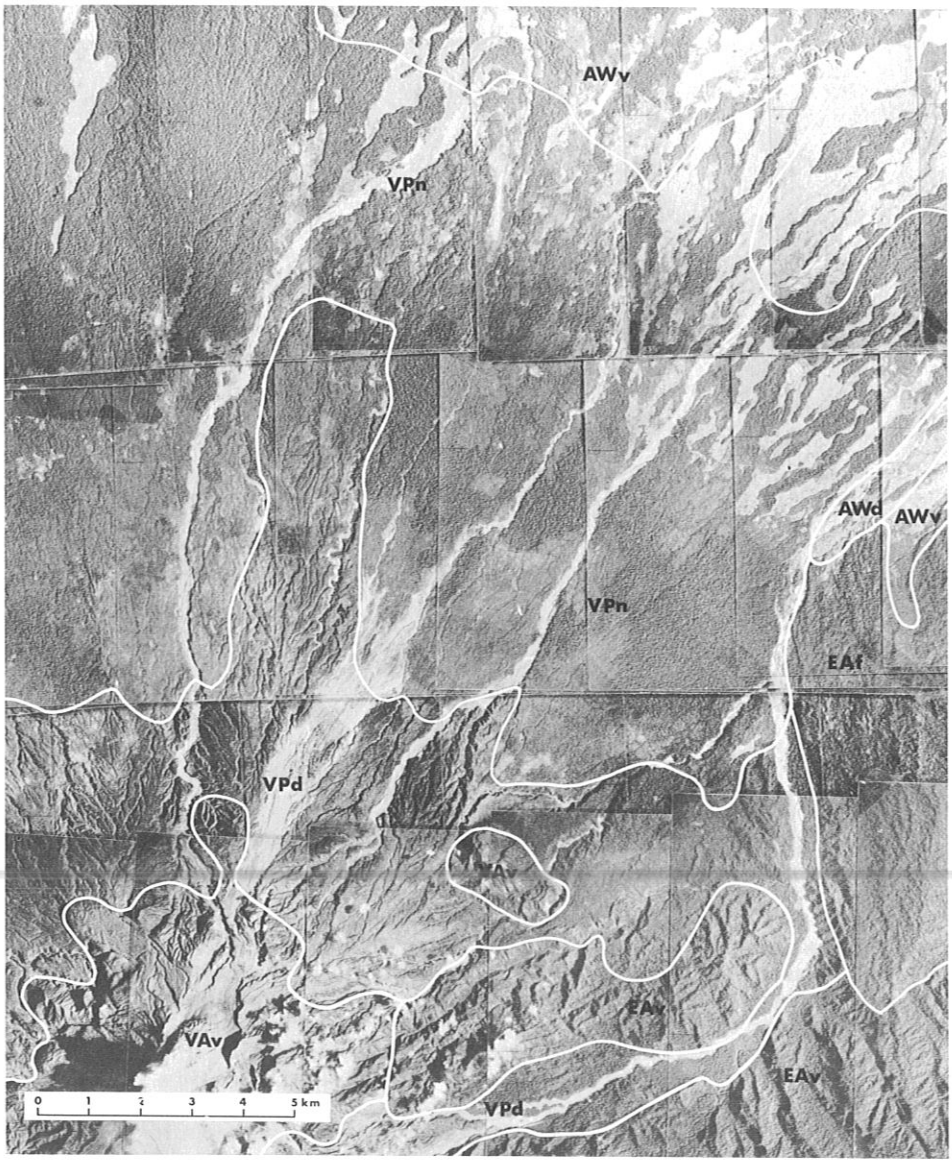
Land-form types: LS, AS, AWd, VPd, VPn. Climatic zone: III.

Northern slope of the active volcano Mt. Victory. The dissected lower flanks of the volcano, VPd land-form type, have a radial stream pattern. They merge into little- or non-dissected foot slopes of VPn land-form type. The vegetation on both land-form types consists of grassland and secondary forest. In the north-east a broad unstable flood-plain merges upslope with terraced fans incised by streams in narrow flood-plains (AWd land-form type). The narrow flood-plains have bare sand and gravel banks (very pale tone) and patches of colonizing tall grassland (*Saccharum spontaneum*) (pale tone). Other seral vegetation consists of scrub, woodland, and forest. An area of swamp woodland (AS land-form type) is wedged between foot slopes and coastal mangrove (LS land-form type).



Land-form types: LS, APr, FSu, XXu, YKr, ZKr. Climatic zone: I.

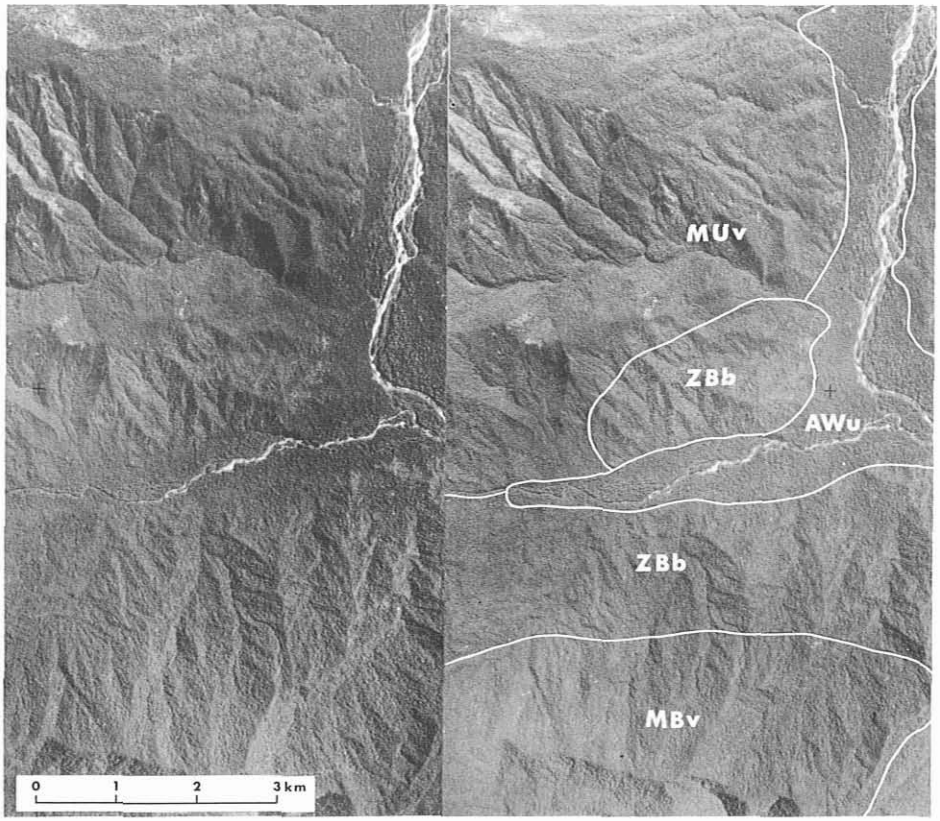
In this coastal area near Kwikila, south-east of Port Moresby, the main land-form types are YKr and ZKr, consisting of steep rounded strike ridges of moderate and moderate to high relief respectively, mainly on limestone. The ridges have shallow alkaline soils and a vegetation of eucalypt savannah (fine mottled tone), grassland (pale tone), and monsoonal woodland (dark tone) that is mostly secondary. Flat valley floors of APr land-form type with dark cracking clay soils are heavily gardened and include some rubber plantations with shade trees of *Samanea saman* showing as a smooth dark tone. The undulating terrain of low relief mapped as XXu land-form type and the gently sloping fans of FSu land-form type are mainly covered by eucalypt savannah. Mangrove vegetation of LS land-form type in the south-west is low and poorly developed and is associated with bare salt flats (white) and low sedge–grassland (pale grey) on the landward side.



Land-form types: AWv, AWd, VAv, VPd, VPn, EAv, EAf. Climatic zones: III and IV. Altitude: 75–1585 m.

