General Report on Lands of the Buna–Kokoda Area, Territory of Papua and New Guinea

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PART I. INTRODUCTION

By H. A. HAANTJENS*

I. GENERAL

The survey of the Buna–Kokoda area was the first of a series of surveys to be carried out in Papua and New Guinea by the Division of Land Research and Regional Survey of CSIRO at the request of, and in cooperation with, the Commonwealth Department of Territories and the Administration of the Territory of Papua and New Guinea.

The objectives of these surveys are to describe, classify, and map the inherent land characteristics of the country — including its surface geology, topography, soils, and vegetation — and broadly assess the land-use potentialities by consideration of these characteristics in relation to the climate, the present land use, and the edaphic requirements of various crops. The concepts on which these surveys are based, notably that of team work by scientists of different disciplines and that of land systems as units of mapping and description of country, have been more fully discussed by Christian (1952, 1958).

Because of pressure of subsequent work, absence of complete air-photo cover for several years after the survey, and consequent lack of base maps, the publication of this report has been long delayed. It has benefited from much experience in editing and presenting the information gained in later preliminary reports from surveys in Papua and New Guinea and published reports on surveys of the mainland of Australia. Yet with one exception nothing has been added to or subtracted from the factual data as they were collected in the field and analysed, correlated, and described in the early draft stages, now seven years ago. The exception is a small number of changes in the land systems of the mountainous western part of the area which could be investigated only very superficially during the survey. These alterations were necessary and possible after some later geological work had been carried out by officers of the Bureau of Mineral Resources, Geology, and Geophysics. Thus, although the general lay-out and set-up of the report are in line with present practice in the Division, the actual contents represent the level of experience and the way of thinking 10 years ago.

The area surveyed (Fig. 1) covers approximately 2700 sq miles and includes a very large part of Popondetta subdistrict and small parts of the Kokoda subdistrict in the Northern District of the Territory of Papua.

At the time of the field survey recent vertical aerial photography at a scale of about 1 : 36,000 was available roughly for the area east and south of the Kumusi River and at 1 : 45,000 for most of Opi River sheet. A large part of the remainder of the area was covered by generally poor trimetrogon wartime runs flown at various heights and directions. Other areas, particularly in the mountains, were not covered at all.

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Wartime military map sheets at a scale of one mile to an inch were available for most of the area, except for Gira River, Ioma, and Mt. Parkes. The reliability of these maps varied greatly and was commonly rather low, because of deficiencies in the air-photos on which they were based and geographical changes after the war and after the eruption of Mt. Lamington.

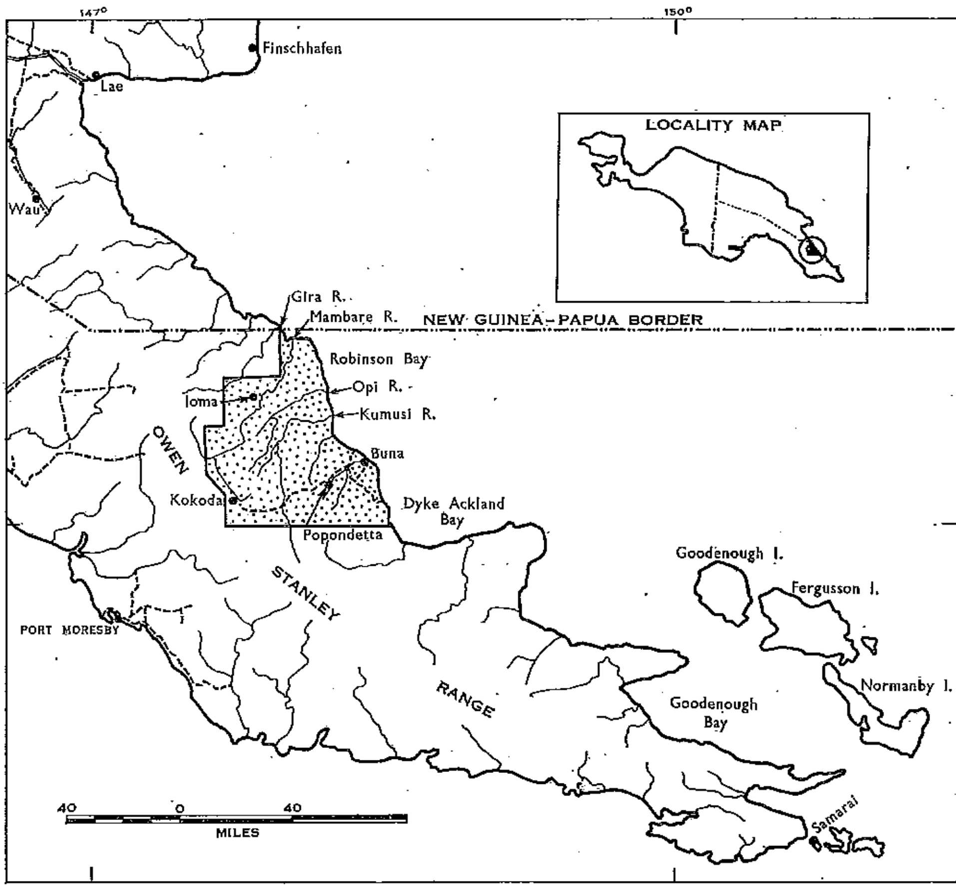

Fig. 1.—Location map.

After the survey most of the area was rephotographed in stages by Adastra Airways Pty. Ltd. at scales of 1 : 40,000 to 1 : 50,000 at sea-level. Danawatu, Menga, Oro Bay, and Popondetta sheets were flown in 1953, Ioma and Mt. Parkes sheets in 1954, Douglas Harbour and Kokoda sheets in 1961. The base map at a scale 1 : 250,000 used in this report was prepared from these recent photographs by the Division of National Mapping, Department of National Development, Canberra.

Field operations lasted from July 1 to October 4, 1953. Traverses made by the main party during this period are shown on an inset to the accompanying map. Many trips of one to three days were made by jeep and on foot radiating from base camps at Popondetta, Inonda, and Kokoda. Longer excursions on foot, by boat, and by canoe were made by the main party along the lower Kumusi River and to Robinson

Bay, and by the geologist round the south of Mt. Lamington, down the Mambare and Gira Rivers to Douglas Harbour, and down the Yodda valley to the Chirima–Mambare junction.

The field party consisted of G. A. Stewart, leader, S. J. Paterson, geologist/geomorphologist, H. A. Haantjens, pedologist, B. W. Taylor, plant ecologist, and R. D. Hoogland, plant taxonomist. K. Gorringe of the Department of Agriculture, Stock and Fisheries, Port Moresby, and M. D. Keary, of the Department of Native Affairs, were seconded to the party for the purposes of general assistance and liaison with the administration and local population. A. J. Hart of the Department of Forests was seconded as a member of the team to report to his department on the forest potential of the area. In addition J. S. Womersley, J. MacDonald, and J. Cavanagh of the Department of Forests and G. K. Graham of the Department of Agriculture, Stock and Fisheries assisted the party in visits in the field.

II. References

Christian, C. S. (1952).—Regional land surveys. *J. Aust. Inst. Agric. Sci.* **18**: 140–6.

Christian, C. S. (1958).—The concept of land units and land systems. Proc. 9th Pacific Sci. Congr., 1957. Vol. 20. pp. 74–81.

PART II. SUMMARY DESCRIPTION OF THE BUNA–KOKODA AREA

By H. A. Haantjens*

This account of the area gives a composite and simplified picture based on the data brought together and interpreted by the authors of the subsequent parts.

I. Climate

The area falls into the tropical rain forest climatic type of Köppen. Recorded average annual rainfall ranges from 120 to 150 in. (Part IV) but there are indications that precipitation is somewhat lower in some lowland areas and it may well be somewhat higher in the mountains. Although there is a marked seasonality in the rainfall, it rarely drops below 5 in. in the driest months. Drought limits plant growth only on rare occasions and in restricted areas where a lower rainfall combines with sandy or shallow soils. Temperatures rarely exceed 95°F and seldom fall below 70°F at sea-level, but there appears to be a gradual drop of 3°F per 1000 ft increase in altitude. Humidity is high throughout the year, winds are mostly gentle, and there is generally extensive cloud cover in the afternoon and early morning.

II. Land Forms

The area is characterized by great variation in land form and by tremendous differences in relief. This variation is primarily caused by tectonic movement in Plio-Pleistocene times and by volcanic activity in the Pleistocene and Recent periods rather than by cyclic erosional processes. However, detailed land forms are strongly determined by erosion, notably the rapid down-cutting of numerous streams and formation of irregular steep slopes by landslips, leading to very sharp crested ridges.

A large part of the area is mountainous (6000 ft and over) and very rugged, but it has three different aspects. In Misima land system it presents a landscape of extremely steep, massive, parallel ridges with abrupt frontal boundaries, which is the result of rapid dissection of recently and strongly uplifted folded metamorphic rocks (Plate 1, Fig. 1). In Botue land system, which owes its relief to intrusion as well as block faulting of basic igneous rock, the mountains have less abrupt boundaries and less steep slopes, whilst the angular drainage pattern is strongly controlled by joints in the rock mass. Some considerable summit areas appear as dissected plateaux and these are probably remnants of an ancient topography existing before the major uplift. The third mountain land system (Hydrographers) represents a severely dissected, extinct volcano, which is still recognizable as such by its skyline (Plate 2, Fig. 1) and its radial drainage pattern.

Fringing the main mountain masses and occurring more in isolation in the north-eastern corner of the area are extensive hilly zones which generally have the greatest relief where they are folded against the mountains, as in Hegahorte land system.

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Other hill complexes in close association with the mountain zone are those of Oivi and Komondo land systems. These are restricted to a major tectonic feature of the mountain zone—the Yodda–Kokoda fault trough valley and its eastern continuation. Extremely intricate patterns of low hills with steep slopes have been carved by minor streams out of nearly horizontally bedded volcanic and sedimentary rocks in the north of the area (Mt. Green and Iauga land systems). In the latter land system the hills form higher plateau areas bound by young fault lines. The lowest part of Iauga land system is virtually the only hilly area with a predominance of gentle rather than steep slopes.

The third major relief element in the area is Mt. Lamington volcano (Plate 1, Fig. 2; Plate 2, Fig. 1), which combines in the one large topographic unit a mountainous summit area of over 5000 ft including dissected lava flows and adventive features (Lamington land system), sweeping, gentle, but strongly dissected middle slopes of ash and lahar deposits between 400 and 3000 ft (Hamamutu, Higatura, and Awala land systems), and shallowly but densely dissected volcanic plains (Eundi and Bohu land systems) between 100 and 800 ft altitude. Radiocarbon dating of a charred wood sample makes it likely that volcanic activity began in late Pleistocene time, with the main build-up taking place in the Recent period and continuing today. The catastrophic eruption of early 1951 caused extensive cover by volcanic ash of the upper slopes and the choking of valleys with volcanic debris (Plate 2, Fig. 2; Amboga land system). A fractured lava dome rose in the central crater area to give the mountain its present height.

The remainder of the area consists of plains ranging from strongly dissected piedmont terraces to permanently waterlogged peat swamps. The terraces (Plate 1, Fig. 1; Kokoda and Ioma land systems) are found discontinuously along the foot of the Owen Stanley Range and the eastern margin of the Ajule Kajale Range. They occur as steep-sided remnants and large plains well above flood level, or they have been dissected into steep low ridges. Their age is probably late Pleistocene.

Alluvial plains of volcanic origin occupy large funnel-shaped areas north-east of Mt. Lamington. Their upper parts (Popondetta and Penderetta land systems) form sandy, high, and markedly dissected outwash fans (Plate 3, Fig. 1) but their lower parts have a more normal flood-plain character (Hanau land system) and include waterlogged distributary plains (Sananada land system) where rivers draining Mt. Lamington are unable to develop proper river mouths and discharge much of their water and silt load via a system of distributary channels. The sequences in these volcanic plains are similar to, but on a vastly larger scale than, those found in the most recent, water-transported, eruption deposits (Plate 4, Fig. 1) of Amboga land system.

Other depositional plains are true flood-plains. In Ilimo land system they are characterized by unusually steep gradients, where deposition took place in front of the rapidly down-wearing Owen Stanley Range. In Deunia land system they form narrow flood-plains and lower terraces as well as distinct levees along the lower reaches of the major rivers in the large lowland plains. Warisota and Ambasi land systems represent small flood-plain areas (Plate 3, Fig. 2) of special character, associated respectively with the Hydrographers and Iauga land systems. The most extensive, generally poorly drained, but most important flood-plains in the area have been mapped as Sagere land system deposited mainly by the Kumusi and Opi Rivers.

In the large area between the eastern foothills, the Iauga plateau, and the volcanic plains the rivers do not carry enough sediment load to build up an alluvial plain, so that vast areas of raw peat could form between the levees of the major rivers and the coast (Koena land system). These swamps (Plate 8) have a water-table permanently at the surface. On their southern margin and scattered through the coastal belt of the volcanic depositional plains occur mineral swamps (Plate 7) of Ambi land system as a transition to the alluvial flood-plains.

The plains are bounded on the coast by strand plains which are only significantly developed in areas of strong sedimentation, that is, near the mouth of major rivers and along the edge of the aggrading volcanic depositional plains. Most of the strand plains consist of parallel beach ridges (Buna land system), but small areas are tidal mangrove flats (Killerton land system).

III. Soils

The great variety of rock types and land forms in the area has produced a complex and varied soil pattern, upon which no single soil-forming factor has exerted a dominant influence. The most important kinds of soil are reddish, strongly weathered and leached clay soils, brown and black volcanic ash soils, and alluvial soils. The red soils represent the most advanced stage, and probably the zonal trend, in soil formation in the area. The volcanic soils cover large areas, are generally fertile, and have interesting pedological characteristics. The large extent of alluvial soils reflects the young history of the area and the activity of erosional processes in shaping the land forms. These soils are also of great agricultural importance. In addition to these three kinds of soil there are little-weathered but strongly leached slope soils covering large areas of mountains and hills, gleyed clay soils associated with reddish clay soils on gentle hill slopes, and poorly decomposed peat soils on large, swampy flood-plains.

The reddish soils occur on all rocks of Pleistocene age or older, including the piedmont terraces of Kokoda and Ioma land systems. Their absence on land surfaces that are certainly younger than Pleistocene and their predominance on surfaces considered to be late Pleistocene suggest that they date from this period. Most reddish soils are characterized by yellow-brown and generally coarser-textured horizons above a red heavy clay subsoil. Thus they appear to be intergrades to red podzolic soils. Some, restricted to basic rocks, are uniform, dark reddish heavy clays. Although not plastic in relation to their high clay content, these soils are generally compact and lack the friability and porosity associated with latosols. Only one soil family, restricted to very wet areas in and near the Yodda valley, has the physical properties of a latosol and gibbsite as prominent clay mineral rather than kaolinite or metahalloysite as in the red soils. All these soils are strongly acid and unsaturated and have high C/N ratios. The cation exchange capacity is low and magnesium dominates the exchangeable cations in the subsoil.

Various kinds of shallow, gleyed, plastic clay soils are associated with the red soils on the lower and more gently sloping parts of the Iauga plateau. They have developed on truly sedimentary rocks of volcanic origin.

Considering the rapid geological erosion in hilly and particularly in mountainous areas, it is not surprising to find that strongly weathered soils do not form a continuous cover. They are restricted to sites that have not been strongly disturbed, i.e. mainly ridge crests and gentle slopes. On steep land undifferentiated slope soils are prevalent. These consist of rather leached and weathered brownish clayey material of variable depth, with few to many rock fragments, and without a clearly developed soil profile because of intermittent or gradual downslope movement.

The volcanic soils form a much more heterogeneous group, because of differences in weathering status and trend of soil formation, although they are clearly related in mineral composition and general morphology. They all have strongly developed, very dark, humic A_1 horizons, which overlie friable brown clay subsoils, yellow-brown to olive-brown sandy clay loam horizons, or dark grey sand.

Soils on airborne ash, generally above 1000 ft, rather resemble the ando soils of Japan or certain yellow-brown loams of New Zealand in that they are highly organic, strongly leached though only moderately weathered, have a high cation exchange capacity, and are characterized by the predominance of an amorphous clay mineral. Such soils occur mainly on the middle slopes of Mt. Lamington, but also on ash-blanketed flats and gentler slopes in Kokoda and Botue land systems. Some soils, on clearly water-transported ash at low altitude, are more weathered than the previous category, yet they are much less leached. They resemble brown forest soils. Very sandy soils with black topsoils that are neither leached nor weathered occur on the volcanic outwash fans north-east of Mt. Lamington (Popondetta and Penderetta land systems). These resemble prairie soils in many respects.

Generally the volcanic soils are characterized by moderately high P_2O_5 content, low C/N ratios, and considerable amounts of weatherable minerals. The exchangeable cations are clearly dominated by calcium.

The alluvial soils covering the extensive flood-plains are for the most part only stratified sediments, mainly of intermediate texture, locally very sandy or very clayey. These soils have only a weakly developed A_1 horizon, although the organic matter content can be unexpectedly high. Many profiles are mottled or gleyed at depths of less than 4 ft, owing to periodical or permanent waterlogging. The alluvial soils are commonly more acid and unsaturated than expected for such recently deposited materials. However, those derived from the Mt. Lamington volcanics tend to have higher pH and saturation. Magnesium is generally co-dominant with calcium in the exchangeable cations. In association with the alluvial soils raw peat soils occur in the lowest part of the large flood-plain area. They consist mostly of little-decomposed plant remains suspended in water and there are indications that they are acid and infertile.

IV. Vegetation

The overriding influence on the vegetation of the optimal climate for plant growth is reflected in the very strong dominance of forest and woodland vegetation on the most diverse land forms and soils. However, there is much variation both in structure and in floristic composition within this broad group. This is partly clearly related to environmental factors, notably drainage conditions and temperature, but partly the reasons for this variation are not fully understood. The most striking feature of the vegetation is the richness in species, several of which are not botanically known and many of which appear to have a distribution governed more by historical and accidental factors than by stringent ecological requirements.

Mountain slopes and especially ridges above 2500–3000 ft above sea-level are covered by lower montane rain forest, characterized by only two tree layers, rather frequent palms, paucity of epiphytes, and rather dense shrub and ground storeys.

Various types of lowland rain forest that are structurally rather similar but show marked floristic differences cover most of the remainder of the mountains, the hills, and the well-drained high plains and terraces. These forests, more than 100 ft high, with three distinct tree layers, plentiful lianas, epiphytes, and buttress roots, and with a scarce ground layer, show a predominantly regional distribution in floristic composition: *Syzygium* sp.–*Flindersia* spp. association occurs in the Yodda–Kokoda valley and on the mountain slopes to the north and south (Plate 1, Fig. 1). The *Anisoptera kostermansiana–Intsia bijuga* association covers the remaining dissected mountain and hill areas except for the northern part (Iauga plateau), which is covered by the *Anisoptera kostermansiana–Eucalyptopsis papuana–Dillenia nalagia* association. Ecologically it may be interesting to note that these three associations appear to be related with areas of strongest relief and with red clay soils and associated acid slope soils, although in Kokoda and Botue land systems they occur also on volcanic soils. However, the main body of volcanic soils on the dissected, sweeping slopes of Mt. Lamington carries rain forest of the *Pometia pinnata–Chisocheton* sp. association (Plate 5). Probably the best development of rain forest in the area was observed on the fertile well-drained plains of Bohu land system. Again the correlation with soils is not perfect and land form may be an equally important factor, as forest of the same association occurs on the well-drained plains with acid red clay soils of Ioma land system.

The flood-plains are characterized mainly by rain forest of the *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association on poorly-drained and frequently flooded land with much smaller occurrences of *Anisoptera kostermansiana–Pometia pinnata* association on better-drained sites. These forests are generally more irregular in structure, with more open canopies and increasing rattan and pandanus (Plate 6).

With increasingly poor drainage of the plains the forest deteriorates further into fluctuating swamp forest, a low irregular forest with open canopy, tangled vegetation, and common sago palms in the lower storey, or into fluctuating swamp woodland with a fairly homogeneous, dense growth of sago (Plate 7). Such vegetation occurs on swamps with mineral soils in areas that are seasonally inundated. On permanently waterlogged peat swamps forest development is even further impeded and restricted to straggling *Campnosperma* swamp forest, woodland, or savannah (Plate 8). The environmental conditions governing the distribution of these vegetation types on peat are not clear. They form intricate patterns with many transitions and in many places merge into the most simple type in this vegetation sequence: herbaceous swamp communities dominated by *Thoracostachyum sumatranum* and *Hanguana malayana*.

The coastal vegetation is characterized by mangrove forest and woodland on small tidal flats and by a very narrow strip of generally secondary coastal forest of the *Barringtonia asiatica–Pterocarpus indicus* association on beach ridges.