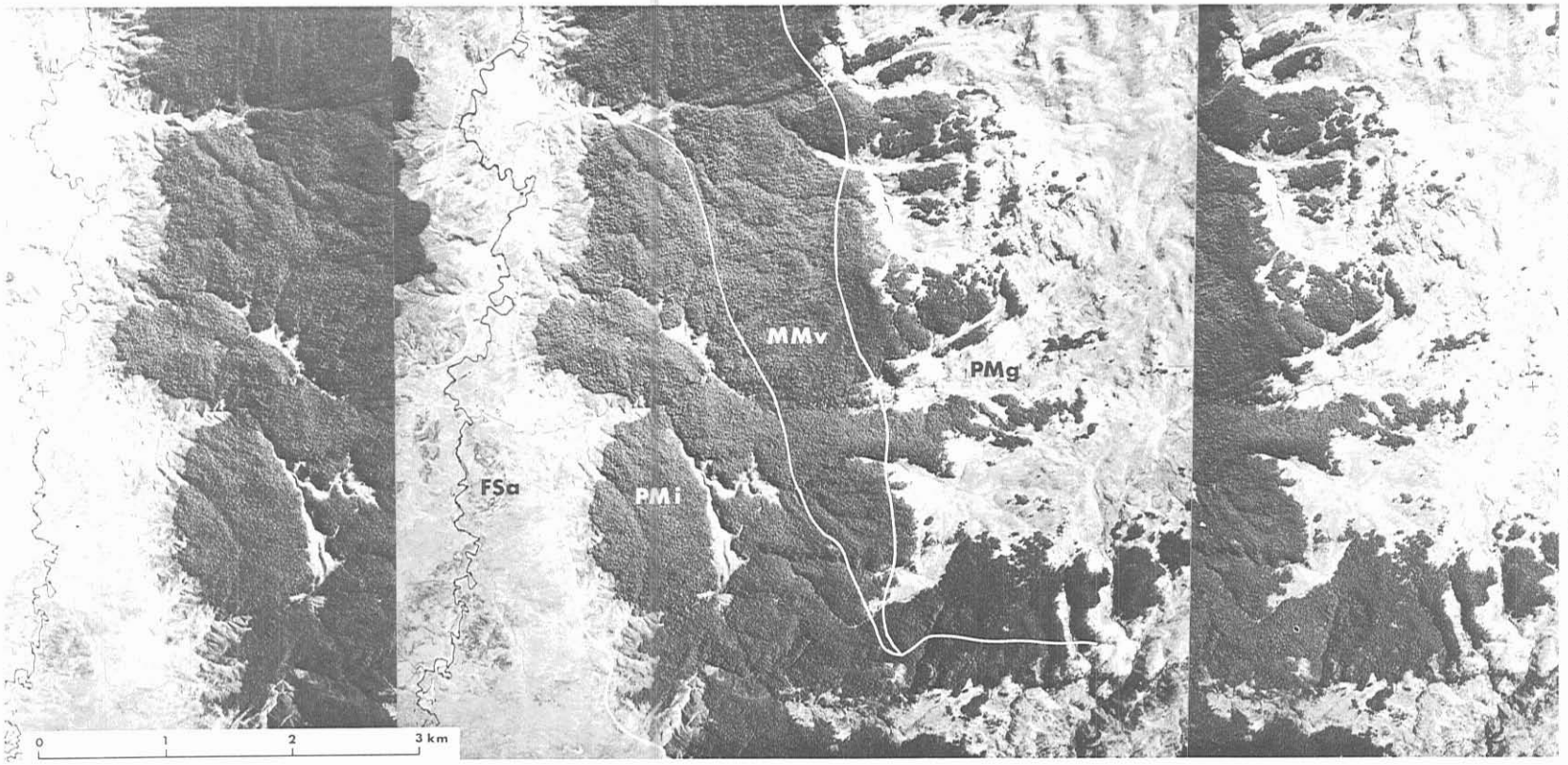
Part of air-photomosaic showing northern slopes of active Mt. Lamington volcano.

Well-preserved lava flows (VAv land-form type) in the south-west pass downslope into dissected (VPd) and non-dissected (VPn) lower flanks. These merge into smooth to gently undulating stable alluvial plains (AWv) that have a high potential for agriculture. Unstable braided rivers in narrow flood-plains form AWd land-form type. The deeply eroded remnants of long extinct volcanoes are mapped as EAv, and their closely dissected flanks as EAf land-form types. Seral vegetation communities predominate on the upper part of the active cone. Large-crowned tall forest is the natural vegetation on the lower flanks and plains, but has been replaced in many localities by grassland, gardens, and regrowth, especially on the plains.



Land-form types: AWu, ZBb, MBv, MUv. Climatic zone: IV. Altitude: 300–1600 m.

Bonua River south-east of Mt. Suckling. Sandy and gravelly tracts of braided rivers flanked by sandy and silty back plains form AWu land-form type. The river tracts have seral vegetation, mainly of *Casuarina cunninghamiana* up to more than 50 m tall, and the back plains have mixed forest with or without emerging *Casuarina*. They are mainly bounded by ZBb land-form type: steep-sided ridges and spurs with a relief up to 400 m, with shallow gravelly soils developed on basaltic rocks, and forest in which tall light-toned *Hopea* and *Anisoptera* locally predominate. MBv and MUv land-form types are mountain ridges that have a relief generally over 400 m. MBv, mainly formed on basaltic rocks, has steep to very steep slopes with a cover of generally medium-crowned forest. MUv, formed mainly on ultramafic rocks, has very steep to precipitous slopes with generally small-crowned forest in which *Casuarina papuana* often predominates, forming a very small-crowned, smooth, often dark-toned canopy; many of the ridge and spur crests have grassland. ZBb and MBv show the densely forested ridge-and-ravine landscape characteristic of much of south-east Papua.



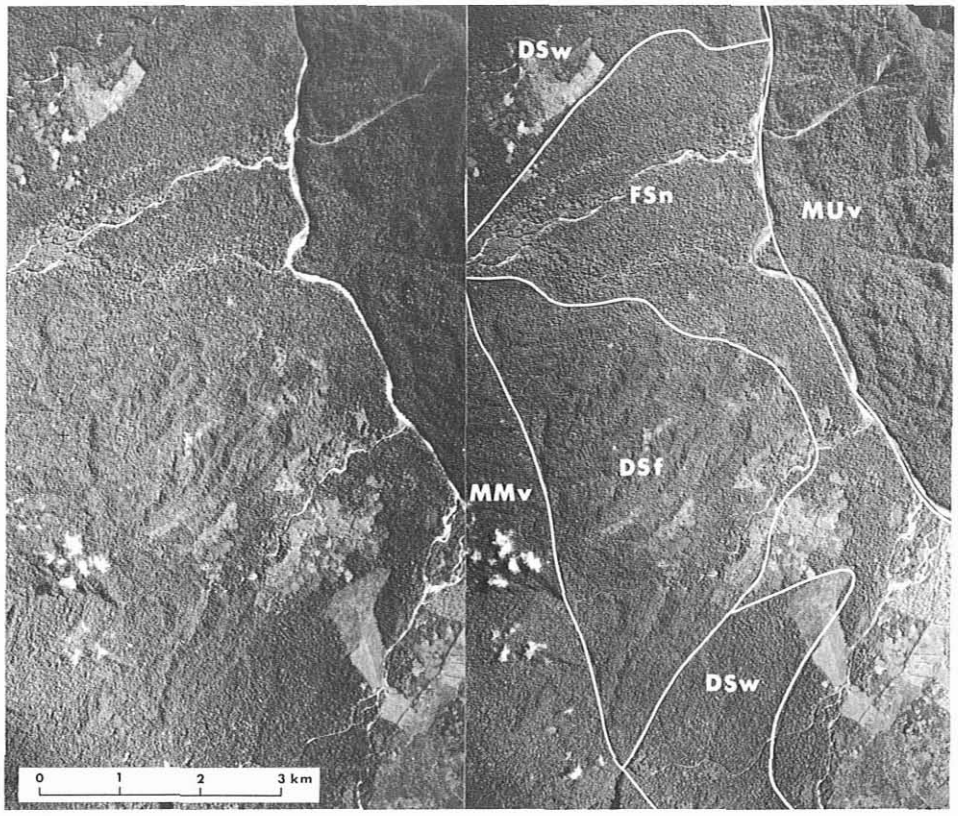
Land-form types: FSa, PMi, PMg, MMv. Climatic zones: V and VI. Altitude: 2800–3600 m.

The Neon basin and summit area of Mt. Albert Edward. The Neon basin, FSa land-form type, consists of concave fans passing down to a narrow swampy flood-plain traversed by the highly sinuous Giumu River. The soils on the fans are mainly moderately well to imperfectly drained and have sandy to loamy textures, although a peat layer over 2 m thick is locally present. The grassland of the fan slopes is largely a fire-disclimax vegetation and shows burn patterns.

PMi land-form type consists of variably dissected irregular high summit surfaces. It is largely covered by lower montane forest, the grey-toned irregular canopy of which probably indicates a predominance of beech (*Nothofagus*). A rim of finely speckled fire-induced tree-fern savannah forms the boundary between the forest and the grasslands of FSa.

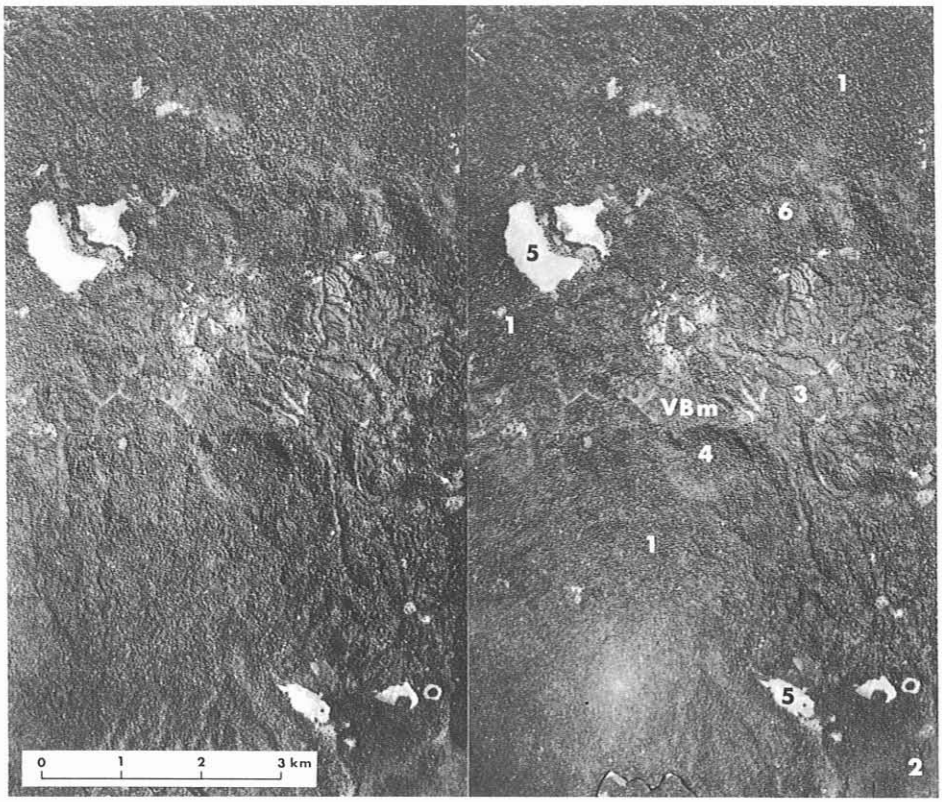
MMv land-form type, consisting of very steep mountain ridges and deep V-shaped valleys, is widespread along the Owen Stanley Range. Locally, as in the stereo triplet, MMv grades into PMi land-form type. The vegetation shown on MMv is lower montane forest, in which there are smooth dark-toned patches of dense small-crowned coniferous forest and open patches with dying beech trees.

PMg land-form type comprises mountain summits that were glaciated during the Pleistocene period. These summits lie above 3500 m and are characterized by U-shaped valleys, cirques, and rock basins occupied by lakes and swamps. The vegetation is low tussock grassland and remnants of montane forest. PMi, PMg, and MMv are formed on schistose metamorphic rocks.



Land-form types: FSn, DSf, DSw, MUv, MMv. Climatic zone: IV. Altitude: 200–600 m.

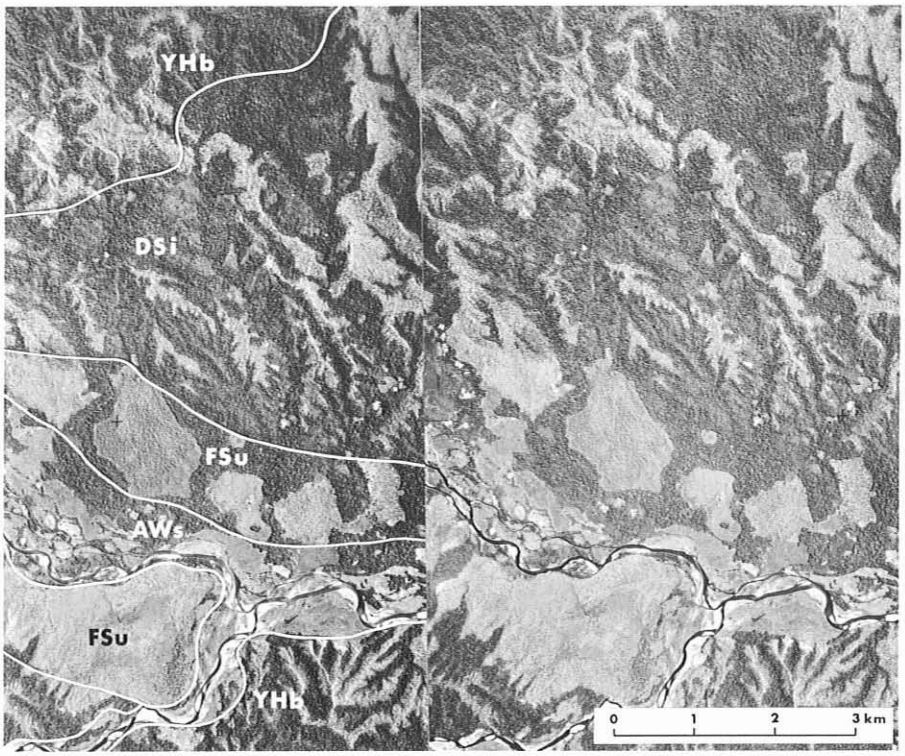
Valley of Mambare River north-west of Kokoda, showing some of the types of alluvial fans: undissected gently sloping alluvial fans of FSn land-form type, broadly dissected fans of DSw land-form type, and closely dissected fans of DSf land-form type. The fans are sharply bounded by densely forested mountain ridges on metamorphic rock to the west (MMv land-form type) and on ultramafic rock to the east (MUv land-form type). The undissected and broadly dissected fans have a high potential for agriculture and large areas of the original vegetation of large-crowned tall forest have been converted to gardens and rubber and cocoa plantations.



Land-form type: VBm. Climatic zone: III. Altitude: 300–800 m.

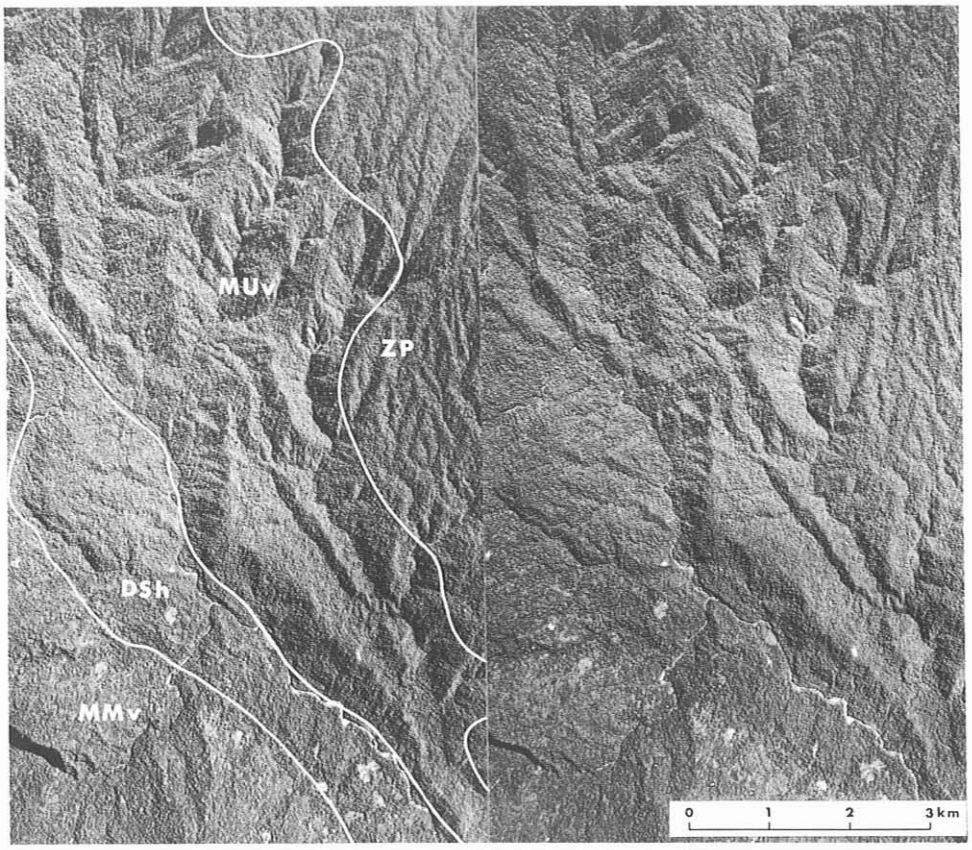
Part of the Managalase plateau between the Pongani and Bariji Rivers.