The two major disruptive influences on this simple natural vegetation pattern have been man and volcanism. Not only has widespread shifting cultivation in the Kokoda valley, on the slopes of Mt. Lamington, and in many flood-plain areas reduced the original rain forest to secondary forest and various stages of forest regrowth (Plate 1, Fig. 1; Plate 3, Fig. 2; Plate 5), but locally this practice, aided by fire, has led to the establishment of man-made grassland,* preserved as such by regular grass fires. Several places were observed where the forest regrowth was so stunted and so invaded by ferns and grasses that conversion into grassland appeared imminent. By far the greatest extent of grassland occurs on the very sandy soils of the north-eastern volcanic outwash fans in a relatively dry part of the area (Plate 3, Fig. 1). There appears to be a definite correlation between the type of grassland and the nature of the habitat. Tall grassland dominated by *Saccharum spontaneum* is most widespread and occurs on well-drained, deep, fertile soils throughout much of the area. Short grassland dominated by *Themeda australis* is found on dry, infertile foot slopes of Hydrographers land system near Oro Bay. In Iauga land system short grasslands dominated by *Imperata cylindrica* and *Apluda mutica* cover much of the shallow, poorly-drained soils on gentle hill slopes.

The boundary of destruction of the forest vegetation as a result of the 1951 eruption of Mt. Lamington is shown on an inset to the accompanying map. The subsequent regrowth communities have a strong successional character and are described in this report in the stage they had reached in August 1953, when they were still predominantly herbaceous. Regrowth was more rapid in areas that had suffered mere devastation of the vegetation than in those which were also covered with considerable amounts of volcanic ash or laharic deposits (Plate 1, Fig. 2). However, the waterlogged banjir deposits in the distributary areas of rivers near the coast were quickly covered by vigorous herbaceous vegetation (Plate 4, Fig. 1).

V. Settlement and Communications

According to the 1960–61 census there were approximately 28,500 indigenous people in the area, an increase of 1500 over the 1952–54 census. The overall population density is thus slightly higher than 10 per sq mile, which corresponds with the general average of the Territory of Papua and New Guinea. This population is not evenly distributed but is concentrated in the coastal parts of the volcanic plains from Oro Bay to the Kumusi River mouth, the coastal parts of the north-eastern hill zone, the Kokoda valley, along the banks of the major rivers, and, above all, on the north-western slopes of Mt. Lamington, where the density is approximately 60 people per sq mile.

The number of Europeans, though considerably increased over the last 10 years, is very small compared to the indigenous population. It is concentrated in the Administration centres at Popondetta, district headquarters, Kokoda, subdistrict headquarters, and Ioma, a patrol post, the Administration Hospital at Saiho, the Anglican Missions at Popondetta, Sasembata, and Gona, and on a number of plantations from Oro Bay to Kokoda.

* The distribution of the grasslands is shown on the accompanying map.

At the time of the survey European plantation agriculture was restricted to coconuts on a small number of plantations near the coast and to rubber on a few plantations on the northern slopes of Mt. Lamington and in the Kokoda valley. Some plantings of cocoa had just been made. Except for minor trade in copra along the coast indigenous agriculture was limited to shifting cultivation (Plate 5) of subsistence crops, amongst which taro (*Colocasia esculenta*) is dominant (Plate 4, Fig. 2). Since 1953 considerable expansion of tree crop plantings, by both indigenes and Europeans, has taken place. The position in 1961 is given in Table 1, which has been compiled from data supplied by the Department of Agriculture, Stock, and Fisheries in Port Moresby. A small cattle industry has been established near Kokoda by Europeans.

TABLE 1
TREE CROPS IN THE BUNA–KOKODA AREA, 1961

Crop	No. of Plantations		Total Area (ac)		Production (tons)	
	European	Indigenous	European	Indigenous	European	Indigenous
Cocoa	36*	1008	5415*	1497	60†	20†
Coffee (robusta)	1	2180	80	529	36	7†
Coffee (arabica)	—	35	—	10	—	—
Rubber	7	300	2600	100	500	6
Coconuts (copra)	2	Many	420	±440	150	5

* Figure may include certain amount of duplication, as cocoa is locally interplanted with coconuts or rubber.

† Production very low because great majority of trees were not yet fully bearing.

By New Guinea standards the area is fairly accessible. A network of good foot tracks links the administration posts and indigenous villages. However, some of these in the alluvial plains are often boggy or flooded during the wet season. Others in the mountainous areas commonly follow creek beds or are very steep. The lower reaches of the Gira, Mambare, and Kumusi Rivers are important for transport by canoe, whilst the Mambare River is navigable for small motor launches as far as Tamata Creek. There are no means of transportation through the peat swamps of the north and communication with the Iauga plateau is maintained along the beach or by sea. In 1953 the main anchorage was at Cape Killerton, which was connected by a gravel and grass road with Popondetta and Kokoda. All major rivers along this route, including the Kumusi, had to be forded. Several secondary jeep roads branch from this main road. One of these to Oro Bay (Plate 3, Fig. 2) is being developed as an all-weather road with bridges across all rivers en route, linking the best natural harbour in the area, where wharf facilities are to be constructed in due course, with the main agricultural and forestry areas. Grassed DC3 airstrips are located at Popondetta and Kokoda, a small strip at Ioma, and large wartime bitumen strips are situated at Anonda and Embi.

The area does not present major problems in road-building. Road metal is generally available in the form of volcanic and igneous river gravel and boulders and locally in occurrences of fresh basalt and agglomerate. Nowhere do road links need to cross rugged mountain areas. The dense radial dissection of Mt. Lamington necessitates the construction of numerous bridges on roads around the mountain whilst in the flood-plains the bridging of the major rivers will pose the biggest problems. Drainage and flooding problems will have to be solved if roads are to be extended into the low-lying parts of the extensive alluvial plains.

VI. Land Use Potential

As in most areas of Papua and New Guinea there is far more poor than good land but on the gentle northern foot slopes of Mt. Lamington and parts of the flood-plains this area possesses some of the best land in the Territory.

The major factors limiting land use are steepness of slopes and poor drainage and flooding. The first factor virtually rules out any economic utilization of the mountains and restricts potential to forestry and local tree crop plantation or extensive grazing in most of the hill areas. Poor drainage virtually prevents use of the extensive peat swamps and in combination with flood hazards it limits the potential of many flood-plain areas to extensive grazing.

A more moderate limiting factor is the strong dissection of otherwise gentle broad slopes of Mt. Lamington and of the high terraces of Kokoda and Ioma land systems. This generally reduces the efficiency of land use as well as the usable area of land, and precludes any large-scale mechanical operations. As this land is invariably well drained and has physically good soils it appears to be most suitable for tree crop plantations.

Soil deficiencies *per se* are never very serious limiting factors in the area. The leached red clay soils on the high terraces of Ioma land system impose a limitation because of their chemical infertility. The very sandy nature of many soils of the north-eastern volcanic depositional plains makes them susceptible to drought. As in both cases maintenance of productivity depends heavily on the topsoil, areas with these soils are best kept under perennial vegetation such as tree crops or pasture. The peat soils of the large flood-plain swamps appear to be so poor that they would not warrant reclamation even if this were technically feasible.

The best land in the area is found on little-dissected or undissected parts of the foot slopes of Mt. Lamington (Awala, Bohu, Eundi land systems), where suitable topography is combined with fertile soils and good drainage. Small areas of similar land are found on terraces in the Kokoda valley. This land is primarily excellent tree crop land. What appears to be very good flood-plain country is found in the Kumusi–Opi River area (Sagere land system) and in the Kokoda valley (Ilimo land system). The former is generally poorly drained because of lack of streams but drainage improvement appears to be rather simple. These flood-plains are first-class arable land, whilst the Sagere land system appears to offer the best possibilities for rice-growing in the area.

The climate of the area provides for optimal vegetative growth virtually throughout the year. However, the absence of a marked dry season may interfere with mechanical farm operations, in particular harvesting and weed control, whilst cloudiness and wetness may delay maturing and reduce yields of certain crops and favour the spread of virus and fungus diseases.

PART III. LAND SYSTEMS OF THE BUNA–KOKODA AREA

By H. A. Haantjens,* S. J. Paterson,† B. W. Taylor,‡ and G. A. Stewart*

I. Introduction

The 30 land systems mapped in this area are the result of the interpretation and correlation of all data collected by the survey team in the field, and of their extrapolation by interpretation on aerial photographs over the whole of the survey area. Wherever relief is marked, land system boundaries are generally drawn on the basis of geomorphological distinctions. Where relief is not noticeable on aerial photographs, mapping is carried out along vegetation boundaries. The kind of differences in a land-forming factor that are used as a basis for mapping depends to a large extent on the degree of their correlation with other factors. For instance, vegetation is allowed to vary widely within one land system if there are no parallel differences in soils and land forms, whilst in other cases a minor variation in land form may be used to distinguish between two land systems if it is strongly correlated with significant differences in soils and/or vegetation. Soil differences *per se* could not be used in mapping land systems in this area, but they have in some cases indirectly led to a further subdivision based on minor differences in land forms or vegetation in the level parts of the area. Mappable differences on aerial photos are also more apt to be used in actual land system mapping if they are indicative of significant differences in potential for development, be it mineral resources, road-building, or coffee-growing. Thus land systems are flexible units that were defined by Christian and Stewart§ as "areas or groups of areas throughout which there is a recurring pattern of topography, soils, and vegetation". At least for the conditions in New Guinea it seems better to leave out the word "recurring", because many land systems form a particular sequence, exhibited only once in each occurrence. Attention should also be drawn in the definition to the nature of land systems as mapping units on aerial photographs and their variability with mapping scale. Land systems as described in this report are therefore best defined as "natural landscapes with a characteristic pattern of rocks, land forms, soils, and vegetation, which is mappable from aerial photographs at the map scale used".

Land systems as used in reconnaissance surveys of complicated terrain must necessarily be compound mapping units, composed of several elements that are genetically related. These elements have been described in the land systems as units. They may be simple, representing a single slope type, with a single kind of soil and vegetation, or they may be complex, as for example a broad-crested, steep-sided, hill ridge. Nearly all units in this report are complex and it is clear that these are in

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§ Christian, C. S., and Stewart, G. A. (1953).—General report on survey of Katherine-Darwin region, 1946. CSIRO Aust. Land Res. Ser. No. 1.

effect not fundamentally different from land systems, apart from the fact that at the given level of photo-interpretation and mapping they are too small, too indistinct, or too insignificant to be mapped out separately. The similarity in character between land systems and units is best illustrated by the fact that both are identical in land systems with only one unit. The advantage of subdividing the land systems into units is that a much more detailed description of the mapping units becomes possible and that this description can be kept very systematic and straightforward.

II. Grouping of Land Systems

The land systems shown on the accompanying map have been grouped primarily according to their geomorphological affinities (see map reference).

This map serves also as a geomorphological and geological map and the order of the geomorphological units and subunits is very largely determined by the stratigraphic succession in the area. Roughly parallel with this is a decrease in relief from the older to the younger geomorphological units.* Within each of these there is a secondary sequence of decreasing relief which is expressed in the order of the land systems belonging to each geomorphological unit. Within the depositional plains unit age and relief are used only to separate the piedmont terraces subunit from the others, but the latter are distinguished on the basis of the nature of the sediments and their drainage status. In each of these subunits the land systems have been grouped according to deterioration in drainage status. Amboga land system does not fit in well with the geomorphological subdivisions, as part of it was incorporated with the active volcano unit and part with the depositional plains unit. Therefore it has been sandwiched in between these two units on the map reference. In this grouping of the land systems there is no corresponding detailed sequence of soil and vegetation types, although certain broad affinities exist. These are dealt with in Parts VII and VIII.

III. Tabular Description of Land Systems

During the survey of the Buna–Kokoda area most mountainous regions were very little traversed and aerial photography of these parts was commonly nonexistent or very poor until several years later. Thus not enough data are available to distinguish and describe units in Misima, Botue, Oivi, Komondo, Hegahorte, Mt. Green, and Ambasi land systems. The description of these land systems is in very general terms. Although complete, the tabular descriptions of the other land systems are necessarily short. For more detailed descriptions of geological and geomorphological features, soils, vegetation, and land classes the reader should refer to the relevant part of this report.

There are not enough climatic data available to allow valid conclusions to be drawn on the climatic differences between land systems or to use climate as a criterion in defining land systems. The land system descriptions therefore do not contain any climatological information. The only interpretation possible in this direction can be derived from the figures given for elevation, which largely controls the temperature, and from data on the relief. Mountainous areas tend to have somewhat higher rainfall which together with lower temperatures makes for a definitely wetter climate. The strong contrasts in relief do make it likely that the orographic influence on

* The simple fold mountains unit is an exception, having been placed in second position because of age of rocks, although its relief is considerably lower than that of the extinct and active volcano units.

rainfall is larger than would appear from the very limited records available. Locally vegetation features also seem to point in this direction.

The terms under the heading "drainage status" are used in the following sense, which is largely in line with the definitions given in the 1951 Soil Survey Manual of the U.S. Department of Agriculture:

Excessively drained.—Water is removed from the land very rapidly. It is too dry for significant periods.

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

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

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

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

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

Wherever possible the land system descriptions are illustrated by block diagrams or plans (drawn by Mrs. N. Geier), the latter for land systems with very little relief. Some care should be exercised in the interpretation of these illustrations, because:

(1) They are drawn at various scales. To assist the reader, the approximate scale is indicated and approximate height figures give an idea of the relief. Each diagram should be viewed in relation to these scale indications, otherwise a wrong impression may be created.

(2) It is normally difficult to assign to the units the same relative area in the block diagram as they occupy in the whole of the land system. In general, large units are shown too small, small units too large.

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

The areas of the land systems were determined on the map with a dot grid with 25 dots per sq centimetre (169/sq inch). The relative areas given for the units are only rough estimates, based on field observations and photo-interpretation. Terms such as "large" and "small" have no absolute connotation but are only used in relation to the total area of each land system.

(1) Misima Land System (110 sq miles)

Rugged, forested mountains, forming foot zone of Owen Stanley Range (Plate 1, Fig. 1). They rise steeply from 800 up to well over 3000 ft.

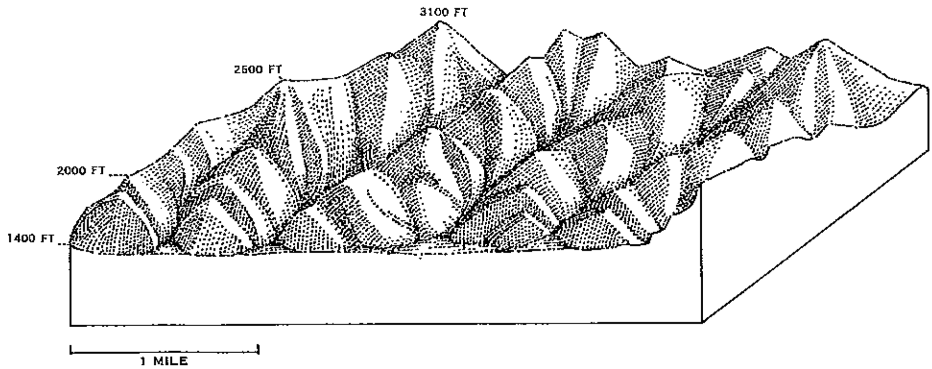


Diagram illustrates only the lower slopes of the Owen Stanley Range.

Geology.—Owen Stanley metamorphics: schist and gneiss, strongly folded and uplifted, bounded in the north by a major fault.

Geomorphology.—South–north trending, massive and smaller mountain spurs with faceted very steep dip slopes along northern boundary. Sharp crests and very steep slopes dissected by many shallow gullies. Coarse-textured pattern of more or less parallel torrential streams in very deep V-shaped valleys.

Soils.—This land system has been classified as rough mountainous land. Truncated weathered red clay soils of Sengi family were observed on some small shoulders.

Vegetation.—On lower slopes mature rain forest, secondary forest, and regrowth of *Syzygium* sp.–*Flindersia* spp. association. Lower montane rain forest will be found at higher altitudes.

Land Class.—Largely VIIIe,so with pockets of VII–VIe,so. Important catchment area.

(2) Botue Land System (460 sq miles)

Forested mountain complex of Ajule Kajale Range. Ridges generally attain a height of 3000 to 4000 ft, locally higher.

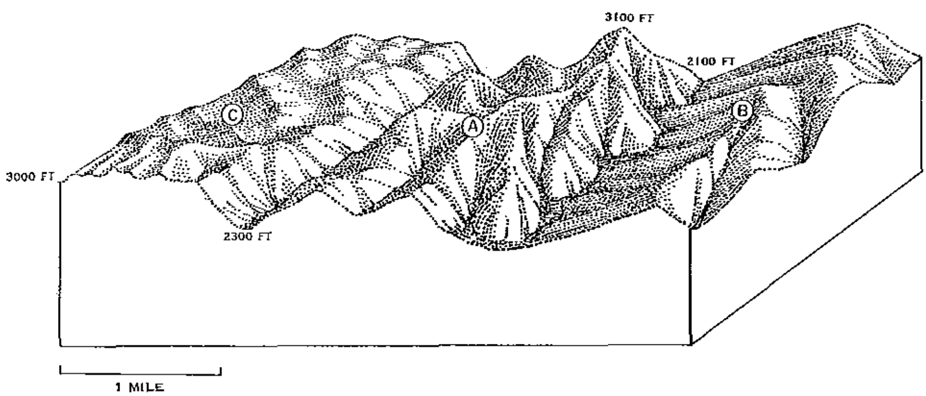


Diagram illustrates the three major aspects of the land system. Their significance and interrelationships are not clear.

Geology.—Ultrabasic and basic igneous rocks: dunite, norite, peridotite, gabbro, dolerite. Generally become more feldspathic from west to east. A mantle of recent volcanic ash, up to 20 ft thick, covers many of the more gentle slopes.

Geomorphology.—Irregular pattern of very steep, moderately to strongly dissected mountain ridges with rounded crests (A on diagram). Locally, mainly along north-eastern boundary, slopes are only moderately steep, long, and little dissected (B on diagram). Low hilly upland areas at summit level and on broad declines occur in south-western part of area (C on diagram). These have a dense pattern of small creeks high above the major rivers which flow in deep gorges. Elsewhere the drainage pattern is rather fine and angular, suggesting strong control by jointing. The western boundary of the land system is clearly fault controlled. The range is probably a combination of dome and block mountains, tilted against the uplifted Owen Stanley Range.

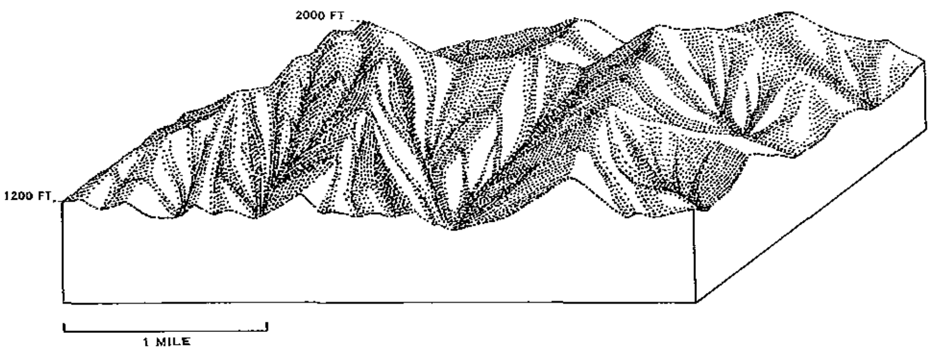
Soils.—Moderately weathered brown ash soils of Higatura family cover many of the more gentle slopes. Strongly weathered red and brown clay soils of Tatai and Kenga families are found on steeper slopes, with probably slope soils and lithosols on very steep slopes.

Vegetation.—On the southern lower slopes mainly mature rain forest of *Syzygium* sp.–*Flindersia* spp. association, which probably gives way to *Anisoptera kostermansiana–Intsia bijuga* association in eastern and northern parts. Aerial photos reveal a distinctly different low forest vegetation over most of the high country in the interior, but this lower montane forest type has not been investigated.

Land Class.—Largely VIIe with smaller areas of VIe on gentler slopes and of VIIIe,so on steepest slopes. Important catchment area.

(3) Oivi Land System (20 sq miles)

Forested hills along the foot of the Owen Stanley Range, reaching altitudes of 1500 to 2500 ft.



Geology.—Low-grade metamorphics, e.g. at Oivi Ridge; ultrabasic igneous rocks (peridotite), e.g. south of Kumusi River.

Geomorphology.—Isolated hill complexes with steep, long, and generally strongly dissected slopes and slightly rounded crests. Drainage pattern of only small gullies and streams.

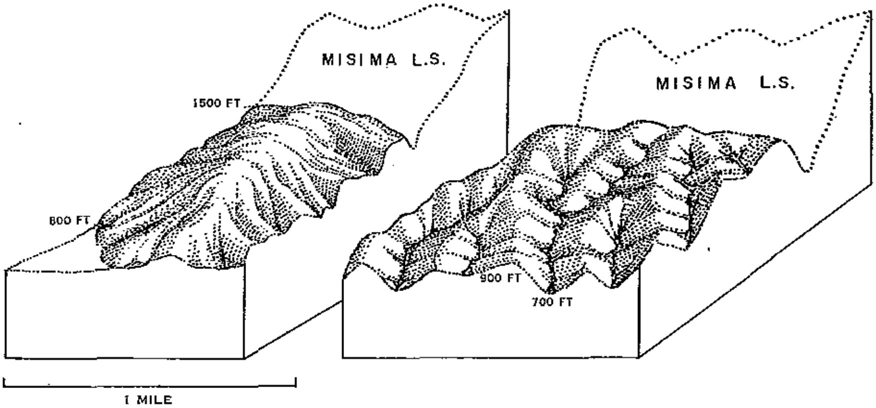
Soils.—Presumably mainly slope soils. Strongly weathered red clay soils of Sengi family were observed on metamorphic rocks of Oivi Ridge. Weathered brown ash soils of Higatura family occurred on some ash-covered foot slopes near Mt. Lamington.