The volcanic terrain making up VBm land-form type consists of moderate to gently sloping undulating lava flows with large-crowned tall forest (1) and steep blocky lava flows with seral vegetation (2) and other volcanic features such as lava domes (3), craters (4), some of which are filled in (5), and scoria mounds and cinder cones (6).



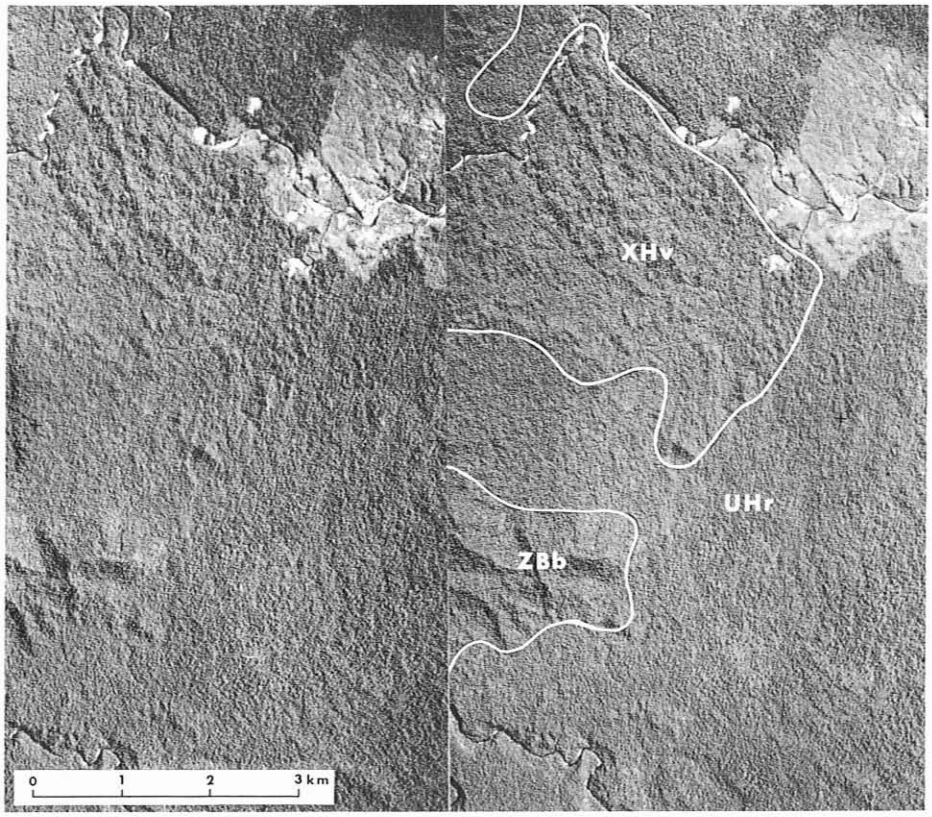
Land-form types: AWs, FSu, DSi, YHb. Climatic zone: II. Altitude 250–450 m.

Musa basin west of Safia. The terraced and generally well-drained plain of the Moni River (AWs land-form type) is bounded by smooth relatively short undissected fan slopes (FSu land-form type). To the north are older irregularly dissected and stepped fan surfaces (DSi land-form type). The branching ridges and spurs of mainly moderate relief in the north-west and south (YHb land-form type) are formed on Plio–Pleistocene sedimentary rocks (Domara River beds). The vegetation consists of eucalypt savannah, medium-crowned slightly deciduous forest, and, especially on the alluvial plains, tall grassland.



Land-form types: DSh, ZP, MUv, MMv. Climatic zone: IV. Altitude: 500–900 m.

Upper course of Moni River west of the Musa basin. Steep-sided ridges on the west side of the river (DSh land-form type) are deeply dissected alluvial and colluvial fans. The mountain ridges to the west are on mainly metamorphic rocks (MMv land-form type) and, like DSh, have mainly secondary forest. Those to the east (MUv land-form type) are on mainly ultramafic rocks. Further to the east are ash-mantled, closely dissected, sloping plateau-like surfaces (ZP land-form type) covered with very dense and tall primary forest. The steep slopes of MUv are less densely forested.



Land-form types: UHr, XHv, ZBb. Climatic zone: IV. Altitude: 30–100 m.

Ioma village north-west of Buna. The mainly gently undulating plains that form UHr land-form type are closely dissected in places to form low rounded ridges. The vegetation is small-crowned locally open forest. XHv land-form type shows an intricate pattern of very steep-sided low hills and ridges. The higher ridges and spurs in the south-west form part of the widespread ZBb land-form type. UHr and XHv are formed on mainly consolidated coarse-grained sedimentary rocks, whereas ZBb is formed on basaltic volcanic rocks.

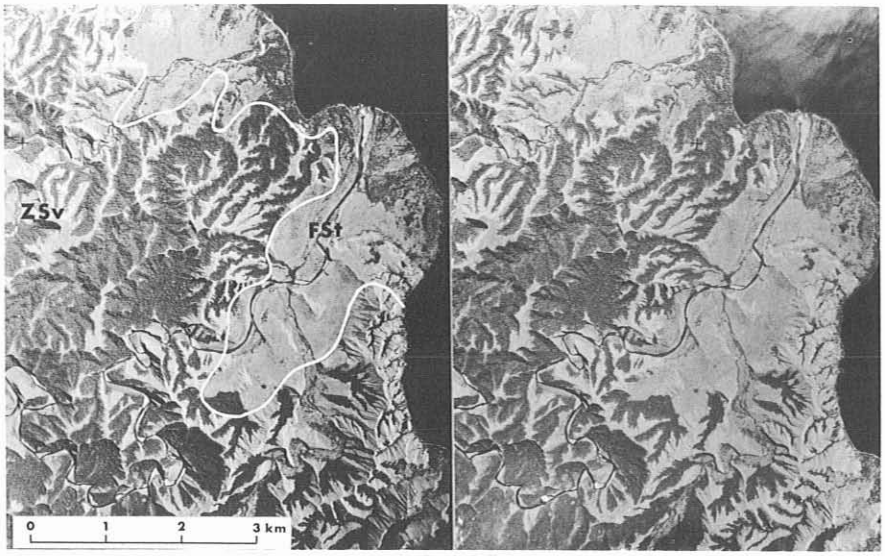


Fig. 1.—Land-form types: FSt, ZSv. Climatic zone: II

Coastal area near Raba Raba, south of Cape Vogel peninsula. The terraced fans of FSt land-form type have gravelly soils and are covered mainly by grassland and savannah of *Albizia procera*. The fans are sharply bounded by ZSv land-form type: very steep-sided ridges formed on poorly consolidated sedimentary rocks; on this land-form type soils are very shallow and stony and support a vegetation of small-crowned slightly deciduous forest on lower slopes and in valleys, and grassland on ridge crests and upper slopes where the original forest cover has been destroyed by frequent burning. Small accordant flat summit areas represent remnant fan surfaces.