Vegetation.—Secondary and mature rain forest of *Syzygium* sp.–*Flindersia* spp. association.

Land Class.—VIIIe,so and VIIc.

(4) Komondo Land System (25 sq miles)

Intricately dissected forested hills in Yodda–Kokoda valley, reaching altitudes of about 1500 ft.



Geology.—Very limited data appear to indicate that the principal rock types are low-grade metamorphics. Ultrabasic rocks occur in north-western part along the Mambare River. Along the foot of the Owen Stanley Range the surface deposits may consist of overburden, commonly agglomeratic in nature.

Geomorphology.—The hill complexes have a fine-textured pattern of branching or radiating, accordant, low, rounded ridges with steep slopes and a drainage system of very small streams. Two isolated ridges occur east of Kokoda. The ridge complexes have a marked south–north gradient and abut against the mountain foot or are separated from it by a steep-sided valley.

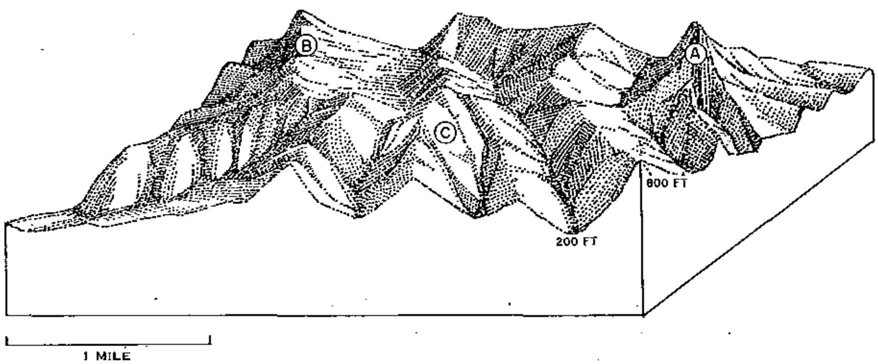
Soils.—Limited data indicate a predominance of strongly weathered red heavy clay soils of Sengi family. In the highest north-western part acid friable brown clay soils of Kenga family were found, as well as slope soils on very steep slopes.

Vegetation.—Secondary forest, regrowth, and mature rain forest of *Syzygium* sp.–*Flindersia* spp. association.

Land Class.—VI–VIIe.

(5) Hegahorte Land System (75 sq miles)

High forested ridges flanking the eastern Ajule Kajale Range and reaching altitudes of 500 to 1000 ft.



Geology.—Presumably mainly quartz dolerite, with locally basalt and tuffaceous sediments.

Geomorphology.—Steepest, highest parts of simple fold mountains. Dissected hogback ridges (A on diagram) and in the north cuestas (B on diagram) are characteristic for this land system, which also includes strongly dissected sharp ridges with less obvious structural control of the land forms (C on diagram). Drainage pattern of only small gullies and streams.

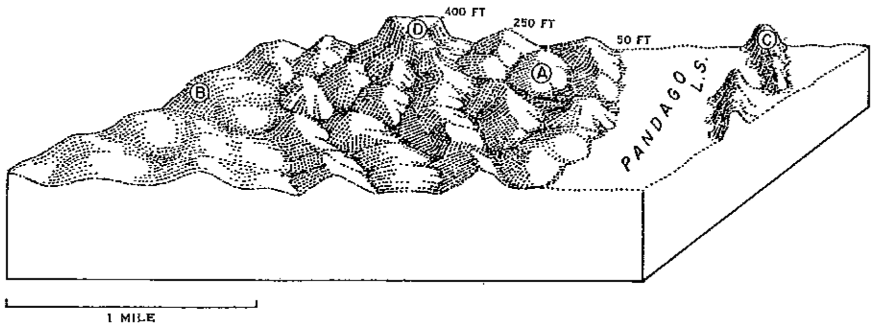
Soils.—No observations. Presumably mainly slope soils with locally strongly weathered red clays of Tatai family and possibly lithosols on precipitous outcrop slopes.

Vegetation.—No field observations. Mainly mature rain forest, presumably of *Anisoptera kostermansiana–Intsia bijuga* association.

Land Class.—VIIIe,so on steepest slopes, VI–VIIe,so on gentler slopes. Part of important catchment area.

(6) Mt. Green Land System (120 sq miles)

Low forested hills with leached reddish clay soils. Extends from Ajule Kajale Range to mouth of Mambare River. Altitude 200–600 ft.



Geology.—Andesitic and basaltic lava, agglomerate, and tuff were observed on Mt. Green and along lower Mambare River, but the petrology of the large area west of Ioma is not known. The hill ridges near Divinikoiari consist of ultrabasic rocks and one ridge east of the upper Kumusi River of basalt. North of Ioma a small area of limestone occurs on top of the volcanic rocks. The strata appear to be generally subhorizontal.

Geomorphology.—Low hilly part of simple fold mountains. Intricate pattern of low, steep ridges with rather sharp, accordant crests (A on diagram). Locally, higher ridges and very steep outcrop slopes indicate warping and minor faulting. Several areas along the boundary of Botue land system have a remarkably smooth topography of little-dissected plateau surfaces and slopes (B on diagram). The isolated ridges (C on diagram) in the flood-plain and ash plain are clearly drowned by the young deposits. Those in the ash plain appear to represent dykes. The limestone hills form dissected mesas, about 400 ft high (D on diagram).

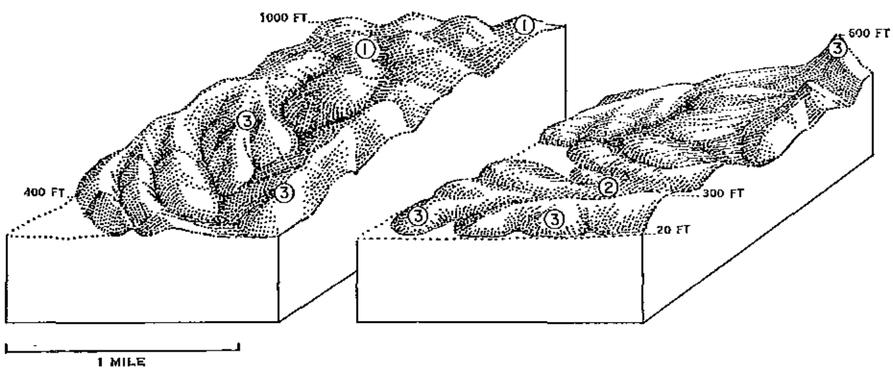
Soils.—Different types of strongly weathered red and brown clay soils appear common. Yellow-brown over red clay soils of Mt. Green family were observed on Mt. Green and south of Itigi. On ultrabasic rocks red heavy clay soil of Tatai family was observed on moderate slopes, less mature brown clay soils of Atamai family on very steep slopes. Information on soils is very limited and no data are available on the soils of the limestone mesas.

Vegetation.—Mainly mature rain forest, locally regrowth, and secondary forest. Very limited information indicates that this belongs to *Anisoptera kostermansiana–Intsia bijuga* association.

Land Class.—Mainly VIe, less VIIe, little VIIIe,so on limestone escarpments.

(7) Iauga Land System (65 sq miles)

Rolling plateau, 400–1200 ft high, along the coast from Opi River to Mambare River.

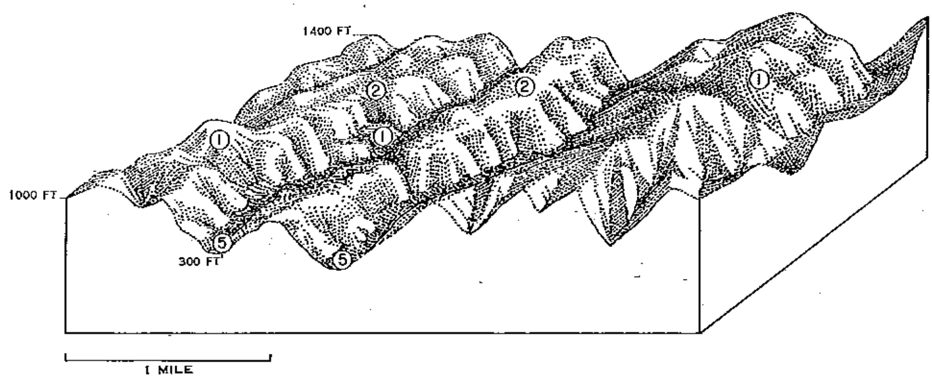


Geology and Geomorphology.—Maturely dissected Iauga volcanics—basaltic and andesitic lavas, agglomerates and tuffs and tuffaceous sandstones forming the warped coastal plateau. Minor occurrence of limestone. Height differentiation due to faulting gave rise to dissected high plateaux (unit 1), undulating low plateaux (unit 2), and steep dissected margins and ridges (unit 3). Almost radial, dense pattern of small dendritic stream systems.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Medium. Central northern part of land system	Complex of low hills and ridges at 400–1000 ft, with V-shaped valleys	No information. Presumably mainly strongly weathered red heavy clay soils of Tatai family. Presumably well drained	No information. Mainly mature rain forest, presumably of *Anisoptera kostermansiana–Eucalyptopsis papuana–Dillenia nalagi* association	VI–VIIe
2	Medium. Several areas in southern and western parts of land system	Undulating to rolling land surfaces at 200–400 ft	Gleyed and commonly shallow clay soils of Dewatutu and Siwarira families. Locally red clays and lithosols on crests, unidentified colluvial soils in hollows. Generally poorly to imperfectly drained	Regrowth and secondary forest of *Anisoptera kostermansiana–Eucalyptopsis papuana–Dillenia nalagi* association. Locally, but especially in southern part, much grassland of *Imperata cylindrica–Apluda mutica* alliance	Mostly IV–VIe,so. Little VIIe, so on steep slopes, IV (padi) d,f in hollows
3	Medium. Throughout land system	Steep dissected slopes at plateau margins and isolated ridges	Complex pattern of shallow gleyed clay soils of Dillenia family and few of Siwarira family; red clay soils of Tatai family and lithosols. Imperfectly to excessively drained		VIIe,so and less VIIIe,so

(8) Hydrographers Land System (180 sq miles)

Rugged foothills and mountain spurs of Hydrographers Range, rising to over 4000 ft (Plate 2, Fig. 1).



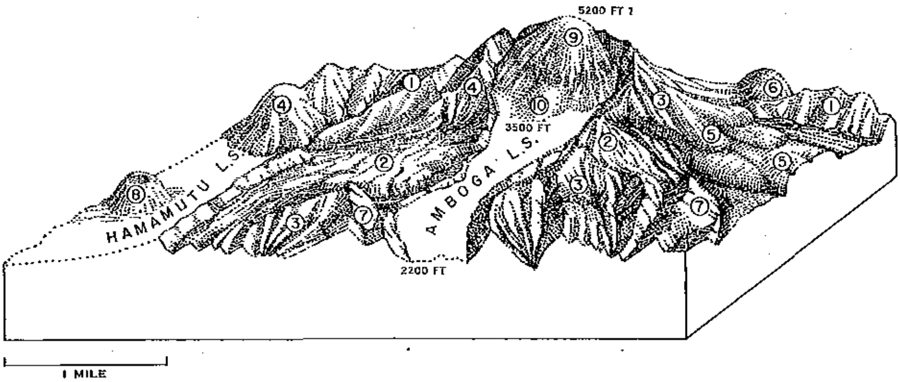
Units 3 and 4 are not shown because they are similar in form to unit 1, but have less relief and are lower.

Geology and Geomorphology.—Extinct volcano, composed of andesitic and basaltic lavas, agglomerates, and tuffs. Pattern of sub-maturely dissected radial ridges, dissected planezes, and amphitheatre valleys. Fine-textured, radial pattern of deeply incised consequent streams.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Very large. Throughout land system	Steep to very steep ridges and V-shaped valleys	Slope soils, and red and brown clays of Sengi and less of Atamai families. Locally weathered brown ash soils of Higatura family on flat crests. Some lithosols on sharp crests and very steep slopes. Well drained	Rain forest of *Anisoptera kostermansiana–Intsia bijuga* association. At highest altitudes lower montane rain forest	VIIe and VIIIe,so
2	Small. Locally in central lower part of land system	Narrow flat-topped ridges and shallow, steep-sided valleys	Weathered brown ash soils of Higatura family and weathered brown clay soils of Atamai family. Well drained	Mainly regrowth stages of *Anisoptera kostermansiana–Intsia bijuga* association	IIe on flat areas, otherwise VI–VIIe
3	Small. North-eastern foot slopes	As unit 1, but generally lower relief	Weathered red clays of Sengi family, mostly strongly truncated. Locally lithosols and slope soils. Well to excessively drained	Grassland of *Themeda australis–Imperata cylindrica–Coelorhachis rottboellioides* alliance	VIIe,so
4	Very small. North-eastern foot slopes, small areas associated with units 1 and 2			Secondary forest (dominated by *Eucalyptus tereticornis*) of *Anisoptera kostermansiana–Intsia bijuga* rain forest association	
5	Very small. Scattered in foothill zone of land system	Narrow alluviated valleys with small meandering streams	Unidentified alluvial and colluvial soils. Poorly to imperfectly drained	Regrowth stages and rain forest of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association	Vf,st

(9) Lamington Land System (30 sq miles)

Summit area, secondary cones, and dissected lava ridges of Mt. Lamington volcano (Plate 1, Fig. 2; Plate 2, Fig. 1). Largely between 2000 and 4000 ft, with summit at 5900 ft.



Geology and Geomorphology.—Pleistocene to Recent andesitic ash and lava, forming steepest and highest parts of a strato-cumulo volcano, and comprising the following elements: more or less dissected ash slopes and screes (units 2, 3, 10) commonly underlain by lava; recent tholoid (unit 9); strongly or little dissected older tholoids and adventive cones (units 4, 6, 8); asymmetrical ridges (unit 7); severely dissected ridges (unit 1) of old lava flows and possibly consolidated old tuffs and agglomerates; little dissected recent coulee lava flows (unit 5). The distribution of these units is shown on inset to accompanying map.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation*	Land Class
1	Large. Largest occurrences on lower E. slopes of Mt. Lamington; others form radial pattern around summit; small areas at base of volcano along Mamama River	Irregular, sharp, high hill-ridges with very steep, strongly dissected slopes	No information, probably mainly slope soils with volcanic ash land near summit area. Well to excessively drained	Seral communities in blast area, ranging from sparse *Saccharum* cane grass and mosses to woodland dominated by *Euroschinus papuanus* and *Musa* spp. Elsewhere rain forest of unknown botanical composition	VIIIe,so, little VIIe,so
2	Medium. Radially arranged on upper slopes of Mt. Lamington, almost wholly above 3000 ft	Slightly concave broad steep slopes with many shallow parallel gullies	Presumably volcanic ash land. Well to excessively drained	Herbaceous seral communities	VIIe
3	Medium. Associated with unit 2 and part of the same radial pattern	Steep, concave slopes, maturely dissected into low parallel ridges	Presumably volcanic ash land and truncated brown weathered ash soils of Higatura family. Well to excessively drained	Seral communities: herbaceous and *Trema orientalis* associes forming single tree layer 15–25 ft high	VIIIe
4	Medium. Three occurrences in summit area, 3 on lower SE. slopes and 2 on lower W. slopes of Mt. Lamington	Strongly dissected convex high hills, rising abruptly above surrounding country. Locally with precipitous rock faces	Presumably lithosols. Lava rock land slope soils and some volcanic ash land. Excessively to well drained	Rain forest of unknown botanical composition. Predominantly woody seral communities and some bare rock in blast area	VIIIe,so
5	Small. Several occurrences on upper W. slopes of Mt. Lamington	Broad ridges with hummocky or undulating surfaces and strongly convex marginal slopes, very steep at base	Presumably lava rock land and volcanic ash land. Excessively to well drained	Seral communities in blast area. Elsewhere rain forest	VIst and VIIIe,so
6	Small. Mainly on W. slopes of Mt. Lamington. One occurrence in SE.	Very steep convex dome-shaped hills, dissected only by shallow gullies	Presumably lava rock land. Excessively to well drained		VII–VIIIe,so
7	Small. Several small occurrences on N. slopes of Mt. Lamington, but also on SE. slopes. Between 2000 and 3000 ft	Sharp ridges with precipitous slopes towards crater and less steep outer slopes	Mainly volcanic ash land and lithosols. Excessively to well drained		VII–VIIIe,so

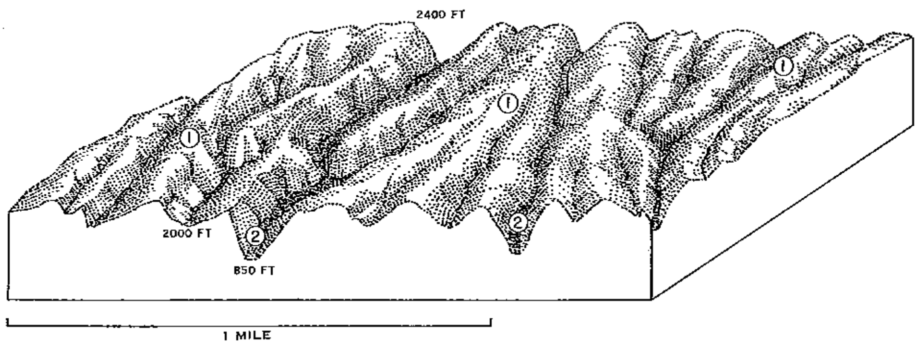
(9) LAMINGTON LAND SYSTEM (*Continued*)

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation*	Land Class
8	Very small. Two occurrences below 2000 ft, one SW. and one SE. of summit area	Steep round hills with slightly convex smooth slopes and clearly defined crater depression	Presumably weathered brown ash soils. Well drained	Rain forest of unknown botanical composition	VIIe
9	Very small. Protruding from summit crater of Mt. Lamington	Dome, formed after 1951 eruption and still active	Lava rock land	Bare ground	VIII
10	Very small. Surrounding unit 9	Steep concave scree slopes	Rubble land. Excessively drained		

* The seral communities in the blast area represent the vegetation existing in August 1953, which is certain to change considerably in structure and botanical composition with the passing of time. The limit of total destruction of the original vegetation by the 1951 eruption is shown on inset to accompanying map.

(10) HAMAMUTU LAND SYSTEM (25 SQ MILES)

Severely dissected slopes of Mt. Lamington below the summit area (Plate 2, Fig. 1). Mostly between 2000 and 3000 ft.



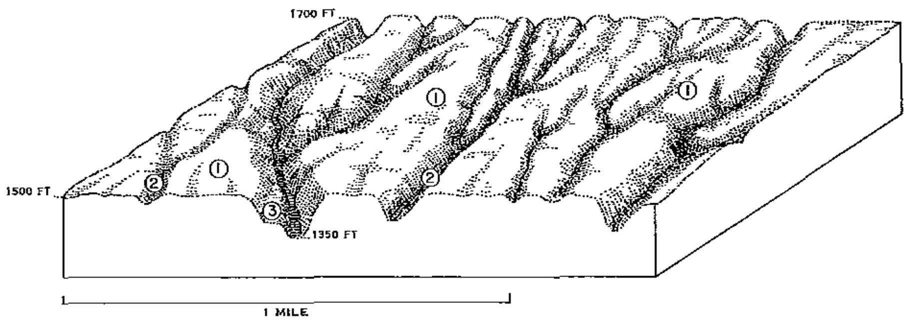
Geology and Geomorphology.—Recent andesitic ash deposits, locally possibly agglomerates and lavas. Maturely dissected upper parts of lahar–glowing avalanche slopes forming complexes of steep ridges. The ridge crests are either at the same level as the surrounding less dissected country or are remnants of a higher surface. Their gradients range from approximately 5% to 10%. There is a fine-textured drainage pattern of small parallel or dendritic streams and few larger ones in gorges, forming part of the general radial drainage of Mt. Lamington.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation*	Land Class
1	Very large. Throughout land system	Roughly parallel or digitate, long, low to moderately high accordant ridges with rounded crests and steep or very steep slopes; separated by narrow stream valleys. Ridge crests have gentle slope away from summit of Mt. Lamington	Weathered brown ash soils of Higatura family, mostly truncated. Locally volcanic ash land on ridge tops. Well drained	Predominantly woody seral communities, dominated by *Euroschinus papuanus* in blast area. On lower slopes rain forest of *Pometia pinnata–Chisocheton* sp. association	VIIe
2	Very small. Along major streams bordering or traversing land system	Precipitous slopes and narrow flood-plains of river gorges, 100–300 ft deep	Strongly truncated brown ash soils of Higatura family and outcrop of fresh ash. Alluvial land on floors of gorges. Excessively drained. Valley floors subject to short floods	Seral communities: *Euroschinus papuanus–Musa* sp. associes on slopes; herbaceous communities dominated by *Saccharum* cane grass on floors	VIIIe,so and little VIIIf,st

* The seral communities in the blast area represent the vegetation existing in August 1953, which is certain to change considerably in structure and botanical composition with the passing of time. The limit of total destruction of the original vegetation by the 1951 eruption is shown on inset to accompanying map.

(11) Higatura Land System (70 sq miles)

Gentle but broken slopes of Mt. Lamington, with yellow-brown ash soils (Plate 1, Fig. 2; Plate 2, Fig. 1). Altitude ranges from about 400 to 3000 ft.



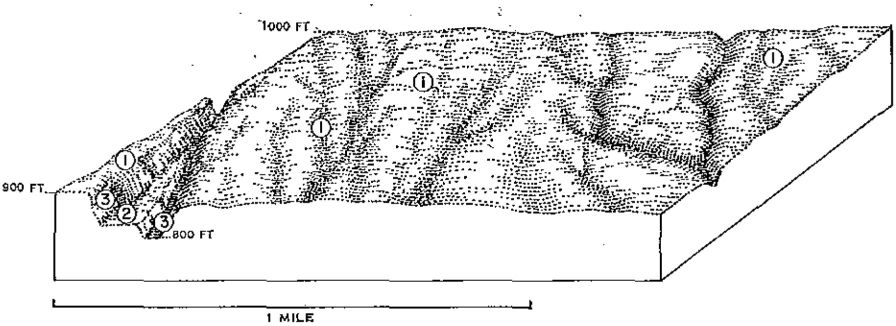
Geology and Geomorphology.—Recent andesitic ash deposits forming the moderately dissected parts of the lahar–glowing avalanche slopes, with gradients of about 3% in the lower part increasing to 8% in the upper part. The greater part of the original gentle ash slopes has been preserved, but is broken by numerous deeply entrenched, roughly parallel, or forking, small and bigger streams with precipitous valley sides. This drainage system forms part of the general radial pattern on the slopes of Mt. Lamington.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation*	Land Class
1	Large. Throughout land system	Smooth or gently undulating, gently sloping high surfaces, narrow (5–20 chains) but long. Locally dissected by shallow gullies	Predominantly weathered brown ash soils (mainly Higatura family, some Ohita family in NW. part, Sangara family in lowest, most northern areas). In upper parts of unit much volcanic ash land. Well drained	Regrowth stages and secondary forest of *Pometia pinnata–Chisocheton* sp. rain forest association. Seral communities within blast area: *Euroschinus papuanus* associes and, on volcanic ash land, a herbaceous community dominated by *Saccharum* cane grass	Mainly IIe, some I and IIIe
2	Medium. Throughout land system, closely associated with unit 1	Steep to precipitous slopes towards small and larger streams, and narrow flood-plains, 40–200 ft below unit 1	Strongly truncated weathered brown ash soils of Higatura family and outcrop of fresh ash. Alluvial land in flood-plains. Well to excessively drained. Flash floods in valleys	Rain forest; in blast area seral communities, dominated by *Euroschinus papuanus*	VIIe and VIIIe, with Vf,st and VIIIf, st in valleys
3	Very small. Small occurrences along major streams	Discontinuous high terraces, well below level of unit 1	Presumably little-weathered brown ash soils of Ohita family and possibly also sandy volcanic soils with black topsoils of Popondetta family. Well drained	Mostly rain forest and some regrowth of *Pometia pinnata–Chisocheton* association	Presumably mainly I, possibly also II–IIIst

* The seral communities in the blast area represent the vegetation existing in August 1953, which is certain to change considerably in structure and botanical composition with the passing of time. The limit of total destruction of the original vegetation by the 1951 eruption is shown on inset to accompanying map.

(12) Awala Land System (80 sq miles)

Smooth to undulating, very gentle slopes of Mt. Lamington (Plate 5) with rather sandy brown ash soils. Altitude between 400 and 2000 ft.



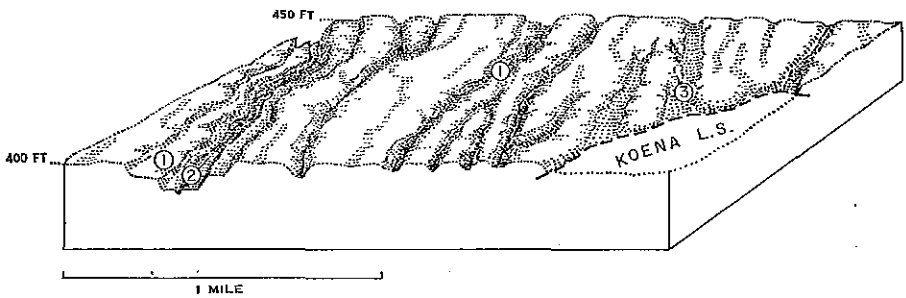
Geology and Geomorphology.—Recent andesitic ash deposits, forming the little or not dissected part of the lahar–glowing avalanche slopes, with a coarse-textured radial pattern of steeply incised major streams. The ash slopes have a gradient of 2·5–3% in the lower part, increasing to 5% in the upper part.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation*	Land Class
1	Very large. Throughout land system	Flat to undulating plains, commonly with many small, rounded, roughly parallel depressions with small streams	Weathered brown ash soils (predominantly Ohita family, some Higatura family west of Amboga River), commonly stony. Well drained	Regrowth stages and secondary forest of *Pometia pinnata–Chisocheton* sp. association, with some large areas of mature rain forest in NE. and SW. parts. Woody seral communities (*Euroschinus papuanus* associes) in blast areas	Mainly IIst and IIIe,st, locally I and IIe, locally Vst
2	Very small. Locally along Kumusi–Mamama and Girua Rivers	Flat high river terraces, distinctly below level of unit 1	No data; presumably similar to unit 1	No field observations, mainly mature forest, presumably of *Pometia pinnata–Chisocheton* association	Presumably II–IIIst and I
3	Very small. Mainly in higher parts of land system associated with unit 1	Precipitous slopes towards major streams, and narrow floodplains, 30–100 ft below unit 1	Mainly outcrop of volcanic ash. Alluvial land in floodplains. Well to excessively drained. Flash floods in valleys	Rain forest and herbaceous seral communities	VIIIe with VIIIf,st and Vf,st in valleys

* The seral communities in the blast area represent the vegetation existing in August 1953, which is certain to change considerably in structure and botanical composition with the passing of time. The limit of total destruction of the original vegetation by the 1951 eruption is shown on inset to accompanying map.

(13) Bohu Land System (155 sq miles)

Forested, dissected volcanic plains north of Mt. Lamington with brown volcanic clay soils. Altitude ranges from 100 to 1000 ft.



Geology and Geomorphology.—Immaturely dissected piedmont-banjir plains of water-transported Recent andesitic volcanic ash. Gradients less than 2·5%. Fine-textured drainage pattern of roughly parallel, small and larger streams, which are steeply but not deeply incised and have generally developed one or two discontinuous erosional terraces in the valleys.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Very large. Throughout land system	Elongated, flat surfaces, 4–40 chains wide. Separated by shallow rounded gullies or steep-sided but not deeply incised (up to 50 ft) stream valleys with commonly one or two high terraces	Weathered brown ash soils (Sangara family, locally Bohu family), having little or no topsoil on steep terrace slopes. Well drained; areas with Bohu soils imperfectly drained	Predominantly rain forest, secondary forest, and some regrowth of *Pometia pinnata–Chisocheton* sp. association. Locally areas of grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	I, with small areas of IId on Bohu soils; VIIe on steep dissection slopes
2	Small. Throughout land system, mostly in central part	Narrow flood-plains and low terraces, with little-incised streams	Fine-textured recent alluvial soils and some river wash. Poorly drained. Probably subject to short floods in wet season	Regrowth and secondary forest of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association	IV (padi) d,f
3	Very small. Along northern edge of land system	Narrow flood-plains	Fine-textured recent alluvial soils and shallow organic soils of Koena family. Swampy to very poorly drained. Probably subject to prolonged flooding in wet season	Swamp communities ranging from swamp forest to herbaceous swamp	VII ps

(14) Eundi Land System (30 sq miles)

Volcanic plains north-west of Mt. Lamington, with rather sandy brown ash soils and alluvial soils. Altitude 200–600 ft.

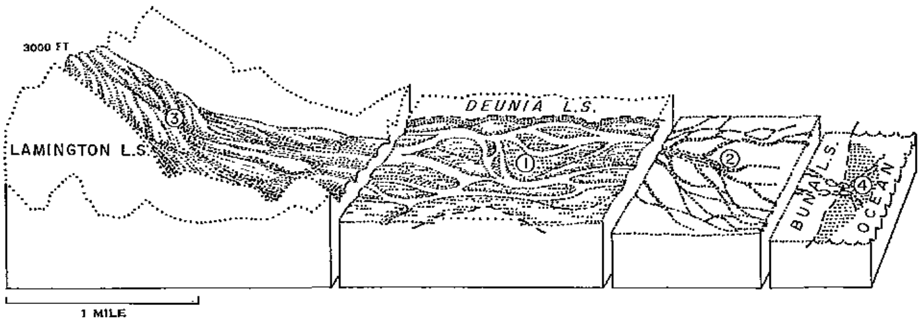
No block diagram or plan, because of low relief and indistinct boundaries of units on aerial photographs.

Geology and Geomorphology.—Almost level Recent andesitic ash deposits forming the little dissected NW. part of the piedmont-banjir plains, which merge here imperceptibly with the lahar–glowing avalanche slopes of Awala land system.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout land system	Elongated, very gently sloping to flat surfaces with sharp, low breaks to unit 2	Predominantly weathered brown ash soils of Ohita family; locally unweathered sandy volcanic soils of Popondetta family. Well drained	Grassland of *Saccharum spontaneum–Imperata cylindrica* alliance and regrowth and secondary forest of *Pometia pinnata–Chisocheton* sp. rain forest association	I and IIso
2	Small. Throughout land system	Elongated, narrow depressions with small streams	Alluvial soils of varying texture. Imperfectly drained; possibly flooded for short periods during wet season	Mainly regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* rain forest association	IVd,f

(15) Amboga Land System (45 sq miles)

Andesitic eruption products of 1951, deposited in Avalanche valley and along major rivers draining Mt. Lamington (Plate 2, Fig. 2). From sea-level to 3500 ft.



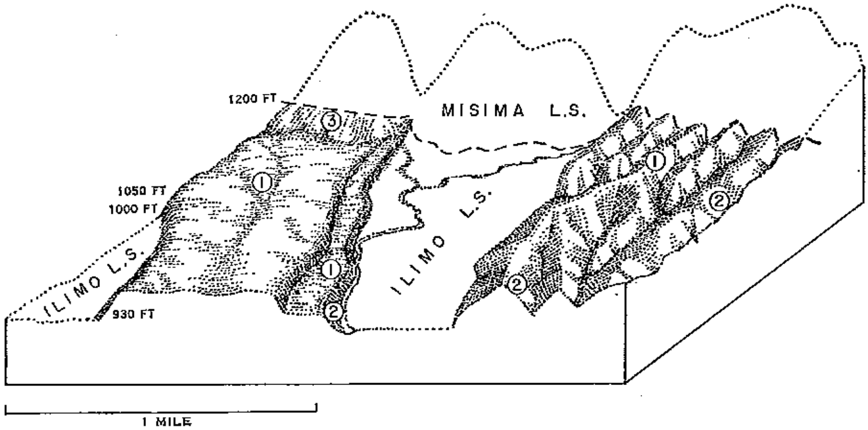
Geology and Geomorphology.—Andesitic deposits from the 1951 eruption, forming lahar–glowing avalanche slopes (unit 3) and banjir plains (units 1, 2) in the valleys of major streams draining Mt. Lamington. Deposits range from very poorly sorted *nuée ardente* deposits with boulders in unit 3 to much better sorted sandy and silty fluviatile deposits in unit 2, those of unit 1 forming a transitional stage. Most of the material of units 1, 2, and 4 was not deposited until several months after the eruption. Drainage of the coarse-textured deposits is largely subsurface, but also by braided stream channels. In the finer-textured flood-out deposits there are numerous poorly developed distributary and drainage channels.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation*	Land Class
1	Large. Upper and middle reaches of major rivers draining Mt. Lamington	Level to slightly undulating narrow flood-plains and braided river beds	Predominantly stony alluvial land. Also rubble land and river wash. Mostly subject to short floods in wet season	Banjir sere: communities dominated by *Saccharum spontaneum* and *Trema orientalis*; also bare ground	VIIIf,st and VIIso, st,f
2	Medium. Near mouth of Girua and Amboga Rivers	Level to slightly undulating flood-outs with many small channels, which were hardly incised in 1953	Predominantly alluvial land with some river wash. Very poorly to poorly drained. Possibly flooded in wet season	Banjir sere: many herbaceous communities	Vd,f and VIIId,f
3	Small. Upper valleys of Banguito Creek, Gawana River, and Amboga River on northern slopes of Mt. Lamington	Irregular, stepped slopes, moderate and strongly dissected in upper part, gentle and little dissected in lower part	Predominantly rubble land, also alluvial land. Mostly excessively drained	Bare ground with moss and ferns in upper part. Seral communities: open herbaceous community dominated by *Imperata cylindrica* and *Saccharum spontaneum* in middle part; closed herbaceous community dominated by *Saccharum spontaneum* in lower part	VIIIst
4	Very small. At mouth of Kumusi and Girua Rivers and at Garara village	Recent deltaic formations of presumably fine sandy volcanic ash. Many anabranching channels	—	Bare ground	VIII

* The seral communities in the blast area represent the vegetation existing in August 1953, which is certain to change considerably in structure and botanical composition with the passing of time. The limit of total destruction of the original vegetation by the 1951 eruption is shown on inset to accompanying map.

(16) Kokoda Land System (55 sq miles)

Terrace remnants with weathered brown ash soils in the Yodda–Kokoda valley and on the west bank of the Kumusi River (Plate 1, Fig. 1). Altitude 400–1400 ft.



Geology and Geomorphology.—Wedge-shaped terraces of two levels in the Yodda–Kokoda fault trough. Pleistocene alluvial and colluvial material covered with weathered andesitic volcanic ash. Although they slope gently downward from the foot of the mountains, their elevation above the valley plain increases away from the mountain foot. Locally densely dissected by very small streams.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout land system	Gently to very gently sloping terrace surfaces	Weathered brown ash soils of Higatura family. Possibly locally unidentified, strongly weathered red clay soils. Well drained	Regrowth stages and some secondary forest of the *Syzygium* sp.–*Flindersia* spp. rain forest association. Some rubber–cocoa plantations	I
2	Medium to small. Throughout land system	Steep to very steep, but commonly short slopes of terrace edges and dissecting streams	Slope soils and some truncated weathered brown ash soils. Well drained	As unit 1, but with much less plantation	VI–VIIe
3	Small. Zone along foot of mountains	Moderate uneven slopes of colluvial zone	Stony land. Well drained	As unit 1, but without plantation	Mainly VIst

(17) Ioma Land System (90 sq miles)

Forested red clay soil plains north-east of Ajule Kajale Range, ranging in altitude from 150 to 400 ft.

No block diagram, because of low order of relief. No plan, because distribution of units is partly regional and cannot readily be seen on aerial photographs.

Geology and Geomorphology.—Probably Pleistocene deposits of mixed petrographic composition, rich in stones and gravel below the surface layers, forming old, elevated piedmont terraces. Eastern boundary with flood-plains locally marked by steep low terrace edge, locally gradual. Plains partly densely dissected by very small streams. Larger streams widely spaced, traversing land system in relatively straight, incised valleys.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout land system	Almost level plain, sparsely dissected by steep-sided gullies. Steep edges along major streams	Strongly weathered red clay soils of Petakiari family. Well drained	Mainly mature rain forest, also secondary forest and some garden regrowth of *Pometia pinnata–Chisocheton* sp. association	IIso
2	Large. Throughout land system	Complex of narrow, rounded or flat, roughly parallel ridges with steep short slopes to interlying gullies and small streams	Strongly weathered red clay soils of Petakiari family, mostly truncated. Well drained		Mainly VIe,so with small patches of IIIe,so
3	Small. Locally along eastern edge of land system	Slightly lower-lying, hardly dissected parts of plain	Weathered brown clay soils of Arumu family. Well to imperfectly drained		II (padi) d

(18) Popondetta Land System (80 sq miles)

Slightly dissected volcanic plains north-east of Mt. Lamington with black, sandy volcanic soils under grassland (Plate 3, Fig. 1). Altitude 50–1400 ft.

No block diagram or plan because of low relief and because the general distribution of units 1 and 2 can be seen on the land system map from the grassland pattern. Unit 3 is confined to the most southern parts of the land system.

Geology and Geomorphology.—Recent, water-transported volcanic sands of andesitic composition, forming the most dissected parts of volcanic outwash plains. Coarse-textured radial pattern of consequent major rivers and finer-textured pattern of minor streams. Much subsurface drainage.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout lower parts of land system	Level to very gently sloping surfaces, 10–20 ft above flood-plain level	Unweathered, sandy volcanic soils with black topsoils of Popondetta family. Small patches of coarse-textured alluvial soils. Well to excessively drained	Grassland of *Saccharum spontaneum–Imperata cylindrica* alliance. Small stands of *Anisoptera kostermansiana–Pometia pinnata* rain forest	IIIso
2	Medium. Throughout lower parts of land system	Level to slightly undulating surfaces, somewhat lower than and with steep or gentle transition to unit 1. Locally some pothole microrelief	Predominantly medium-textured, rarely fine-textured alluvial soils. Poorly to imperfectly drained. Flash flood hazards	Rain forest and regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association and on best-drained sites *Anisoptera kostermansiana–Pometia pinnata* association	IVd,f and IV (padi) d,f
3	Small. Highest parts of land system, on slopes of Mt. Lamington, south of Popondetta airstrip	Gently sloping surfaces with minor undulations. Dissected by small streams	Unweathered sandy volcanic soils with black topsoils of Popondetta family; commonly more or less stony and locally merging into stony land. Well to excessively drained	Rain forest, but mainly regrowth stages of *Anisoptera kostermansiana–Pometia pinnata* association	II–Vst

(19) Penderetta Land System (10 sq miles)

Poorly drained volcanic grass plains with sandy soils, north-east of Mt. Lamington. Altitude 200–500 ft.

No block diagram or plan because of low relief and because the general distribution of the two units can be seen on the land system map from the grassland pattern.

Geology and Geomorphology.—Thin Recent volcanic sand deposits overlying weathered clayey volcanic deposits. Slightly dissected upper part of volcanic outwash plain. Coarse-textured drainage pattern of very small streams. Perched water-table on fine-textured substrata.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout land system	Very gently sloping to level surfaces, 15–30 ft above flood-plain level	Unweathered sandy volcanic soils with black topsoils of Penderetta family. Rarely little-weathered brown ash soils of Ohita family. Mostly poorly drained	Grassland of *Saccharum spontaneum–Imperata cylindrica* alliance, commonly with many scattered small trees	IIId
2	Small. Throughout land system	Level surfaces, slightly lower than unit 1, mostly along small streams	Unidentified alluvial soils, probably medium-textured. Poorly to imperfectly drained. Flash flood hazards	Regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association	IV (padi) d,f

(20) Hanau Land System (85 sq miles)

Slightly undulating plains with volcanic derived alluvial soils near the lower Amboga and Samboga Rivers and behind Gona (Plate 6). Altitude 10–150 ft.

No block diagram or plan because of low relief and because general distribution of units can be seen on the land system map from the grassland pattern.

Geology and Geomorphology.—Recent alluvium, derived from Mt. Lamington. Very weakly dissected, rather low parts of volcanic outwash plain. Generally coarse-textured drainage pattern of small streams, but denser pattern of well-incised streams in the area around Hambarata.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout land system	Almost level surfaces, slightly lower than units 2 and 3	Mainly medium-textured, but also fine-textured alluvial soils. Poorly to imperfectly drained. Liable to flooding	Mainly regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association. On best-drained areas *Anisoptera kostermansiana–Pometia pinnata* association	IVd,f and IV (padi) d,f
2	Medium. South of Gona and in Samboga River area	Elongated and commonly slightly undulating surfaces, rising slightly above unit 1	Unweathered, sandy volcanic soils with black topsoils of Popondetta family. Well to excessively drained	Grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	IIso
3	Small. Around Hambarata (west of Amboga River)		Mainly medium-textured but also coarse- over fine-textured alluvial soils. Moderately weathered mottled ash soils. Poorly to imperfectly drained		IId, III (padi) d
4	Very small. Some scattered small patches between Amboga and Girua Rivers	As units 2 and 3, but smaller	Coarse-textured alluvial soils. Well drained	As units 2 and 3, but also garden regrowth	IIso
5	Extremely small. Along coast	Gently sloping narrow beach and low backing ridge	Dark beach sand	Bare ground, and seral community of herbs, dominated by *Ipomoea pes-caprae*. Also forest of *Barringtonia asiatica–Pterocarpus indicus* association	VIII

(21) Sanananda Land System (40 sq miles)

Poorly drained forested flood-plains with volcanic derived alluvial soils near mouth of Amboga and Girua Rivers. Altitude 10–50 ft.

No block diagram or plan because of lack of relief and indistinct regional distribution of units.