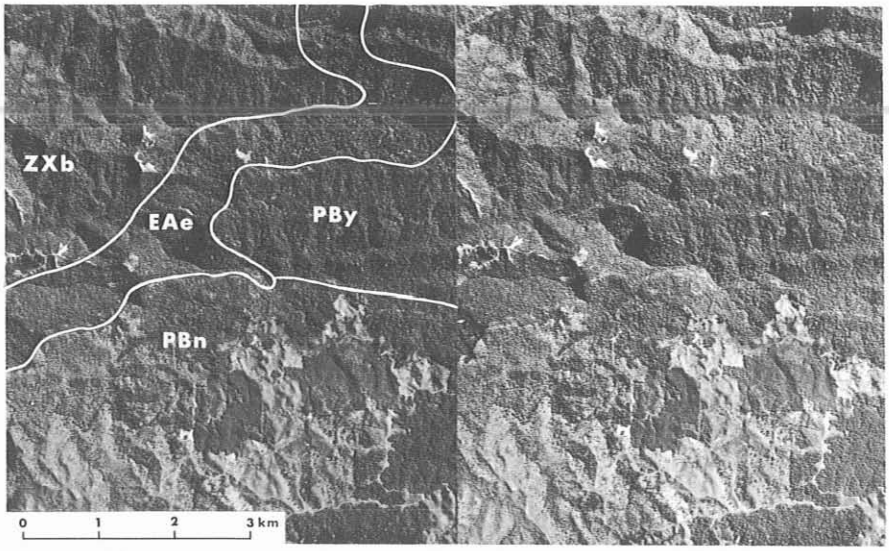


Fig. 2.—Land-form types: EAe, PBn, PBy, ZXb. Climatic zone: III. Altitude: 500–700 m.

Sogeri plateau north-east of Port Moresby. PBy and PBn land-form types are dissected plateau surfaces on basaltic volcanic rocks, mainly agglomerate. PBy is more deeply dissected and consequently has more relief than PBn. The vegetation consists of small-crowned forest with *Castanopsis* and *Casuarina*, rubber plantations, grassland, and eucalypt savannah. The plateau is bounded by the very steep to precipitous slopes and cliffs of EAe land-form type. In the north, hill ridges with prominent spurs (ZXb land-form type), formed on sedimentary and igneous rocks, are covered by small-crowned forest with, towards the south-west, patches of grassland and eucalypt savannah.

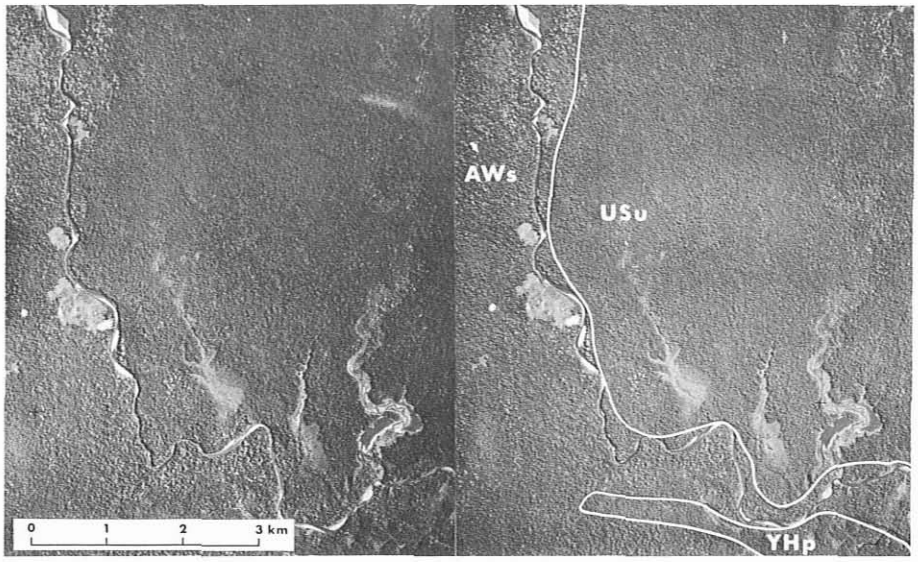


Fig. 1.—Land-form types: AWs, USu. Climatic zone: III. Altitude: 25 m.

Mori River north-east of Cape Rodney. USu land-form type consisting of very gently undulating terrain of very low relief on unconsolidated sediments is covered by dense small-crowned forest. Swampy areas occupying drowned valleys are a characteristic feature of USu. The soils are commonly rich in gravel consisting of lateritic iron concretions and are generally poorly drained. In contrast, the alluvial plain of AWs land-form type to the west has large- to medium-crowned forest and is moderately to well drained.

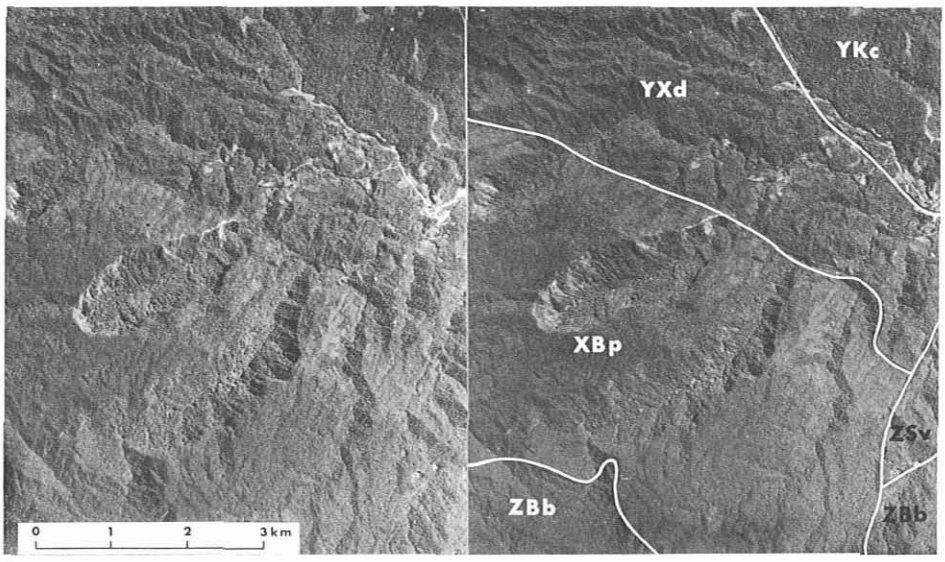


Fig. 2.—Land-form types: XBp, YKc, YXd. Climatic zones: III and IV. Altitude: 200–1000 m.

Tameo River south of Cape Frere. XBp land-form type is a closely dissected convex planar surface, part of a large dome of mainly early Tertiary basaltic rocks. The dissection is generally shallow, except for several deep amphitheatre-headed gorges. *Casuarina* and *Castanopsis* are common in the dark-toned small-crowned forest canopy. YXd land-form type to the north consists of closely spaced ridges and spurs of moderate relief on Tertiary sedimentary and igneous rocks. YKc land-form type in the north-east consists of limestone scarps and stepped dip slopes.

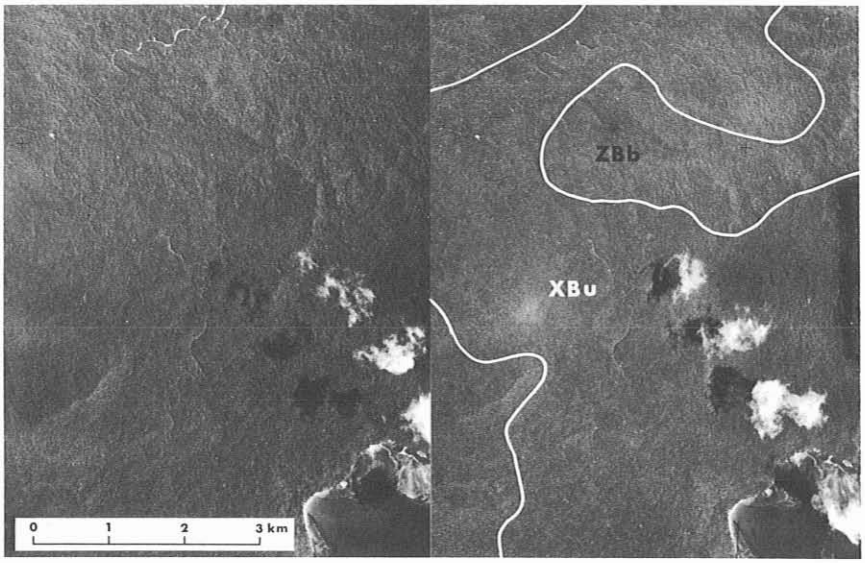


Fig. 1.—Land-form types: XBu, ZBb. Climatic zone: III.