Geology and Geomorphology.—Recent alluvium derived from Mt. Lamington, deposited by river distributary systems in lowest parts of the volcanic outwash plain. Poorly defined stream pattern with rapidly changing courses of distributary channels, owing to strong sedimentation. Large seasonal fluctuations in ground-water level.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Very large. Throughout land system	Level low-lying flood-plain with few small shallow streams	Great variety of alluvial soils, ranging from coarse- to fine-textured. Poorly drained; liable to flooding	Regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* rain forest association	IVd,f and IV (padi) d,f
2	Small. Locally bordering on the eruption flood deposits of Amboga land system	Level low-lying flood-plains with few distributary channels	Coarse- and medium-textured alluvial soils. Very poorly to poorly drained; liable to frequent and possibly destructive flooding	Seral communities with *Octomeles sumatrana* frequent	Vd and V (padi) d,f
3	Small. Isolated occurrences in Amboga River area	Level low-lying flood-plain	Medium- and fine-textured alluvial soils. Very poorly drained; liable to flooding	Rain forest of *Pometia pinnata–Dillenia quercifolia–Palaquium* sp. alliance (*Palaquium* sp. association)	V(padi) d,f
4	Very small. Small patches, commonly linearly arranged	Elongated very slight rises	Mainly coarse-textured alluvial soils. Imperfectly to well drained	Garden regrowth and grassland of *Saccharum spontaneum –Imperata cylindrica* alliance	IIso and IId
5	Extremely small. Along coast	Gently sloping narrow beach and low backing ridge	Dark beach sand	Bare ground, and seral community of herbs, dominated by *Ipomoea pes-caprae*. Also forest of *Barringtonia asiatica–Pterocarpus indicus* association	VIII

(22) Ilimo Land System (60 sq miles)

Steeply graded alluvial plains between 300 and 1400 ft in the Yodda–Kokoda valley (Plate 1, Fig. 1).

It is not possible to present a realistic block diagram or plan, because of the very poor quality of the available aerial photographs, the very low relief, and the scarcity of field data.

Geology and Geomorphology.—Rather steeply graded (4–8%) fluvial plains, of recent deposits, mainly derived from Owen Stanley metamorphics. The plains are little to moderately dissected, with lower terraces along major streams. The land system includes the lowest part of volcanic-ash-covered piedmont terraces (unit 2), which cannot be distinguished on aerial photographs. Slightly higher and older terraces of unit 3 consist of deposits probably derived from the Ajule Kajale igneous complex.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Very large. Throughout land system	Gently sloping, smooth to slightly undulating surfaces, moderately broken by gullies and incised streams, with 1 or 2 discontinuous low terraces. Marked decrease in gradient away from Owen Stanley Range	Medium- to coarse-textured alluvial soils, locally stony; some stony land in highest parts and river wash along major stream beds. Well to imperfectly drained, with few poorly to very poorly drained depressions, which are liable to flooding	Mainly regrowth stages of *Pometia pinnata–Alstonia scholaris – Octomeles sumatrana* rain forest association. Few large patches of grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	Mainly I and IIst with some IIIe,st and Vst in southern parts and IV–Vd,f in lowest parts
2	Small. Not well known. Probably mainly between Kokoda and Oivi Ridge	Gently sloping, smooth to slightly undulating surfaces, 10–20 ft higher than unit 1. Little dissected by gullies	Weathered brown ash soils of Higatura family. Well drained	As unit 1, but no grassland	Mainly I with some IIe
3	Very small. Two or three occurrences in northern part of land system, close to Ajule Kajale Range	Narrow, SE.–NW. elongated, commonly dissected terrace surfaces, 10–30 ft higher than unit 1	Strongly weathered brown clay soils of Arumu family. Well to imperfectly drained		IIso on flats, VIe,so on dissection slopes

(23) Deunia Land System (85 sq miles)

Forested alluvial terraces and levees of major rivers. Altitude 10–400 ft.

No block diagram or plan, because the distribution of the units is regional and can be deduced from the map, and because of very low relief in this land system.

Geology and Geomorphology.—Low river terraces and levees of Recent alluvium of mixed composition, forming rather unstable parts of fluvial plains.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Along middle reaches of Mambare, Kumusi, and Girua Rivers	Flat to somewhat hummocky flood-plain terraces and narrow flood-plains. Unit is bounded by higher plains, terraces, or hills	Coarse-textured alluvial soils on terraces. Alluvial land, commonly stony and some river wash on flood-plains. Well to poorly drained. Subject to short floods in wet season	Rain forest, secondary forest, and regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association, with high frequency of *Octomeles*	Flood-plains VIf,st,so and VIf,d. Terraces IVf,d
2	Medium. Along lower reaches of Mambare and Kumusi Rivers. The two units merge imperceptibly into each other	Flat to gently undulating river levees, with steep banks along river and very gentle back slopes. Rising 4–8 ft above adjoining swamps	Coarse- to medium-textured alluvial soils. Well to imperfectly drained. Rare, shallow flooding in wet season. Highest areas above flood level	Regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association. Few patches of grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	IVf, IVf,d, and some IIso

(24) Warisota Land System (25 sq miles)

Small flood-plains north of the Hydrographers Range (Plate 3, Fig. 2). Altitude 20–400 ft.

No block diagram or plan, because of very low relief and indistinct distribution of units on aerial photographs.

Geology and Geomorphology.—Recent alluvium derived from Hydrographers Range volcanics, forming narrow fluvial plains. Normal valley stream patterns in upper valleys and large lower valleys.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Lower, downstream parts of land system	Level narrow valley floors and flood-plains	Predominantly fine-textured, but also medium-textured alluvial soils. Very poorly to poorly drained, because of high water-table; liable to flooding	Secondary forest and rain forest of *Pometia pinnata–Dillenia quercifolia–Palaquium* sp. alliance (*Palaquium* association)	Mainly V (padi) d,f
2	Medium. Higher, upstream parts of land system and along biggest streams in lower parts	Level narrow valley floors and slight levees	Predominantly medium-textured, but also fine-textured alluvial soils. Imperfectly to well drained; rare, short floods	Mainly secondary forest and regrowth of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association. Some grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	I and IV d,f

(25) Ambasi Land System (15 sq miles)

Small alluvial plains and coastal flats in northern part of the area. Altitude up to 50 ft.

No block diagram or plan because of very low relief and indistinct distribution of units on poor wartime aerial photographs.

Geology.—Recent fluviatile and marine deposits, of predominantly andesitic composition.

Geomorphology.—Small alluvial plains. Along coast low beach ridges separated by narrow swales. Poorly developed drainage system of small creeks.

Soils.—Predominantly imperfectly to very poorly drained medium-textured alluvial soils but coarse-textured on beach ridges and in most swales.

Vegetation.—Mainly regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* rain forest association. Some regrowth stages of *Barringtonia asiatica–Pterocarpus indicus* rain forest association along coast. Very locally mangrove forest and fluctuating swamp forest.

Land Class.—Probably mainly II–III (padi) d, some V (padi) d, f in lowest spots, and IIIso on beach ridges.

(26) Sagere Land System (155 sq miles)

Generally poorly drained flood-plains with predominantly fine-textured alluvial soils, in the centre of the area. Altitude 50–200 ft.

No block diagram or plan, because of very low relief, indistinct features on aerial photos, and commonly regional distribution of units.

Geology and Geomorphology.—Recent alluvium of mixed mineralogical composition, forming rather stable parts of fluvial-deltaic plains. Coarse-textured drainage pattern of meandering rivers and small streams. Considerable seasonal fluctuation in ground-water table.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Predominantly west of Kumusi River, only locally in eastern part	Flat to slightly undulating flood-plain, sparsely dissected by hardly incised small streams	Medium- to fine-textured alluvial soils. Poorly to imperfectly drained. Possibly mainly well drained in valleys in south-eastern part. Large areas shallowly inundated during wet season	Mainly regrowth stages but in south-eastern valleys mainly rain forest of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association	Probably mainly I in upper parts, II (padi) d and III (padi) d,f in lower parts
2	Large. Predominantly east of Kumusi River and along lower reaches of Opi River		Medium- to fine-textured alluvial soils. Poorly to very poorly drained. Largely inundated during wet season	Mainly rain forest of *Pometia pinnata–Dillenia quercifolia–Palaquium* sp. alliance. Some fluctuating swamp woodland of *Metroxylon sagu* association in depressions	Mainly III (padi) d,f, locally V (padi) d,f
3	Small. Scattered occurrences throughout land system, but predominantly east of Kumusi River	Elongated slight rises above general flood-plain level	Medium-textured, rarely coarse-textured alluvial soils and unweathered sandy soils with black topsoils of Popondetta family. Well drained	Regrowth of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association and grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	IIso and I
4	Very small. Along major streams west of Kumusi River	Narrow strips of slightly higher ground, which have the appearance of levees	Weathered brown clay soils of Arumu family. Well to imperfectly drained	As unit 1	IIso

(27) Ambi Land System (45 sq miles)

Sago swamps with alluvial soils near the coast and along southern edge of peat swamps (Plate 7). Mainly between 5 and 40 ft.

No block diagram or plan, because of lack of relief and regional or indistinct distribution of units.

Geology and Geomorphology.—Recent alluvium, derived mainly from Mt. Lamington, but also from other sources. Low, swampy parts of flood-plains, commonly forming distributary swamps. Very little surface drainage, few small outlet streams. Water-tables mostly well below surface in dry season and above ground surface in wet season.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Medium. Mainly in Amboga–Girua River area	Level very low-lying flood-plains	Coarse-, medium-, and fine-textured alluvial soils. Swampy to very poorly drained. Inundated during wet season	Fluctuating swamp woodland: *Metroxylon sagu* association	VIIp, s
2	Medium. Mainly in Kumusi River area			Swamp forest: *Campnosperma auriculata–Syzygium* sp. alliance. Fluctuating swamp forest: *Planchonia timorensis–Metroxylon sagu* association. Swamp woodland: *Campnosperma auriculata–Metroxylon sagu* alliance	VIIp, s

(28) Koena Land System (415 sq miles)

Extensive peat swamps with woody and herbaceous vegetation in the Kumusi–Mambare plain (Plate 8). Altitude 5–40 ft.

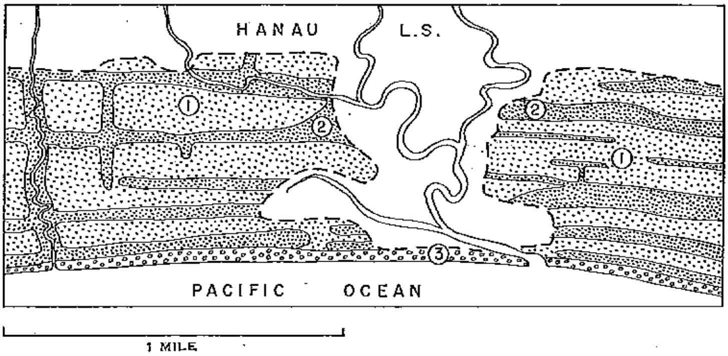
No block diagram or plan because of lack of relief and regional and indistinct distribution of units.

Geology and Geomorphology.—Recent organic deposits, locally mixed with alluvial clay and forming extensive peat swamps without surface drainage except for one small stream from Lake Koena. Also small peat bogs in cut-off meander bows and blocked narrow valleys, one of which is situated on south-western slopes of Mt. Lamington at about 2500 ft.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Very large. Throughout land system	Extensive or small back swamps	Organic soils of Koena family. Permanently swampy; water-table at or over surface	Swamp forest, swamp woodland, swamp savannah, and herbaceous swamp formation	VIIId,so
2	Small. Commonly along the edges of the land system, especially along levees of traversing large streams	Swampy flood-plains, with slightly hummocky surface, the highest parts being 1 or 2 ft above unit 1	Organic soils of Koena family and fine-textured alluvial soils. Permanently swampy; water-table near or at surface	*Metroxylon sagu–Thoracostachyum sumatranum* complex, consisting of rounded clumps of *Metroxylon sagu* association surrounded by swamp savannah or herbaceous swamp formation	VIIId,so
3	Extremely small. Along coast	Gently sloping narrow beach and low backing ridge	Dark beach sand	Bare ground and seral community of herbs, dominated by *Ipomoea pes-caprae*. Also forest of *Barringtonia asiatica–Pterocarpus indicus* association	VIIIso

(29) Buna Land System (30 sq miles)

Discontinuous parallel beach ridges and swales along the coast. Altitude 0–20 ft.



Geology and Geomorphology.—Recent coastal deposits, mainly volcanic sands with local concentrates of dark minerals. Series of roughly parallel beach ridges and swales along part of the coast, mainly near mouths of major rivers. Drainage is mainly subsurface and by very small parallel streams in swales.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Large. Throughout land system	Long, narrow, slightly rounded, low beach ridges. Roughly parallel	Unweathered sandy soils with black topsoils of Popondetta family and some dune land. Well to excessively drained	Grassland of *Saccharum spontaneum–Imperata cylindrica* alliance	IIso
2	Medium. Throughout land system, alternating with occurrences of unit 1	Long, narrow to rather wide, slight depressions. Roughly parallel	Unidentified alluvial soils, probably mainly coarse- and medium-textured. Very poorly to poorly drained	Regrowth stages of *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* rain forest association, some fluctuating swamp woodland of *Metroxylon sagu* association, and possibly other swamp communities	Vd,f
3	Small. Along sea front	Gently sloping narrow beach and low backing ridge	Dark beach sand	Regrowth stages and remnant forest of *Barringtonia asiatica–Pterocarpus indicus* association on well-established ridges. Seral communities, dominated by *Ipomoea pes-caprae*, *Calophyllum inophyllum*, or *Casuarina equisetifolia* on beach front or newly formed spits	VIIIso

(30) Killerton Land System (10 sq miles)

Small tidal mangrove swamps.

No block diagram or plan, because of lack of relief and regional or indistinct distribution of units.

Geology and Geomorphology.—Recent marine deposits, forming brackish tidal marshes with small tidal creeks diurnally flooding and draining the land.

Unit	Relative Area and Distribution	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	Very large. Throughout land system	Low-lying tidal flats with some irregular slight rises and depressions	Tidal swamp. Swampy, subject to tidal inundation or with shallow brackish water-table	Mangrove forest and some mangrove woodland	VIIId,f
2	Very small. Locally along sea front	Gently sloping, narrow beach	Volcanic or coral beach sand	Bare ground and seral communities, dominated by *Ipomoea pes-caprae*	VIIIso

PART IV. CLIMATE OF THE BUNA–KOKODA AREA

By R. O. Slatyer*

I. Introduction

The paucity of meteorological recording stations in Papua renders a sensitive appraisal of climate very difficult, but as there appears to be no marked variation in climate within this area, data for the three existing stations—Buna, Ioma, and Kokoda—provide adequate information for most purposes.

The area falls into the tropical rain forest climatic type of Köppen (1936) and is characterized by two major seasons, one drier than the other, which are determined mainly by the prevailing winds. From May to October, south-easterly winds blow fairly constantly, while from December to March, winds from directions between north-west and north-east predominate. In the intervening months of November and April, the winds are usually light and variable.

The most important features of the climate are the generally heavy rainfall and the absence of marked temperature changes in different seasons.

Copious rains fall during the December to March period and in the transitional months, but even during the south-east season the average monthly rainfall is usually in excess of 4 in. Temperatures and humidities are high and almost uniform throughout the year. These features are reflected in abundant plant growth but they make for a climate which is enervating for Europeans.

Because of the low latitude, dawn and twilight are of very short duration and day length hardly changes from season to season.

II. General Climatic Characteristics

(*a*) *Rainfall*

The average annual rainfall exceeds 120 in. (Table 2) at the three existing

Table 2

ANNUAL RAINFALL CHARACTERISTICS FOR THREE STATIONS*

	Buna	Kokoda	Ioma
Number of years	24	10	17
Average annual rainfall (in.)	120·61	142·50	155·76
Average number of wet days	162	206	177
Mean rain per wet day (in.)	0·74	0·69	0·90

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

stations and probably exceeds 100 in. in all parts of the area. In general, the annual rainfall increases in a westerly direction, but an orographic effect is also evident. At

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Oro Bay, on the eastern coastal extremity of the area, there are indications that rainfall may be somewhat lower than in other parts, but the absence of rainfall records means that this cannot be substantiated.

In Figure 2, histograms of monthly rainfall at Buna, Kokoda, and Ioma are given. These reveal the marked seasonal variations in rainfall, and the large amounts of rain received even in the "driest" months.

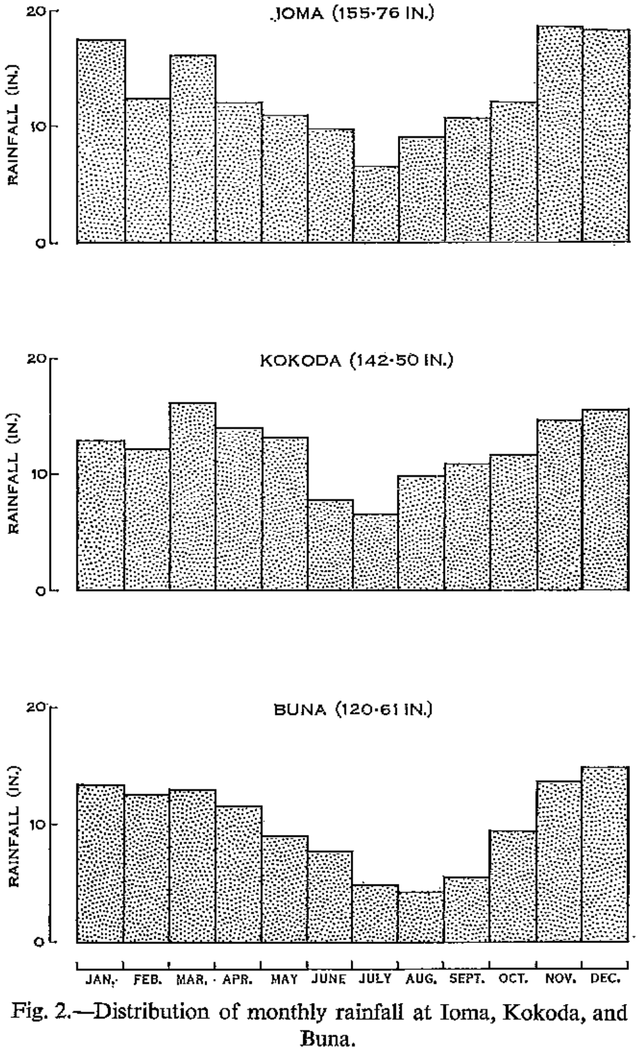

Fig. 2.—Distribution of monthly rainfall at Ioma, Kokoda, and Buna.

Intensity of rainfall on an average basis is very high and of the order of 0·70–0·90 in. per wet day. Because of the importance of rainfall intensity in agricultural cultivation, a special study has been made of the rainfall at Buna (Table 3). This probability table has been made up from the frequency distributions of daily rainfall within fortnightly periods throughout the year, and the probability of receiving falls of rain within the ranges indicated can be readily extracted.

Even in the driest months it is evident that rain falls on at least three or four days per fortnight. A large proportion of all registrations are below 0·25 in. and most of the remainder are in excess of 0·50 in. In all but the driest months one or two falls per fortnight exceed 1 in. and in the wettest periods one such fall usually exceeds 2 in. From Table 3 it is also evident that daily falls in excess of 4 in. are of rare occurrence at Buna and no fall of more than 8 in. was registered in the period

TABLE 3

PROBABILITY OF RECEIVING DAILY AMOUNTS OF RAINFALL AT BUNA IN EXCESS OF THOSE SPECIFIED

Period	0 in.	0·25 in.	0·50 in.	1·00 in.	2·00 in.	4·00 in.	8·00 in.
Jan. 1–Jan. 14	0·48	0·28	0·19	0·11	0·04	0·01	
Jan. 15–Jan. 28	0·58	0·33	0·24	0·14	0·06	0·01	
Jan. 29–Feb. 11	0·50	0·29	0·22	0·14	0·07	0·01	
Feb. 12–Feb. 25	0·50	0·28	0·18	0·11	0·06		
Feb. 26–Mar. 11	0·53	0·31	0·23	0·16	0·06	0·01	
Mar. 12–Mar. 25	0·50	0·30	0·20	0·13	0·05	0·02	
Mar. 26–Apr. 8	0·53	0·28	0·19	0·11	0·07		
Apr. 9–Apr. 22	0·47	0·24	0·19	0·11	0·05	0·02	
Apr. 23–May 6	0·49	0·30	0·20	0·10	0·04	0·01	
May 7–May 20	0·47	0·27	0·17	0·09	0·03		
May 21–June 3	0·44	0·24	0·16	0·10	0·03		
June 4–June 17	0·40	0·20	0·13	0·07	0·02		
June 18–July 1	0·34	0·19	0·12	0·07	0·02		
July 2–July 15	0·39	0·20	0·13	0·06	0·01		
July 16–July 30	0·34	0·15	0·09	0·05	0·01		
July 31–Aug. 13	0·23	0·09	0·05	0·03	0·01		
Aug. 14–Aug. 27	0·31	0·13	0·07	0·04	0·01		
Aug. 28–Sept. 10	0·39	0·20	0·11	0·06	0·02		
Sept. 11–Sept. 24	0·47	0·19	0·12	0·05	0·01		
Sept. 25–Oct. 8	0·34	0·18	0·12	0·05	0·01		
Oct. 9–Oct. 22	0·39	0·22	0·16	0·08	0·04	0·01	
Oct. 23–Nov. 6	0·48	0·28	0·20	0·10	0·06	0·01	
Nov. 7–Nov. 20	0·56	0·33	0·20	0·14	0·05		
Nov. 21–Dec. 3	0·53	0·36	0·27	0·18	0·07	0·01	
Dec. 4–Dec. 17	0·52	0·32	0·25	0·15	0·07	0·01	
Dec. 18–Dec. 31	0·50	0·31	0·22	0·14	0·07	0·02	

of years (1913–41) examined. In the May to September period, no falls of more than 4 in. occurred. This general decrease in intensity as well as frequency of rainfall in these months is well illustrated.

Variabiilty of rainfall on a year-to-year basis is of limited significance because of the large amounts of rain which fall even in years of low rainfall. The possibility of receiving inadequate amounts of rainfall during any one month is of much more importance, especially in relation to plant growth. Hounam (1951) has analysed the possibility of receiving different amounts of monthly rainfall throughout the year, and his analysis for Buna is reproduced in Table 4.

The general picture of seasonal distribution shown in Figure 2 is well illustrated here. It can be seen that in each of the months November to April, at least 8 in. of rain can be expected in more than three-quarters of the years. In the drier period from May to September, totals of this magnitude could only be expected in less than one year out of two, and in July and August, monthly totals of less than 2 in. can be expected in one year in four.

(b) *Temperature*

Throughout the area, particularly on the coast, temperatures are uniformly high throughout the year. Hogan (1940) reports that there is no definite seasonal distribution of temperature, but that there are two periods of warm and cooler weather which are associated with the north-west and south-east seasons respectively. The temperatures seldom rise higher than 95°F and rarely fall below 70°F at sea-level and more variation is noted with altitude than with other geographical variables.

TABLE 4

MONTHLY RAINFALL PROBABILITY FOR BUNA

(Chances of receiving specified monthly amounts or more. Expressed as percentage)

(After Hounam 1951)

Specified Amount (in.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	100	100	100	100	100	100	88	94	98	100	100	100
2	99	100	100	100	98	98	72	67	93	96	100	100
3	97	97	100	97	95	95	60	50	85	90	100	99
4	96	94	100	94	91	90	52	40	75	84	99	97
6	91	86	94	84	75	63	38	22	40	71	93	91
8	85	78	83	72	51	33	24	14	24	51	83	85
12	52	58	60	44	24	12	10	5	2	18	53	67
16	23	24	36	13	10	7	—	—	—	6	25	30
20	11	6	10	7	4	4	—	—	—	—	12	18
24	5	—	2	5	—	—	—	—	—	—	6	9

In this connection, Challis (1940) has observed a drop of 3°F with every 1000 ft in elevation.

In Figure 3, the annual curves of maximum and minimum temperatures are given for the coastal station of Buna and for Kokoda, 1200 ft above mean sea-level. It can be seen that maximum temperature levels are slightly higher at Kokoda, but the minimum figures are appreciably lower and this is reflected in the diurnal temperature ranges of approximately 20°F at Kokoda and only 8–12°F at Buna.

Minimum temperature varies less than maximum, although variation in both elements is very slight. At Buna, over the 5-year period 1937–41 inclusive, maximum temperatures were almost entirely confined to the range 80°F–90°F, only five registrations of less than 80°F and four in excess of 90°F being recorded. The highest individual daily maximum was 92°F in February and the lowest 74°F in July. With minimum temperatures only six registrations in excess of 77°F were made and the highest individual minimum was 83°F. The lowest minimum recorded was 66°F, of which five recordings were made.

(c) Humidity

Mean 9 a.m. relative humidity and saturation deficit figures for all months at Buna and Kokoda are plotted in the lower portion of Figure 3. Relative humidity levels are very high at both stations and vary very little throughout the year. The period of lowest relative humidity, at both stations, is at the end of the south-east season. When absolute values are compared, as in the saturation deficit curves, it is evident that Kokoda is slightly more humid than Buna in nearly every month.

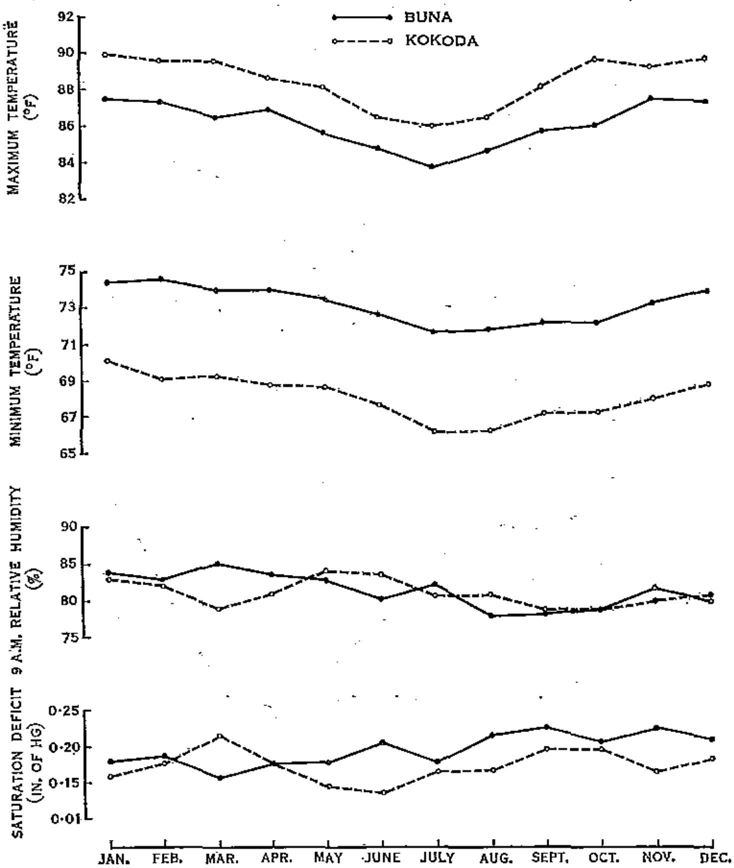

Fig. 3.—Monthly mean maximum and minimum temperatures, 9 a.m. relative humidity, and saturation deficit at Buna and Kokoda.

Even in the "driest" months, the relative humidity is 77–78% at Buna and 79% at Kokoda, and the saturation deficit does not exceed 0·23 (expressed as in. of mercury) in any month. By comparison, Darwin in northern Australia has a saturation deficit in excess of 0·23 in. every month.

Variations in relative humidity between morning (9 a.m.) and afternoon (3 p.m.) are of the order of 4–8% on the coast and slightly more inland (R.A.A.F., personal communication). Saturation levels are usually reached at night and dews are common. At elevated localities a high frequency of morning mist and fog indicates the saturated condition of the air mass.

III. Climate in Relation to Plant Growth

(a) Length of the Growing Season

From the preceding discussions on general climatic characteristics, it is evident that the uniformly high temperatures are very suitable for plant growth.

In order to assess the adequacy of the rainfall in this respect, the formula of Thornthwaite (1948) for estimating moisture requirements for plants has been

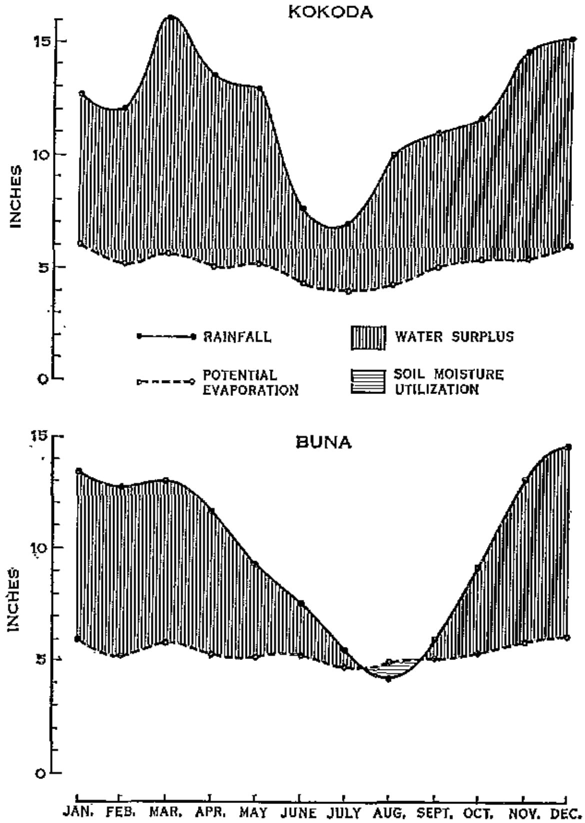

Fig. 4.—Mean monthly water surplus and deficit at Kokoda and Buna.

adopted and applied to Buna and Kokoda, the two stations for which temperature information is available.

When the average rainfall for all years of records is compared with the estimated potential evapotranspiration (Fig. 4) it is seen that in no month does the moisture requirement exceed the moisture supply at Kokoda and there is a deficit in only one month at Buna. The Thornthwaite formula, however, provides for excess rainfall to be stored in the soil up to a maximum of 4·0 in. and as the deficit at Buna in August was only 0·4 in. the growing season for both stations, on this general basis, would be considered to be of 12 months' duration. A more accurate picture is obtained when the monthly rainfall in individual years is used. The results obtained from this second analysis are shown in Table 5.

At Kokoda, the growing season, on this basis, is very seldom of less than 12 months' duration. In half of the years examined, the rainfall in at least 1 month failed to equal the potential evapotranspiration, but stored soil moisture satisfied the deficit in most instances. At Buna, on the other hand, the growing season is frequently of less than 12 months' duration but is rarely as short as 8 months. The period of water deficiency usually occurs between July and October with July and August the most likely months.

TABLE 5

LENGTH OF GROWING SEASON

	Buna (29 Yr of Records Examined)	Kokoda (10 Yr of Records Examined)
Percentage of years in which duration of growing season was:		
12 months	65	90
11 months	10	10
10 months	10	0
9 months	10	0
8 months	5	0
7 months	0	0
6 months	0	0

In the application of Thornthwaite's climatic index to actual conditions, two main points must be borne in mind. The first is that actual evapotranspiration decreases progressively as any period of dry weather ensues, and soil moisture becomes less available. Studies in northern Australia (Slatyer 1955) have shown that if a month of dry weather follows a period of heavy rainfall, the actual evapotranspiration decreases progressively during the month, and the total is only about one-half of the potential evapotranspiration.

This indicates that although the potential water need for a month may be 5 in., only 2–3 in. are utilized if no rain is received. On this basis the 4 in. of soil moisture storage which Thornthwaite allows may last appreciably longer than would be expected if the potential evapotranspiration rate was maintained until moisture reserves were exhausted. The application of this principle to the records of Buna and Kokoda would in general reduce each period of water deficiency by approximately 1 month.

The second important factor is that the soil storage figure of 4 in. applies only to some soils and crops, even though it is a useful mean figure. In the Buna–Kokoda area the storage is about 3 in. in the lightest soils and about 9 in. in the heavy soils with high organic matter concentrations. As the heavy soils are of widespread occurrence, it is evident that the high storage figure will provide sufficient water to carry plants through a long drought period. Even if the water needs are estimated at potential evapotranspiration levels, the application of the climatic index with 9 in. soil storage indicates a 12-month growing season in all years at Kokoda. At Buna only 1 year of the 29 examined has a season of less than 10 months and 85% of the years have a 12-months season. When actual evapotranspiration is used to estimate water needs (that is, assuming water needs in a dry month as one-half of the potential evapotranspiration) the growing season at Buna is 12 months in 9 years out of 10.

In the assessment of land use potential it must be remembered that any period of water stress will have an effect on plant growth and development. Although such a period may be detrimental with respect to plant growth, it is frequently of benefit to yield, and in the selection of crop plants for the area consideration should be given to these aspects.

(b) *Other Climatic Factors of Influence on Plant Growth*

As can be gathered from the preceding paragraphs, there are no major limitations to plant growth for the greater part of the year in this area. When particular crops are under consideration, however, other factors besides water shortage may limit crop growth and, perhaps more particularly, crop production. Factors of importance could include excess cloudiness, persistent rain, or very heavy rain.

(i) *Cloudiness*.—The Royal Australian Air Force (personal communication) reports that there is a tendency for average cloud amount to vary as monthly rainfall varies, but the change from month to month and from season to season is not great and, in general, skies during the daytime in the coastal areas are clouded to the extent of four- to six-tenths of total cloud. Inland there is more cloud than on the coast.

The cloud amount is greatest in the afternoon if clouds of the cumulus type are present. Such clouds usually form at about 9 a.m. and reach their greatest stage of development as cumulo-nimbi in the late afternoon with frequent thunderstorms, after which they dissolve. When stratified types of clouds occur, diurnal variation of cloud amount is a minimum, and cloud may persist unbroken for days. The bases of the cumulus clouds are usually not less than 3000 ft but the height of the base of the stratified cloud may be as low as 1000 ft, and such clouds would, of course, completely envelop Kokoda and neighbouring localities. Stratified clouds are most common in the north-west season, but cumulus types occur throughout the year.

The most important agricultural effect of excess cloudiness is probably in regard to photosynthesis and carbohydrate storage in plants. Heinicke and Childers (1937) have demonstrated that in exposed apple leaves, photosynthetic rates are reduced when light intensity falls below one-third of full sunlight. Because many leaves on a whole plant are shaded by others, however, they found that for a whole tree, photosynthesis increased progressively up to full sunlight. Similar results on the leaves of loblolly pine and maize were obtained by Kramer and Clark (1947) and Verduin and Loomis (1944) respectively. This indicates that plants such as sugar-cane or rice which depend upon rapid photosynthesis to build up crop yield may have their yields reduced if grown in the higher and more cloudy areas. On the other hand pastures, and plants which are frequently grown under partial shade, such as coffee, cocoa, or tea, may be well suited to these conditions.

(ii) *Very Heavy Rainfall.*—Very heavy falls of rain can have a most destructive effect on areas of cultivation, leading to both soil erosion and direct damage to crops. However, from Table 3 it is evident that at Buna there is very little likelihood of daily falls in excess of 4 in. occurring, but falls of 2–4 in. can be expected about once a fortnight in the wettest months. Falls of this order should not cause much damage unless received in a very short space of time.

(iii) *Persistent Rain.*—Continuous rain, even though not of excessive intensity, can have an effect on crop production by directly influencing flowering and maturation, by indirectly affecting water absorption through a restriction of soil aeration, and through other processes. To assess the probable duration and time of occurrence of such wet spells, daily rainfall was examined and the probability of receiving at least 0·25 in. of rain on consecutive days assessed. This level was chosen arbitrarily to represent minimum rainfall sufficient to keep the soil permanently saturated and the air moist. On this basis, it was found that there is little probability of the occurrence of more than six consecutive wet days, even in the wettest months, so the influence of such periods on crop plants should not be of much importance.

IV. References

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

Challis, B. G. (1940).—The climate of New Guinea. *In* "Results of Rainfall Observations Made in Papua, Mandated Territory of New Guinea, Solomon Islands, New Hebrides, etc." (Government Printer: Melbourne.)

Heinicke, A. J., and Childers, N. F. (1937).—The daily rate of photo-synthesis during the growing season of 1935 of a young apple tree of bearing age. Mem. Cornell Agric. Exp. Sta. No. 201.

Hogan, J. (1940).—A brief survey of the weather of Papua. *In* "Results of Rainfall Observations Made in Papua, Mandated Territory of New Guinea, Solomon Islands, New Hebrides, etc." (Government Printer: Melbourne.)

Hounam, C. (1951).—Meteorological and climatic conditions over British New Guinea and adjacent islands. *In* "Resources of the Territory of Papua and New Guinea". Vol. 1, Ch. 3. pp. 35–54. (Government Printer: Melbourne.)

Köppen, W. (1936).—Das geographische System der Klimate. *In* "Handbuch der Klimatologie". Vol. I, Pt. C. (Gebruder Borntrager: Berlin.)

Kramer, P. J., and Clark, W. S. (1947).—Comparison of photosynthesis in individual pine needles and entire seedlings at various light intensities. *Plant Physiol.* **22**: 51–7.

Slatyer, R. O. (1955).—Studies of the water relations of crop plants grown under natural rainfall in northern Australia. *Aust. J. Agric. Res.* **6**: 365–77.

Thornthwaite, C. W. (1948).—An approach toward a rational classification of climate. *Geogr. Rev.* **38**: 55–94.

Verduin, J., and Loomis, W. E. (1944).—Absorption of carbon dioxide by maize. *Plant Physiol.* **19**: 278–93.

PART V. GEOLOGY OF THE BUNA–KOKODA AREA

By S. J. Paterson*

I. Regional Geology

The Buna–Kokoda area consists of part of the northern exposed section of the Cape Vogel basin and part of Glaessner's (1950) Morobe arc and Owen Stanley folded zone. The basin is typical of Kay's (1947) eugeosynclines, for it is an orogenically and volcanically active linear belt of long-continued subsidence, characterized by volcanic rocks, tuffaceous sandstones, cherts, and dark shales. It lies between two metamorphic-igneous arcs of which the Morobe arc and Owen Stanley folded zone

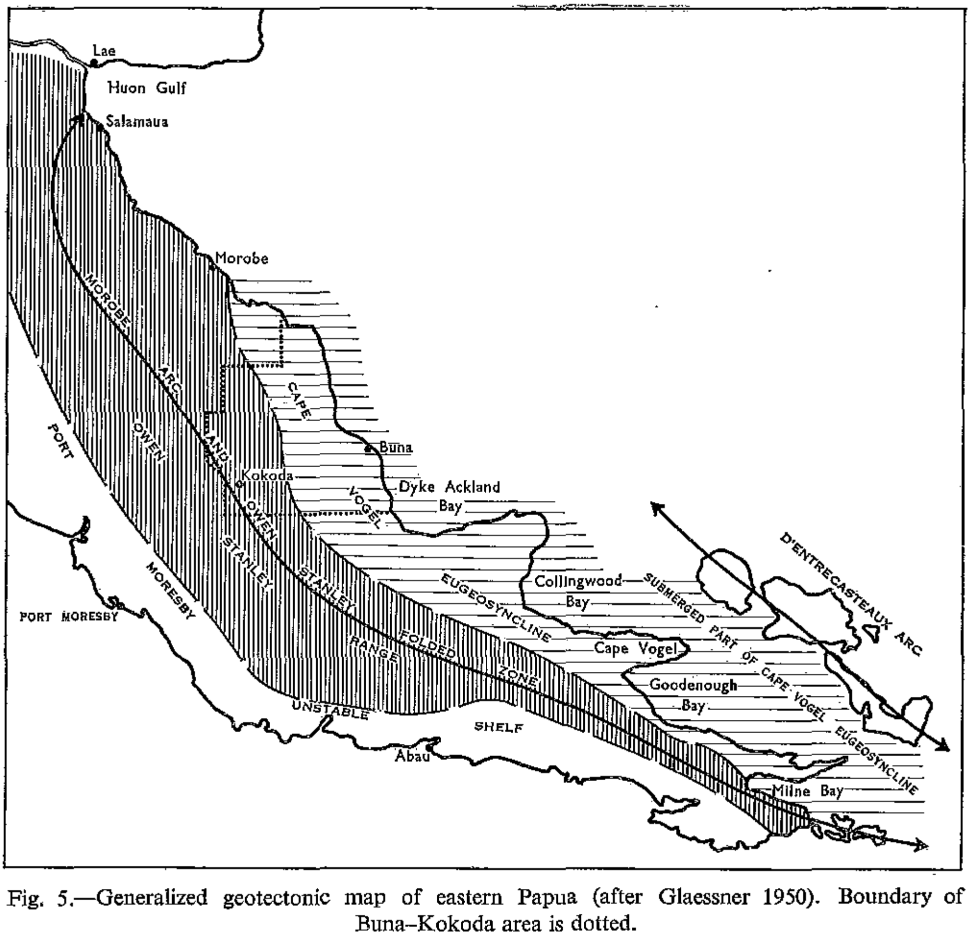

Fig. 5.—Generalized geotectonic map of eastern Papua (after Glaessner 1950). Boundary of Buna–Kokoda area is dotted.

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are one and the D'Entrecasteaux arc is the other. The greater part of the basin is at present covered by the sea. The relationship between basin and arcs is shown on Figure 5.

II. Stratigraphy

The exposed section of the Cape Vogel basin lying within the area contains a thick sequence of lower Burdigalian (lower "f_{1-2}" stage of the Dutch classification) and possibly Aquitanian ("e" stage) volcanics and tuffaceous sediments, thin Burdigalian ("f_{1-2}" stage) limestones, isolated outcrops of Pliocene sandstones and mudstones, and thick Quaternary volcanics and alluvia. The part of the Morobe arc and Owen Stanley folded zone is composed of metamorphic rocks of the Owen Stanley Range and igneous rocks of the Ajule Kajale Range. The stratigraphy is summarized in Table 6. Its relationships to the geomorphological units, subunits, and land systems are indicated on the reference to the accompanying map.

(*a*) *Probably Palaeozoic*

(i) *Owen Stanley Metamorphics.*—The oldest exposed rocks are the metamorphics located along the northern slopes of the Owen Stanley and Guaya Ranges (Misima land system). These were originally described by Stanley (1919), who named them the "Owen Stanley Series". They consist of "highly altered biotite schists and gneisses of igneous origin and epidote and chlorite schists and gneisses". In the same area the writer examined quartz–muscovite–chlorite gneiss, garnetiferous calc–silicate rock, calc schist, garnetiferous cordierite–actinolite schist, and glaucophane–cordierite schist (see Appendix I).