South coast west of Guauguarina Bay. The irregularly undulating terrain and rounded ridges of low relief (XBu land-form type) are formed on basaltic volcanic rocks and covered by dense, commonly tall, small-crowned forest in which dipterocarps, especially *Hopea*, are common. The higher ridges, mapped as ZBb land-form type, have a similar vegetation.

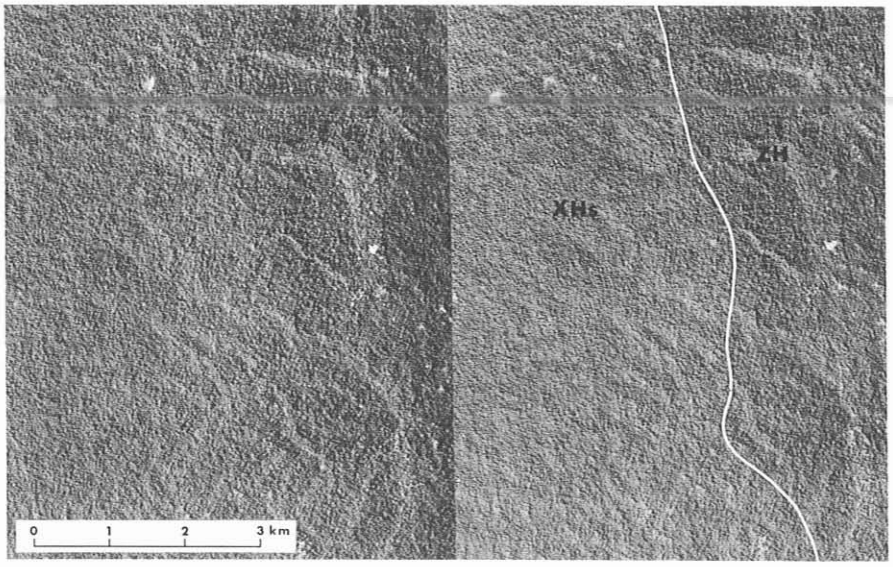


Fig. 2.—Land-form types: XHs, ZH. Climatic zone: III. Altitude: 75–150 m.

Kurai Range west of Monkton River. The intricate pattern of accordant low hill ridges with steep to moderate side slopes (XHs land-form type) is covered by generally small-crowned and locally open forest. ZH land-form type to the east, consisting of asymmetrical high hill ridges and spurs, is the western part of a deeply dissected anticlinal structure. Both XHs and ZH are formed on sedimentary rocks.

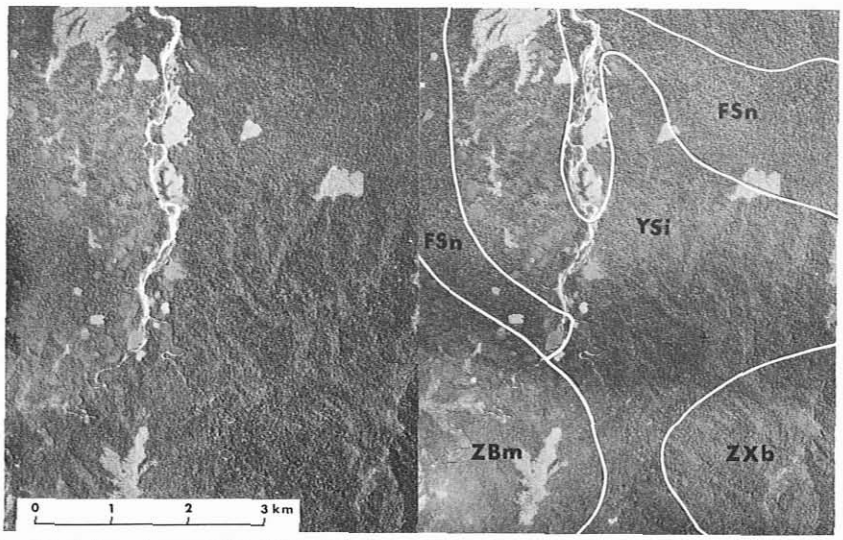


Fig. 1.—Land-form types: FSn, YSi, ZXb, ZBm. Climatic zones: II and III. Altitude: 300–500 m.

Urere River, south side of the Musa basin. YSi land-form type, consisting of irregular ridges of moderate relief on poorly consolidated sedimentary rocks, contrasts with ZXb land-form type, consisting of branching ridges of high relief on sedimentary and igneous rocks. ZBm land-form type, formed on mainly basaltic volcanic rocks, differs from ZXb in having generally gentler slopes. Smooth, very gently sloping alluvial fans of braided rivers form FSn land-form type. The vegetation consists of medium-crowned slightly deciduous forest and locally eucalypt savannah. On the fans the forest is large-crowned and tall and has locally been replaced by tall grassland.

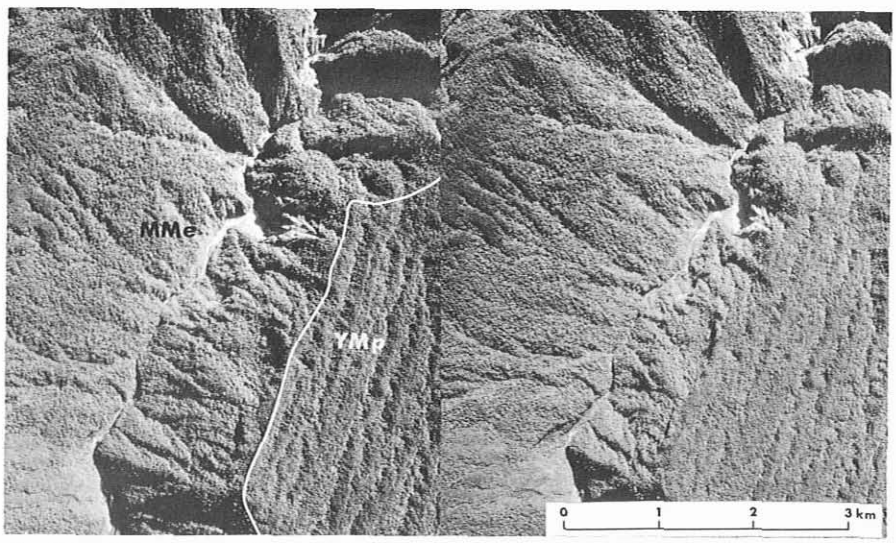


Fig. 2.—Land-form types: YMp, MMe. Climatic zones: IV and V. Altitude: 200–1800 m.

Northern slopes of the Goropu Mountains east of Mt. Suckling. YMp land-form type, consisting of closely spaced parallel valleys separated by narrow steep-sided accordant ridges, is part of the relatively shallowly dissected Goropu Mountains dome. *Nothofagus* predominates in the canopy of the lower montane forest cover. To the west is the very deeply dissected part of the dome mapped as MMe land-form type, consisting of extremely steep to precipitous mountain ridges and spurs, with numerous landslide scars. *Nothofagus* locally forms pure tall stands showing up as smooth dark tones. Both land-form types are formed on metamorphic rocks, mainly schists.