The age of the rocks is unknown, but they are pre-Tertiary, for they are the basement rocks of the Cape Vogel basin. The degree of metamorphism suggests that they are of Palaeozoic age.

(*b*) *Mesozoic and/or Lower Tertiary*

(i) *Low-grade Metamorphics.*—No sediments of Mesozoic age were observed during the survey, but Davies (personal communication, 1959) reports lithified greywacke, mudstone with calcareous veining, and sericite siltstone in the Kokoda–Yodda fault trough. These rocks are steeply dipping and show much minor faulting, and the siltstones may be intruded by dolerite on Oivi ridge. They might be Mesozoic or Lower Tertiary in age.

(ii) *Ajule Kajale Complex.*—Serpentinized peridotite and dunite, olivine gabbro, olivine-hypersthene gabbro, hornblende gabbro, augite norite, and hypersthene dolerite intrude the Owen Stanley metamorphics in the Buna–Kokoda area. The main mass of the complex forms the Ajule Kajale Range (Botue land system), which lies to the north of the Kokoda–Yodda valley. The complex name has been taken from the range name and the type exposures occur in the Arumu River in the vicinity of 8°50′S. lat. and 147°46′E. long. This mass is elongated in the north-north-west direction and extends from near the Kumusi River–Oivi Creek junction to north of the Chirima–Mambare River junction. Peridotite and dunite also occur in the Guaya Range, on the southern side of the Mamama River, south of Mt. Lamington (Oivi land system).

The age of the intrusions is not known, but they are thought to be Mesozoic or early Tertiary. Similar gabbros, dolerites, and serpentines are found in the Port Moresby area, where Glaessner (1952) regards the intrusions as being of Oligocene age.

TABLE 6

STRATIGRAPHY OF THE BUNA–KOKODA AREA

Age	Formation	Description	Thickness (ft)
Recent to Pleistocene	Mt. Lamington volcanics	Poorly consolidated andesitic ash and agglomerate; hornblende–augite andesite, hornblende–biotite andesite, hypersthene–augite andesite, and lamprobolite andesite flows and coulees	c.3500
Recent to Pleistocene	Alluvium	Unconsolidated gravel, sand, silt, and peat with beach ridges containing concentrates of augite, hornblende, and magnetite	Unknown
Pleistocene	Hydrographers Range volcanics	Andesitic tuff and agglomerate; augite basalt, augite andesite, augite–hypersthene andesite, biotite–hypersthene andesite, and lamprobolite andesite flows	c.6000
		Angular unconformity	
Pliocene (probably)	Mamama formation	Greyish mauve carbonaceous sandstones, mudstones, and laminated shale; fine and coarse conglomerates containing pebbles of basalt and serpentinized peridotite	100+
		Disconformity	
Miocene "f_{1-2}" (Burdigalian)	Robinson Bay limestone	White, grey, and pale pink massive algal-foraminiferal detrital limestones	400+
Miocene "f_{1-2}" (Burdigalian and possibly Aquitanian)	Iauga formation	Olivine and augite basalts, augite andesite, quartz microdiorite, agglomerate, andesitic tuffs, and tuffaceous sandstone	2000+
		Angular unconformity	
Mesozoic or Early Tertiary	Ajule Kajale complex	Peridotite, dunite, olivine gabbro, olivine–hypersthene gabbro, hornblende gabbro, augite norite, and hypersthene dolerite	?
Mesozoic		Lithified fine greywacke, mudstone, and sericitic siltstone	?
Palaeozoic (probably)	Owen Stanley metamorphics	Quartz–muscovite–chlorite gneiss, garnetiferous calc–silicate rock, calc–silicate rock, calc schist, and glaucophane–cordierite schist	?

(c) *Tertiary.*

(i) *Lower Burdigalian and Possibly Aquitanian: Iauga Formation.*—Iauga formation forms the base of the Tertiary sequence in the northern part of the Cape Vogel basin. The formation is typically developed in the Iauga plateau (Iauga land system), between latitudes 8°20′ S. and 8°19′ S. in the vicinity of longitude 148°05′ E., and the formation name is taken from the plateau name. The type exposures are located along the northern and eastern slopes of the plateau. Similar rocks are found east of the Ajule Kajale Range.

The volcanics are predominantly basaltic, ranging from olivine and augite basalt to augite andesite and quartz microdiorite. These are accompanied by agglomerate, andesitic tuff, and tuffaceous sandstone. Olivine and augite basalt and agglomerate containing boulders of these lavas are dominant on the northern slopes of the plateau. The eastern and southern slopes are composed of similar lavas, but these are accompanied by greater development of andesite, andesitic tuff, and tuffaceous sandstone. The low hills east of the Ajule Kajale Range (Mt. Green land system) extending south-east from the Gira River are dominantly composed of agglomerate, andesitic tuff, and calcareous tuffaceous sandstone. The sharp, higher eastern foothills (Hegahorte land system) consist mainly of quartz dolerite and basalt (Davies, personal communication).

The thickness of the formation is unknown, but it is estimated to be over 2000 ft.

The only fossiliferous sample (No. 83), a tuffaceous sandstone collected from the uppermost part of the formation, yielded the following foraminifera: *Miogypsina kotoi* Hanzawa, *Lepidocyclina* cf. *verbeeki* Newton & Holland, *Amphistegina* sp. Kicinski (Paterson and Kicinski 1956), who made the determinations, states that the fauna does not differ from that of the overlying conformable Robinson Bay limestone. At least the uppermost beds of the Iauga formation are of Burdigalian age; the rest possibly belong to older stages.

The volcanics of the Iauga formation are petrologically related to the Ajule Kajale complex (Appendix I) and it is likely that they are phases of the same period of igneous activity.

(ii) *Burdigalian: Robinson Bay Limestone.*—Algal-foraminiferal detrital limestone, ranging in colour from white to pale pink, conformably overlies the Iauga formation. It is in turn disconformably overlain by the Pliocene Mamama formation. The limestone is massive and poorly bedded.

The limestone crops out on the northern arm of Robinson Bay (Iauga land system), on the eastern slopes of the Iauga plateau, and the formation name is taken from the bay name. The type exposures occur at 8°07′ S. lat. and 148°09′ E. long. The type section contains 60 ft of limestone, which dips to the west at 45°. The section grades upwards from a tuffaceous limestone through limestone containing small percentages of tuffaceous material, such as clinopyroxenes, plagioclase, and zeolites, to pure limestone.

The limestone also occurs as thin cappings on hills of Iauga formation material in a zone extending from the mouths of the Mambare and Gira Rivers to the northern slopes of the Ajule Kajale Range (Mt. Green land system). An outcrop of limestone in the vicinity of the Ioma Administration Station is known as Armit caves. The caves were not visited in the field but a stereocomparagraph examination of aerial photographs suggests the presence of some 400 ft of limestone.

The limestone is richly fossiliferous and Kicinski (Paterson and Kicinski 1956) has determined two main assemblages. These are discussed in detail in the reference given above, but briefly they are:

Samples 44–50, 64, 72–3, 81–2, 87–9 and 100–4:

Borelis haueri (d'Orb.)
Miogypsina kotoi Hanzawa
Austrotrillina howchini (Slumberger)
Lepidocyclina (N.) *ferreroi* Provale
L. (N.) *verrucosa* Scheffen
L. (N.) *angulosa* Provale
L. (N.) cf. *verbeeki* Newton & Holland
L. (N.) *sumatrensis* Brady
L. (N.) *rutteni* van der Vlerk
L. (N.) *inflata* Provale
Linderina sp. indet.

This assemblage is typical of the Burdigalian ("f_{1-2}" stage).

Sample 78:

"*Assilina*" cf. *orientalis* Douville
Borelis (*Neoalveolina*, Silvestri) *haueri* (d'Orb.)
B. pygmea Hanzawa
Miogypsinoides dehaarti van der Vlerk
Flosculinella bontangensis (Rutten)
Alveolinella fennemai Checchia-Rispoli
Lepidocyclina (N.) *rutteni lauensis* Cole.

This assemblage is apparently older than that contained in the other samples. However, it is regarded as being of Burdigalian ("f_{1-2}" stage) age.

(iii) *Probably Pliocene: Mamama Formation.*—Sediments of the Mamama formation only crop out in two isolated localities. The type exposures occur in a small tributary of the Mamama River at 9°02′ S. lat. and 148°10′ E. long. just south of the survey area, and the formation name is taken from the Mamama River. Stanley (1919) described the beds as:

40 ft of coarse conglomerate containing pebbles of serpentinized peridotites and basalts;
6 in. of fine conglomerate and mudstone;
3 ft of laminated shale with plant remains;
18 in. of greyish mauve mudstone.

The beds are subhorizontal and rest unconformably on rocks of the Owen Stanley metamorphics.

Similar rocks form bars (shown on the map) in the Mambare River, near the villages of Sia and Bebewa (approximately 8°10′ S.lat. and 148°01′ E.long.). In this locality some 100 ft of fine-grained loosely compacted sandstone and carbonaceous mudstone crop out in an anticlinal structure disconformably overlying Robinson Bay limestone.

All specimens collected from the two localities were found to be unfossiliferous but, because of their relationship to the Robinson Bay limestone and their similarities to Pliocene rocks from various parts of New Guinea, they are regarded as being of Pliocene age.

(*d*) *Quaternary*

(i) *Pleistocene: Hydrographers Range Volcanics.*—Deposits of the Hydrographers Range volcano appear to rest unconformably on the probably Pliocene Mamama formation and, in common with the deposits of other extinct or dormant volcanoes in New Guinea, are regarded as being of Pleistocene age.

The formation name is taken from the range name, and the range is located in the vicinity of 8°54′ S. lat. and 148°22′ E. long. The range is composed of tuffs overlain by basalt, andesite, and agglomerate containing basalt and andesite boulders. Columnar lava flows and agglomerate beds predominate, and the deposits have a maximum thickness of about 6000 ft.

(ii) *Pleistocene to Recent: Mt. Lamington Volcanics.*—The volcanics of Mt. Lamington consist of andesitic ash and agglomerate, with an aggregate thickness of about 3500 ft, overlain by lava flows and coulees of hypersthene–augite–biotite andesite, hornblende–biotite andesite, hornblende–augite andesite, and lamprobolite andesite.

The formation name is taken from the mountain name and the type locality is in the vicinity of 8°55′ S. lat. and 148°10′ E. long.

The age of a charred wood sample, marked "wood sample" on inset to accompanying map, from ash beds at an altitude of 2000 ft at the bottom of a gorge near the summit area, has been determined by ^{14}C dating* to be between 13,500 and 14,000 years. These ash beds belong to an early phase of volcanic activity, thus Mt. Lamington was active during late Pleistocene time. The catastrophic eruption of the explosive Pelean type that occurred in 1951 has been fully described by Taylor (1958).

(iii) *Pleistocene to Recent: Alluvium.*—Possibly Pleistocene piedmont deposits occur along the eastern slopes of the Ajule Kajale Range and in the Kokoda–Yodda fault trough. Some of the deposits of the fault trough may, however, be of lacustrine origin. The material consists of poorly consolidated coarse conglomerate, sand, and mud, and a maximum thickness of about 150 ft occurs in the fault trough. An extensive low, flat, young alluvial plain forms a wide belt extending from the base of Hydrographers Range to the Gira River. The material consists of unconsolidated gravel, sand, silt, and peat derived from a wide variety of metamorphic, igneous,

* Grateful acknowledgment is made to the Dominion Laboratory, D.S.I.R., Wellington, New Zealand, for carrying out the age determination.

and sedimentary rocks. Beach ridges are located where the plain is advancing towards the sea and these contain concentrates of heavy minerals. Those derived from Mt. Lamington are rich in hornblende and magnetite (sample 1), those derived from Iauga formation contain much augite (sample 76).

III. Structure

The Owen Stanley metamorphics, the basement rocks of the Cape Vogel basin, are closely folded and micro-folding is common. The Iauga formation, Robinson Bay limestone, and Mamama formation, the deposits in the basin, are dominantly broadly folded, and steep dips and close structures are only found in the neighbourhood of major faults.

Two major fault troughs are located within the area and these are associated with the Kokoda and Yodda and the Sia and Bebewa faults (see accompanying map). The trend of the Kokoda fault in the eastern part of the Kokoda–Yodda valley suggests that the fault passes under the centres of volcanic activity at Mt. Lamington and the Hydrographers Range. The Baru fault has important topographic expression in the Iauga plateau. The geometry of the faulting is largely unknown.

IV. Geological History

The deposition and metamorphism of the Owen Stanley metamorphics are pre-Tertiary (probably Palaeozoic) events and the intrusion of the Ajule Kajale complex probably took place during Mesozoic or Lower Tertiary time. Glaessner (1952) regards similar intrusions in the Port Moresby area as being of Oligocene age.

Within the area deposition in the Cape Vogel basin apparently commenced in Lower Tertiary time, when the Iauga formation, of dominantly volcanic composition, was deposited. Volcanic activity was prolonged and violent and over 2000 ft of volcanic material accumulated. This and later volcanic activity during the Pleistocene and the Recent characterize the basin as a typical eugeosyncline. Volcanic activity temporarily abated during Burdigalian time and the Robinson Bay limestone was deposited conformably on the Iauga formation.

No Upper Miocene sediments were found in the area and the probably Pliocene Mamama formation lies disconformably on the Robinson Bay limestone. Thus non-deposition in Upper Miocene time or an erosional break in late Upper Miocene time is indicated.

Broad folding and strong faulting movements occurred during late Pliocene or early Pleistocene time.

These movements formed at least two fault troughs and resulted in differential uplift of the Iauga plateau. Faulting probably located the centres of volcanic activity.

During Pleistocene to Recent time there was much renewed volcanic activity in the southern part of the area and extensive alluvial-deltaic plains formed whilst lacustrine sediments were deposited in the Kokoda–Yodda valley.

V. References

Glaessner, M. F. (1950).—Geotectonic position of New Guinea. *Bull. Amer. Ass. Petrol. Geol.* **34**: 856–81.

Glaessner, M. F. (1952).—"Geology of Port Moresby, Papua." *In* Sir Douglas Mawson Anniversary Volume, ed. M. F. Glaessner and E. A. Rudd. (University of Adelaide: Adelaide.)

Kay, M. (1947).—Geosynclinal nomenclature and the craton. *Bull. Amer. Ass. Petrol. Geol.* **31**: 1289–93.

Paterson, S. J., and Kicinski, F. M. (1956).—Account of the geology and petroleum prospects of the Cape Vogel basin, Papua. Rep. Bur. Miner. Resour. Aust. **25**: 47–70.

Stanley, E. R. (1919).—Geological expedition across the Owen Stanley Range. Ann. Rep. Papua (1917–18): 75–84.

Taylor, G. A. (1958).—The 1951 eruption of Mount Lamington, Papua. Bur. Min. Resour. Aust. Bull. No. 38.

PART VI. GEOMORPHOLOGY OF THE BUNA–KOKODA AREA

By S. J. Paterson*

I. Geomorphological Regions

The area contains parts of four geomorphological regions. These are shown on an inset to the accompanying map and are as follows:

(1) The Main Cordillera, a portion of which occupies the western part of the area. This is made up of complex mountains, the Owen Stanley and Ajule Kajale Ranges, which rise to over 6000 ft.

(2) The Mambare Foothills, bordering the eastern slopes of the main cordillera and consisting of low ridges, hogbacks, cuestas, mesas, and a warped-faulted coastal plateau.

(3) The Mt. Lamington–Hydrographers Range Volcanic Region, which occupies the southern part of the area. This region consists of an active and an extinct volcano.

(4) The Kumusi–Mambare Lowlands, a vast fluvial-deltaic plain, which occupies the eastern part of the area.

II. Geomorphological Units and Subunits

For descriptive purposes the area has been resolved into a number of geomorphological units (von Engeln 1942) characterized by a common structure and common processes acting on the structure. Where possible the units have been subdivided into subunits, which are variations within the same structural unit. The relationship between geomorphological units and subunits on the one hand and land systems and geological formations on the other hand is indicated in the reference to the accompanying map. The distribution of the geomorphological units and subunits is shown on this map.

(a) *Complex Mountains and Hills*

This unit consists of that part of the main cordillera of New Guinea which is drained by the Mambare (excluding the Chirima branch) and Kumusi River systems. It is subdivided into three subunits: the metamorphic mountains, the igneous mountains, and the metamorphic and igneous hills.

(i) *Metamorphic Mountains*.—The north-eastern slopes of the Owen Stanley Range form this subunit. It is composed of strongly contorted metamorphics, and the topography is extremely rugged (Misima land system). The slopes rise to over 7500 ft and along the Yodda fault they are composed of dip slopes dipping to the north-east at 30° to 45°. They are drained by a coarse-textured pattern of parallel mountain streams, which flow in narrow V-shaped gorges. The drainage pattern is visible in Plate 1, Figure 1.

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The mountains are a combination of fold and block mountains; they have a complex internal folded structure and much of their present height is the result of faulting.

(ii) *Igneous Mountains.*—The Ajule Kajale Range forms this subunit. The range is composed of ultrabasic and basic plutonic and hypabyssal rocks (Botue land system).

The mountains are combination dome and block mountains and the topography is rugged, especially in the central part where the altitude is about 6000 ft. Low hilly areas at summit level and on broad declines occur in the south-west and are probably remnants of an old surface, pre-dating the latest uplift. Aerial photographs indicate that joint systems exert strong control on the drainage pattern, which is fine and angular. In many places the more gentle slopes are covered by more than 6 ft of volcanic ash from Mt. Lamington.

(iii) *Metamorphic and Igneous Hills.*—This subunit forms a series of isolated high (Oivi land system) and low (Komondo land system) ridge complexes, just north of the Kokoda fault scarp. They consist partly of low-grade metamorphic rocks and partly (probably largely) of basic and ultrabasic igneous rocks. The low ridges commonly have a fan-shaped arrangement and abut the fault scarp. They are partly covered with overburden from the Owen Stanley Range. All ridges have steep and generally densely dissected slopes and rounded crests. They stand up to 1000 ft above the surrounding valley plain and reach altitudes of 1500–2500 ft.

(*b*) *Simple Fold Mountains and Hills*

This unit embraces the low north-eastern foothills of the Ajule Kajale Range and a low coastal plateau. They are mainly formed from Iauga formation rocks (basalt, andesite, microdiorite, agglomerate, andesitic tuffs, and tuffaceous sandstone) capped in places by Robinson Bay limestone, which forms a few dissected mesas in Mt. Green land system.

The foothills of the Ajule Kajale Range include a series of sub-maturely dissected ridges, hogbacks, and cuestas formed on quartz dolerites, basalts, and tuffaceous sediments (Hegahorte land system). Otherwise they consist of intricately dissected low hills of subhorizontal volcanic rocks (Mt. Green land system). The altitude of this zone ranges from about 200 ft to 1000 ft.

A warped-faulted coastal plateau (Iauga land system) is located in the north-eastern corner of the area. Its altitude ranges from about 1200 ft in the north to about 400 ft in the south, and its boundaries are strongly fault-controlled.

(*c*) *Extinct Volcano*

The Hydrographers Range, an extinct strato volcano reaching an altitude of 6000 ft and composed of basalt and andesite flows and agglomerate beds, occupies the south-eastern corner of the area (Hydrographers land system). Notwithstanding strong dissection, for it is probably of Pleistocene age, the general volcanic profile is clearly visible (Plate 2, Fig. 1) and the summit area is distinct, though no crater is discernible. The mountain has the typical forms of a dominantly effusive tropical volcano. The original slopes have been largely reduced to radial razorback ridges, which exhibit many landslip scars and are separated by a fine-textured pattern of youthful V-shaped valleys cut by radial consequent streams. Some of the ridges have narrow flat crests on which volcanic ash from Mt. Lamington has accumulated. The narrow valleys widen considerably in the foothill zone, although the sides still remain steep, and in some of the headwater tracts there are amphitheatre valleys similar to those found on the Hawaiian volcanoes, but on a smaller scale. On the lower slopes the gently inclined lava flows show some tendency towards narrow triangular-shaped plateaux known as planezes. These are closely but not deeply dissected.

(*d*) *Active Volcano*

Mt. Lamington is an active strato-cumulo volcano built of unconsolidated ejectamenta and lava flows and characterized by a lava dome. It occupies the southern central part of the area. The mountain reaches an altitude of more than 5000 ft and is asymmetric in outline, for its development is restricted on the east by the Hydrographers Range and on the south by the Guaya and Owen Stanley Ranges. The unit is subdivided into three subunits: the summit and adventive features, the lahar–glowing avalanche slopes, and the piedmont-banjir plains. These are based on the scheme developed by Schmidt (1934) to account for the two discontinuities of slope in the profile of this type of tropical volcano.

(i) *Summit and Adventive Features*.—This complicated subunit, corresponding to Lamington land system, includes such features as tholoids and adventive cones of different type and age, lava flows and coulees, and ash slopes. A detailed picture of the distribution of these elements is given on an inset to the accompanying map.

The tholoid or lava dome is a prominent feature of a cumulo volcano (Plate 1, Fig. 2). The present tholoid has been extruded within the crater since the last eruption in 1951 (see also Taylor 1958), and it is composed of much-fractured, viscous, andesitic lava. Its surface is strewn with boulders and has numerous vents issuing steam and volcanic gases.* It rises about 1500 ft above the crater floor.

Remnants of previously extruded tholoids are located to the east and south and form part of the present crater wall. They are dissected and were partly removed by later eruptions.