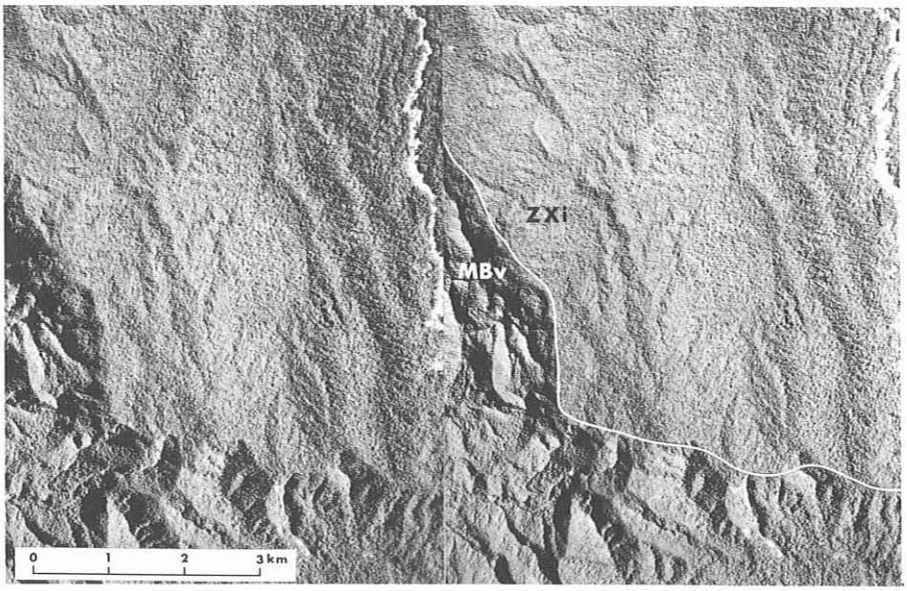


Fig. 1.—Land-form types: ZXi, MBv. Climatic zone: V. Altitude: 1900–2200 m.

Mountains south-west of Kosipi. The subparallel to branching hill ridges of ZXi land-form type contrast strongly with the steeper and more mountainous terrain of MBv land-form type. *Nothofagus* dominates the forest in the north-east. Part of the road between Woitape and Kosipi is shown in the east. ZXi is formed on basalt and probably also sedimentary rock, and MBv is formed on mainly basaltic volcanic rocks.

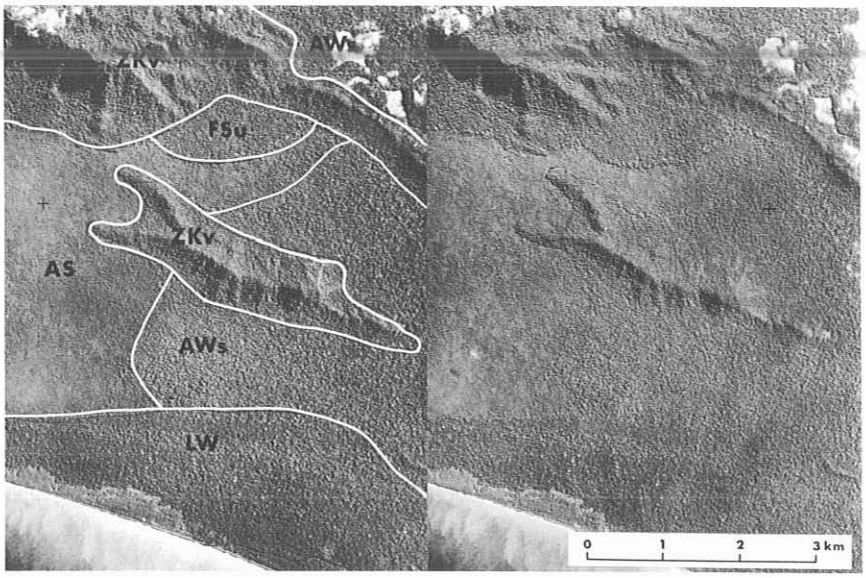


Fig. 2.—Land-form types: LW, AS, AWs, FSu, ZKv. Climatic zone: III.

South coast between Bailebu and Bonua Rivers. The very steep knobbly strike ridges of ZKv land-form type are formed of limestone and associated chert. They are flanked by permanent swamp (AS) and moderately well to imperfectly drained alluvial plains (AWs). Small fans, mostly too small to be mapped (FSu), occur locally at the foot of the hills. Densely forested beach ridges (LW) line the coast; the forest has locally been replaced by coconut plantations (pale tone).

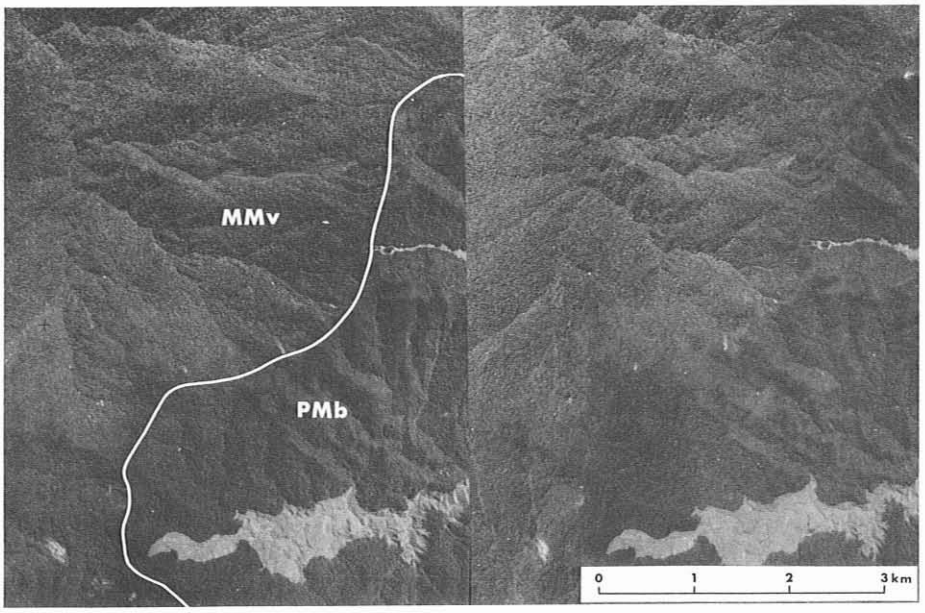


Fig. 1.—Land-form types: PMb, MMv. Climatic zone: V. Altitude: 2300–3100 m.

Mt. Obree in the Owen Stanley Range. The vegetation on the deeply dissected plateau that makes up PMb land-form type consists of dark-toned coniferous lower montane forest, with pale-toned tree-fern savannah on the lower slopes of some V-shaped valleys. Several landslip areas are visible on the very long steep slopes of MMv land-form type to the west where the dominant vegetation is lower montane forest. The country rocks are schists of the Owen Stanley Metamorphics.

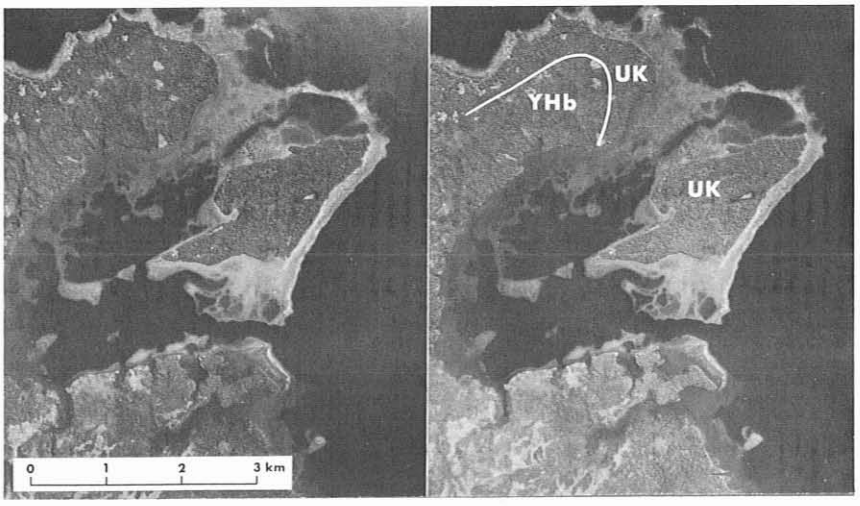


Fig. 2.—Land-form types: UK, YHb. Climatic zone: II.

North coast east of Awaiama Bay. The flat to gently undulating terrain of UK land-form type represents raised coral reefs; they are themselves flanked by present-day fringing reefs. YHb land-form type is formed mainly on consolidated sedimentary rocks. Gardens and areas of grassland show as pale patches within the general dark-toned forest cover.

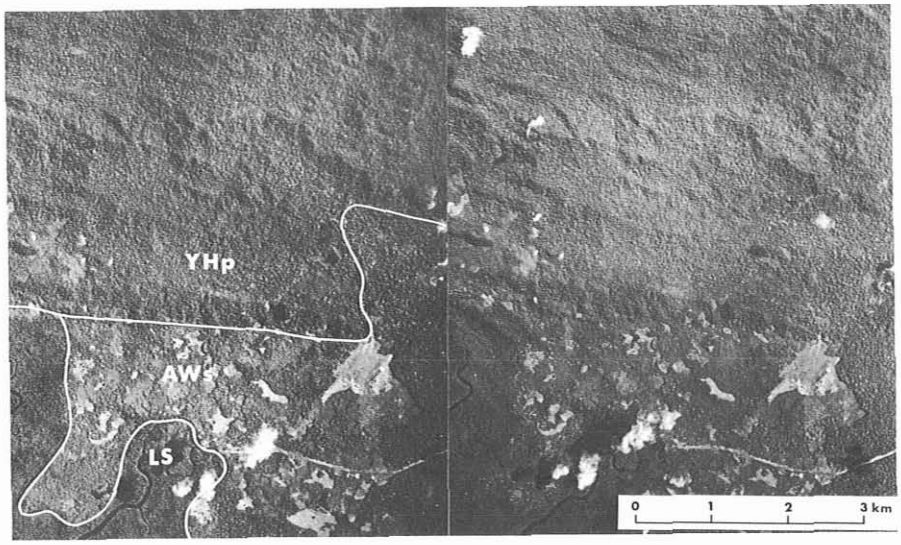


Fig. 1.—Land-form types: LS, AWs, YHp. Climatic zone: III.

South coast north of Cape Rodney. The parallel and branching ridges of YHp land-form type are formed of fine-grained sedimentary rocks, including calcareous siltstone and chert. They are bounded to the south by well-drained heavily gardened alluvial plains of AWs land-form type. The northern end of coastal mangrove swamps of LS land-form type is visible in the south-west.

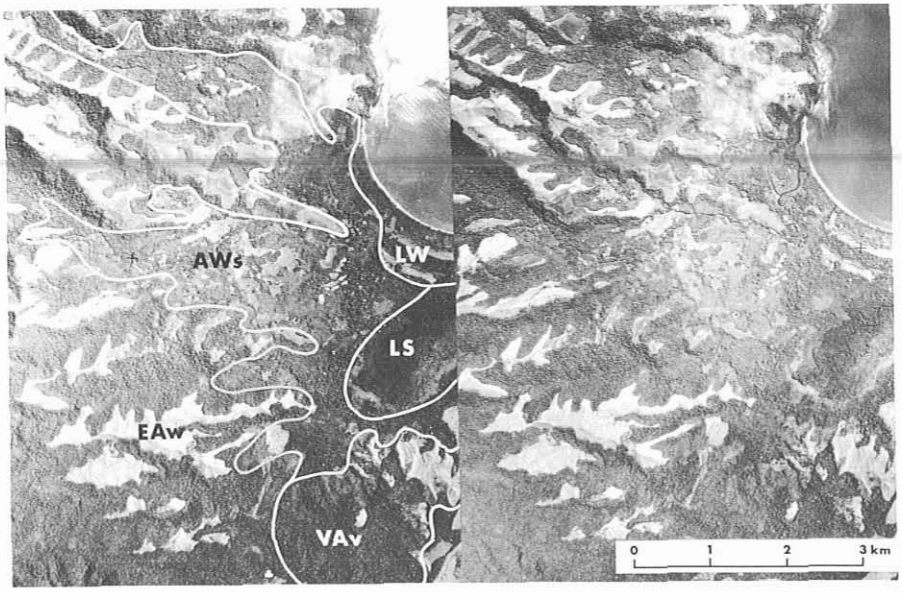


Fig. 2.—Land-form types: LS, LW, AWs, VAv, EAw. Climatic zone: II.

North coast, eastern slopes of Hydrographers Range. EAw land-form type, part of the dissected lower flanks of the deeply eroded Hydrographers strato-volcano, is characterized by very long subparallel ridges separated by U- and V-shaped valleys. On the crests the original forest cover has been destroyed by man-induced fires and replaced by grassland. VAv is a relatively little-eroded volcanic cone. The volcanic terrain is sharply bounded by the alluvial plain (AWs) to the east. Mangrove swamps (LS) and beach ridges (LW) occur along the coast.

Fig. 1.—Boulder bar in upper Bonua River, AWu land-form type. The highest parts of the bar are being colonized by grasses, mainly *Saccharum spontaneum*. Even-aged stands of *Casuarina cunninghamiana* have developed on sites that are above the level of frequent flooding.

Fig. 2.—Terraced fans of FSt land-form type near western end of Goodenough Bay. Deciduous trees are mainly *Pterocarpus indicus*.

Fig. 1.—The larger of the Myola "lakes" in the Owen Stanley Range near Mount Kenevi, north-east of Port Moresby, 2000 m a.s.l. The intermontane basin, FSa land-form type, is formed of fans, covered partly with lower montane forest, partly with low grassland, that pass downslope into narrow swampy grass-covered flood-plains. The hills at top left are part of an irregular summit surface mapped as PMi land-form type.

Fig. 2.—Crater lake of Waiowa volcano, formed during an eruption in 1943–44. A forest of *Casuarina cunninghamiana* and lower *Neonauclea* and *Timonius* has developed on the blocky sides of the crater since its formation. In 1969, when the photo was taken, some of the casuarinas had girths over 1·40 m and heights over 35 m.

Fig. 1.—Slope on the east side of the Goropu Mountains dome showing the close parallel dissection characteristic of YMp land-form type. The grassland consists mainly of *Themeda australis* and *Eulalia leptostachys*; emergent culms are of *Ophiuros tongcalingii*. The very steep-sided ridges on the right belong to ZSv land-form type.

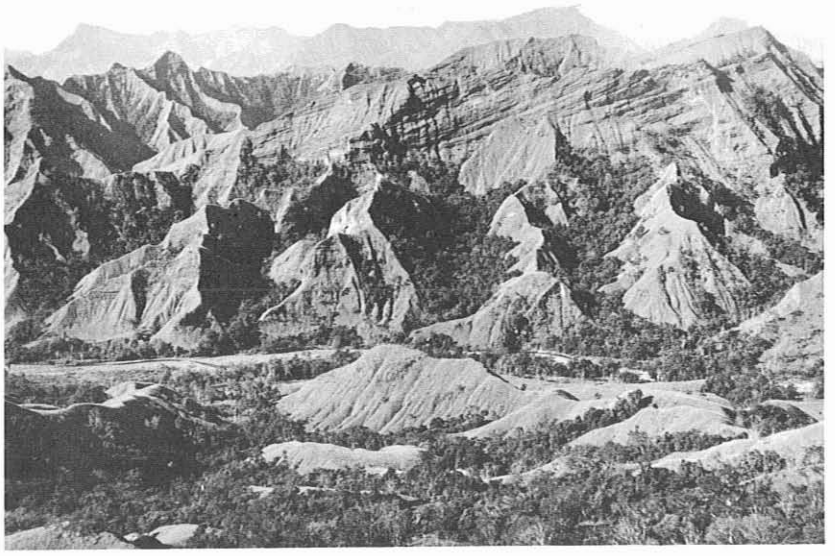


Fig. 2.—Hills of ZSv land-form type with knife-edged ridges and extremely steep side slopes on the north coast near Raba Raba. The hills are formed of poorly consolidated coarse-grained fan deposits that have been uplifted and then deeply incised by rapidly eroding streams.

Fig. 1.—Rounded grass-covered limestone hills of ZKr land-form type, near Kwikila, south-east of Port Moresby. The grassland consists mainly of *Themeda australis*. Remnants of small-crowned low slightly deciduous forest occur locally along drainage lines.

Fig. 2.—MMe land-form type, Mt. Suckling. The broad crest in the foreground, on schist, is at 3060 m a.s.l. and has a vegetation of tussock grassland. Behind are extremely steep slopes with bare landslide areas and lower montane forest which is rich in *Araucaria*.

Fig. 1.—Steep rounded ridges with conspicuous spurs of ZXb land-form type, here formed mainly on basaltic volcanic rocks, east of Kemp Welch River. The grassland consists mainly of *Themeda australis*. Remnants of small-crowned slightly deciduous forest are preserved on lower slopes and in valleys. A patch of eucalypt savannah occurs on the low ridge in the centre of the photo.

Fig. 2.—"Screw palm" in open pandan savannah with undergrowth of ferns and grasses on a broad ridge south of Milne Bay, 100 m a.s.l.