Most of the adventive cones are similar to the tholoids and appear to be extrusions of highly viscous lava. One of these occurs in the true summit area, but outside the old crater wall. The others are found in three groups: a cluster of four, three of which are very young and undissected, on the upper western slopes; a row of three, of which only one is young, on the lower western slopes; and a group of four, of which only one low dome is undissected, on the lower south-eastern slopes. It is not always easy to distinguish between the dissected adventive domes and dissected lava flows. Associated with the two lowest groups of domes are two ash cones with a clear central crater depression, one in the south-west and one in the south-east.

Lava flow and coulees appear to be a late development in the activity of the volcano, for they are extruded upon the ash and lahar–glowing avalanche slopes.

* At least in 1953.

The oldest flows are concentrated on the south-eastern flank of the mountain and are strongly dissected into rugged ridges of high relief. Included in this group are two occurrences on the north-east slopes that are possibly dissected domes or adventive cones, and a few flows on the upper western slopes that appear to be strongly dissected but younger coulees. Younger lava flows of the coulee type are restricted to the western slopes of the volcano (Plate 2, Fig. 1). They are viscous andesitic flows with a pronounced convex surface and only initial gully dissection. With the inclusion of the strongly dissected coulees mentioned above, at least three successive flows can be recognized. Also included in the lava flows are a number of short asymmetrical and probably tilted ridges. These have rock-cut faces towards the crater and dissected more gentle slopes away from it. They are found in two groups north and south-west of the summit.

The ash slopes are the slopes formed by the dry accumulation of ash and cinders in a narrow zone of steep declivity encircling the crater. They commonly cover lava flows that form the actual crater wall. On the other hand the ash slopes are discontinuous, for in part they have been locally sealed under younger lava flows of the coulee type. Included in the first category is the talus slope around the present tholoid.

The ash slopes have a markedly radial drainage pattern of dry gullies and are subdivided on the inset map into superficially and severely dissected types of slopes. This difference is probably due to the age and degree of dissection of the underlying lavas.

(ii) *Lahar–Glowing Avalanche Slopes.*—The lahar–glowing avalanche slopes are formed of volcanic material transported down the mountain by lahars (mud flows) and glowing avalanches (flows of incandescent volcanic material carried by hot air and volcanic gases). The slopes form a zone below and encircling the ash slopes. This zone is confined on the south and east by the foothills of the Guaya and Hydrographers Ranges, but it is extensively developed to the north and west (Plate 2, Fig. 1). The average gradient of the slopes ranges from 2·5% to over 8%. Strong and deep dissection by many radial consequent streams in a large part of this subunit (Hamamutu and Higatura land systems) makes travel around the mountain extremely difficult. However, large undulating areas, mostly at low elevations, are little dissected (Awala land system).

Lahar deposits blocking small valleys have formed three small lakes on the northern, eastern, and south-western flanks of the mountain.

(iii) *Piedmont-banjir Plains.*—The piedmont-banjir plains form the lowermost slopes of the mountain and are only found on the unconfined northern flank. The combined term piedmont-banjir—piedmont after von Engeln (1942) and banjir after Schmidt (1934)—is used to indicate material deposited in fan fashion at the base of the mountain by rivers in flood. Owing to the greater distance of river transport, the deposits are better sorted than those occurring on the other slopes, but they are irregularly stratified. The plain has a gradient of from 1% to 2% and grades into the lahar–glowing avalanche slopes. It is dissected by few large and many small radial consequent streams.

(e) *Depositional Plains*

This unit includes all the low-lying, nearly flat country between the foothills of the main cordillera, the volcanic mountains, and the sea, and in the Kokoda–Yodda fault trough. It is subdivided into five subunits: the piedmont terraces, the volcanic outwash plains, the fluvial-deltaic plains, the peat swamps, and the strand plains.

(i) *Piedmont Terraces*.—Piedmont terraces (Plate 1, Fig. 1) occur in the Kokoda–Yodda fault trough and along the base of the foothills of the Ajule Kajale Range in the vicinity of Ioma.

The terraces in the trough (Kokoda land system) are generally at an altitude of 900–1200 ft and abut against the Yodda fault scarp. There are two terrace levels, one being approximately 30 ft below the other. These slope away from the scarp with gradients of 4% to 6%, and strong dissection has produced numerous triangular-shaped remnants. A layer of recent volcanic ash from Mt. Lamington covers their surface to a depth of at least 6 ft.

Some of the terraces located in the western part of the trough may be of lacustrine origin, for it seems likely that Pleistocene trough movements dammed the Mambare River for a period.

The terraces in the vicinity of Ioma (Ioma land system) have a range of altitude of 100 to 500 ft. They are usually separated from the fluvial-deltaic plains by a dissected, short, steep decline and are partly densely dissected.

(ii) *Volcanic Outwash Plains*.—These plains (Plate 3, Fig. 1) occupy large funnel-shaped areas north-east of Mt. Lamington and consist of mainly sandy fan-sediments deposited after earlier eruptions of the volcano. The main streams are more or less braided, fast-flowing, and well incised in the upper parts of the plain (Popondetta and Penderetta land systems), but in the lower parts they are more meandering (Hanau land system). Their courses become indistinct with many small distributary channels in the low-lying coastal part of this subunit (Sananda land system), which is inadequately drained by numerous small local streams. The development of these outwash plains caused the blockage of four valleys in the northern foothills of the Hydrographers Range, thus giving rise to the formation of the Embi lakes.

(iii) *Fluvial-deltaic Plains*.—This subunit includes all non-swampy flood-plains throughout the area, and can be regionally subdivided into four groups.

The largest tracts of fluvial-deltaic plain occur in the central part of the area and are formed by the major river systems of the Gira, Mambare, Opi, and Kumusi Rivers. In the higher parts of the plains these rivers are slightly incised, but they have built low levees in the lower parts, where they have markedly meandering courses (Deunia land system). Changes in stream beds occur frequently as shown by numerous cut-off meanders and by differences on aerial photographs taken in 1943, 1951, and 1954. Large areas traversed by these rivers are poorly drained and frequently inundated (Sagere land system).

The flood-plains formed by numerous fast-flowing streams between the terrace remnants in the Kokoda–Yodda fault trough (Ilimo land system) are characterized by steep gradients of up to 8%.

A system of small flood-plains, for the most part extending up wide valleys in the foothills (Warisota land system), is formed by the rivers draining the Hydrographers Range (Plate 3, Fig. 2).

Small flood-plains with minor beach ridge development and associated with the Iauga plateau were mapped in this subunit as Ambasi land system.

(iv) *Swamps.*—Peat swamps (Koena land system) occupy large areas of the depositional plains on both sides of the lower Mambare and Kumusi Rivers. The swamps occur in areas behind the levees where the deposition of sediment is minor compared with the rate of accumulation of organic matter. The thickness of peat is unknown but it is more than 7 ft at short distances from the edges of the swamps. The greatest thickness probably occurs in the Lake Koena area. The swamps have a permanent surface water-table and are drained by only a few small streams. They are separated from the sea by narrow sandy beaches or beach ridges.

Swamps with mineral soils (Ambi land system) occur as more or less isolated patches on low parts of the fluvial plains, mainly close to the coast. These are very wet or inundated during the wet season, but have a water-table below the surface in the drier part of the year. The delta of the Kumusi River is included in this.

(v) *Strand Plains.*—In the Buna–Gona area, where the shoreline is advancing seaward, a succession of beach ridges and swales has formed parallel to the shore (Buna land system). The height difference between ridges and swales is of the order of 5 to 10 ft and except for the front slope of the foremost ridge, they are well fixed by vegetation.

In some places between the Opi and Kumusi River mouths, the sea is in ascendance and the shoreline is retreating, leaving dead trees standing in the sea.

Raised coral beaches, elevated from a few feet to 30 feet above sea-level, border the Iauga plateau, and disjointed coral reefs fringe the shoreline of the remainder of the area. The patchy and minor reef development is probably the result of retardation of coral growth by the vast quantities of debris discharged into the sea by the rivers.

Tidal mangrove flats (Killerton land system) are nowhere extensive and are mainly associated with major beach ridges and with rocky foreshores of the Iauga plateau and Hydrographers Range. One of the largest occurrences is associated with the delta of the Mambare River.

III. Geomorphogeny

The late Pliocene–early Pleistocene folding–faulting movements may be considered the initiation point in the development of the present land forms. They were responsible for the formation of the Kokoda–Yodda and the Sia–Bebewa fault troughs, the differential uplift of the Iauga plateau, and probably the location of the Hydrographers Range centre of volcanic activity.

At that time the areas now covered by fluvial-deltaic deposits were probably shallow seas in which the Iauga plateau and the low hills near Divinikoiari and Deunia villages were islands.

The movements accelerated erosion and the first results were the deposition of extensive piedmonts. It is probable that movement along the Kokoda fault dammed the Mambare River and that lacustrine material accumulated in a temporary lake.

During the late Pleistocene, the centre of volcanic activity shifted to Mt. Lamington, which is still active.

During the present erosion cycle the uplands throughout the area were strongly dissected. The erosion products, together with the enormous quantity of unconsolidated material supplied by Mt. Lamington, built up the extensive fluvial-deltaic plain that has linked the former islands — Iauga plateau and hills near Divinikoiari and Deunia villages—to the mainland. Generally, this plain is continuing to advance seawards.

IV. References

von Engeln, O. D. (1942).—"Geomorphology: Systematic and Regional." (The Macmillan Company: New York.)

Schmidt, K. G. (1934).—Die Schuttstrome am Merapi auf Java nach dem Ausbrauch von 1930. *Ingen. Ned. Ind.* **1**(4): 91, 123, 143.

Taylor, G. A. (1958).—The 1951 eruption of Mount Lamington, Papua. Bur. Min. Resour. Aust. Bull. No. 38.

PART VII. SOILS OF THE BUNA–KOKODA AREA

By H. A. HAANTJENS*

I. CLASSIFICATION

The soil profiles examined during this reconnaissance survey have been placed in seven major soil groups (*a–g*)† and one group (*h*) of miscellaneous land types. Group *h* is used in conformity with American soil survey practice (U.S. Department of Agriculture 1951). Groups *a* to *g* are groups of convenience that appear to suit the local conditions. They are to be considered as morphogenetic units which have been given brief descriptive names. Each group has been subdivided into more narrowly defined taxonomic units, which have been given locality names and called soil families.

The relationships of the major soil groups and constituting soil families with great soil groups and with the higher categories of the comprehensive classification of the U.S. Soil Conservation Service (1960) are set out in Table 7.

II. SOILS AND LAND SYSTEMS

The distribution of the major soil groups and soil families over the land systems is presented in Table 8.

Strongly weathered reddish clay soils of group *a* are characteristic of all mountainous and hilly land systems with rocks of Pleistocene or older age. The proportion of such soils in these land systems is roughly inversely correlated with the magnitude of relief and steepness of slopes. It is only minor in the very steep Misima, Oivi, and Hegahorte land systems, co-dominant to dominant in the less steep Botue and Hydrographers land systems, and dominant in the low hilly Komondo, Mt. Green, and Iauga land systems. The relationship of the soil families within group *a* to parent rock is not clear-cut. The Tatai family is restricted to more basic or calcareous rocks but the Sengi and Mt. Green families, which are rather similar, together cover a whole range of parent materials. The Kenga family occurs on both rather acidic and basic rock, but is restricted to the wettest parts of the area. Thus the formation of this latosolic gibbsite clay soil appears to be largely governed by excessive leaching.

The reddish soils re-occur in Table 8 on terraces of the Kokoda and Ioma land systems, where they seem to be exclusively represented by the less clayey and rather bright-coloured Petakiari family. The evidence for Kokoda land system is not conclusive, as red clay soil was only found buried beneath volcanic ash soils or as truncated profiles on steep terrace edges. As these elevated terraces must be due to higher sea-levels and/or climatic variations or to marked tectonic activity, they are considered to be of Pleistocene age. The weathered ash cover tends to confirm this

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† These letters refer to the paragraphs in which the soils are described in Section III below and in Tables 7–9.

TABLE 7

COMPARISON OF SOIL CLASSIFICATION IN THIS REPORT WITH GREAT SOIL GROUPS AND 7TH APPROXIMATION COMPREHENSIVE CLASSIFICATION OF U.S. SOIL CONSERVATION SERVICE

Major Soil Group and Soil Family	Sample Profile No.	Great Soil Groups (with Author References)	Classification according to 7th Approximation
(*a*) Strongly weathered red and brown clay soils			
Tatai	P5	Possibly reddish brown lateritic soil (Thorp and Smith 1949) but not a typical latosol (Kellogg 1948; Cline 1955)	Not quite enough data, but possibly Oxisol, suborder Udox, class 9.32
Sengi	P20	Transition between reddish brown lateritic soil and red podzolic soil (Thorp and Smith)	Probably Ultisol, suborder Umbrult, great group probably Typumbrult, subgroup Orthic
	P22	As P20	As P20, although with some difficulty could be Ochric(?) subgroup
Mt. Green	—	Probably as Sengi	Probably as Sengi
Petakiari	P11	Yellow latosol (Kellogg)	Probably Oxisol, similar classification to Tatai
Kenga	P18	Yellow latosol (Kellogg)	Most likely Oxisol in area, similar classification to Tatai
Atamai	—	Uncertain, as these are rather atypical accessory soils in this group. Most likely classified as latosols	Impossible to classify because of lack of data
Arumu	—		
(*b*) Shallow gleyed clay soils			
Dewatutu	P4	No proper correlation appears possible. Seems transitional between grey-brown podzolic soils and planosols (Thorp and Smith)	Insufficient data for definite classification. Whichever choice is made, unsatisfactory or inconsistent results are obtained. Best fitting is Mollisol, suborder Alboll, great group Argalboll, subgroup Orthic or possibly Aquollic. Soil could also be classified as Alfisol, suborder Udalf, great group Typudalf, subgroup Aquollic
Siwariri	—	Possibly humic gley (wiesenboden) or low humic gley soils (Thorp and Smith)	No proper classification possible without further data
Dillenia	—		
(*c*) Moderately to little weathered brown ash soils			
Sangara	P3	Brown forest soil (Cline 1949; Nygard, McMiller, and Hole 1952; Robinson 1949), similar to latosolic brown forest soils of Hawaii (Cline 1955)	Mollisol, suborder Udoll, great group Hapludoll, subgroup Andeptic or Orthic
	P9	As P3	As P3, except that mollic epipedon is marginal in this profile
	P10	As P3	As P3
Bohu	—	Insufficient data for proper correlation	Insufficient data for classification. Probably an Aquollic Hapludoll

TABLE 7 (*Continued*)

Major Soil Group and Soil Family	Sample Profile No.	Great Soil Groups (with Author References)	Classification according to 7th Approximation
Higatura	P8	Ando soil (Thorp and Smith; Swanson 1946)	Inceptisol, suborder Andept, great group Umbrandept, subgroup Orthic
	P17	As P8	Inceptisol, suborder Andept, great group Ochrandept
	P19	As P8	As P8
	P21	As P8	As P8
Ohita	P7	Transitional between ando soil and prairie soil	Virtually as P8, possibly Mollic rather than Orthic
(*d*) Unweathered, sandy volcanic soils with black topsoils			
Popondetta	P2	Prairie soil (Thorp and Smith)	Mollisol, suborder Udoll, great group Hapludoll, subgroup Andeptic or Entic
Penderetta	P1	Wiesenboden (humic gley soil) to prairie soil transition (Thorp and Smith)	Mollisol, suborder Udoll, great group Hapludoll, subgroup Aquentic
(*e*) Undifferentiated soils on consolidated rock			
Slope soils	—	Little information. Possibly regosols (Thorp and Smith). The preweathered soil material is somewhat latosolic in character	Not enough data for classification. Probably Entisol, suborder Udent
Lithosols	—	Lithosols (Thorp and Smith)	Entisol, suborder Udent, great group Hapludent, subgroup Lithic
(*f*) Alluvial soils			
Coarse-textured soils	P23	Alluvial soils (Thorp and Smith)	All profiles are Entisols. Further subdivision rather different from system used in this report. Very poorly drained profiles of all groups are in suborder Aquent, great group Psammaquent for very coarse-textured profiles of first two families (subgroup Orthic for coarse, Haplic for coarse-over-fine); great group Haplaquent for less coarse-textured profiles of first two families and all of last two, subgroups Orthic and Udic. Some very coarse-textured, better-drained profiles of first family are in suborder Psamments, great group Orthopsamment, subgroup Orthic or Aquic. All other better-drained soils are in suborder Udent, great group Hapludent, subgroups Orthic (P23) or Aquic (P6, P13, P15)
Coarse-textured soils with fine-textured subsoils	P6		
Medium-textured soils	P13 P15		
Fine-textured soils	—		
(*g*) Organic soils			
Koena	P12 P14	Bog soils (Thorp and Smith)	Histosols

TABLE 8

DISTRIBUTION OF SOILS OVER LAND SYSTEMS ARRANGED BY GEOMORPHOLOGICAL UNITS AND SUBUNITS

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

Major Soil Group and Soil Family	Complex Mountains				Simple Fold Mountains and Hills			Extinct Volcano	Active Volcano							Depositional Plains														
	Meta-morphic Moun-tains	Igneous Moun-tains	Hills						Summit and Adventive Features	Lahar-Glowing Avalanche Slopes			Piedmont-banjir Plains		1951 Eruption Products	Piedmont Terraces		Volcanic Outwash Plains				Fluvial-deltaic Plains					Swamps		Strand Plains	
	Misima	Botue	Oivi	Komondo	Hegahorte	Mt. Green	Iauga	Hydrographers	Lamington	Hamamutu	Higatura	Awala	Bohu	Eundi	Amboga	Kokoda	Ioma	Popondetta	Penderetta	Hanau	Sananunda	Ilimo	Deunia	Warisota	Ambasi	Sagere	Ambi	Koena	Buna	Killerton
(*a*) Strongly weathered red and brown clay soils																														
Tatai		S			m	m	S																							
Sengi	m		m	*D*				S																						
Mt. Green						*D*																								
Petakiari																m?	*D*													
Kenga		S		S																										
Atamai						m		m																						
Arumu																	m					m				m				
(*b*) Shallow gleyed clay soils																														
Dewatutu							m																							
Siwarira							S																							
Dillenia							S																							
(*c*) Moderately to little weathered brown ash soils																														
Sangara											m		*D*																	
Bohu													m							m										
Higatura		S	m					m	m	*D*	*D*	m				*D*						m								
Ohita									m		S	*D*		*D*					m											
(*d*) Unweathered sandy volcanic soils with black topsoils																														
Popondetta											m			S				*D*		S						m			*D*	
Penderetta																			*D*											

(*e*) Undifferentiated soils on consolidated rock														
Slope soils	S	m	*D* m	*D*	S	S				m				
Lithosols	m	m		m m	m	m								
(*f*) Alluvial soils														
Coarse-textured								m			m S	S S m m	S	m
Coarse- over fine-textured											m m	m		
Medium-textured								m			S m *D* S	*D* m S *D* S	S	m
Fine-textured								m m			m m S	S S	S	
(*g*) Organic soils														
Koena								m					*D*	
(*h*) Miscellaneous land types														
Rough mountainous land	*D*													
Lava rock land						S								
Volcanic ash land						S	S m							
Rubble land						m			S					
Stony land										m	m			
Riverwash								m	m			m m		
Alluvial land							m m m		*D*			m S		
Dune land														m
Beach sand											m m	m	m	m m
Tidal swamp														*D*

(Part V). It may thus be tentatively concluded that a land surface in this area has to be more than 10,000 years old to produce soils of this degree of weathering. The sporadic occurrence of the Arumu family on younger surfaces hardly detracts from this statement, because these soils appear to be definitely less weathered than the others in this group and may in effect be older alluvial soils consisting of strongly pre-weathered material, derived from reddish soils.

Another group of soils that is predominantly found in hilly and mountainous land systems is the slope soils of major soil group *e*. They become more common as the red soils decrease in extent. For the extremely rugged Misima land system they have not been separately described but have been included in the miscellaneous land type of rough mountainous country. These soils consist of strongly weathered regolith material, such as C-horizon material of weathered reddish soils. Because of creep, slipping, and larger landslides the mobility of this material on steep slopes is too great for the soils to develop markedly organized profiles. The presence of similar soils on the very steeply dissected older lava flows in Lamington land system is only a supposition, because these sites were not examined. True lithosols are not of major importance in any land system. This is due to the deep weathering, dense vegetative cover, and low erodability of the soils in this humid tropical area.

The shallow gleyed clay soils of group *b* are restricted to the lower, undulating plateau surface of Iauga land system. They commonly occur on slopes that would not normally impede the surface drainage. It is likely that impermeability of the tufface-ous sediments is a contributing factor to the poor internal drainage. This impermeability would tend to reduce leaching and thus partly account for the general shallowness of the soils.

The moderately to little weathered brown ash soils of group *c* are principally related to the land systems of the active volcano. The distribution of the component soil families corresponds well with the geomorphological subunits. Wherever the parent material indisputably is subaerial volcanic ash, the soils belong dominantly to the Higatura family, which is strongly akin to ando soils. Such is the case on gentle slopes of Botue, Oivi, and Hydrographers land systems and on the flat areas of Kokoda land system, all of which could not have been covered with anything but airborne ash, as well as parts of the slopes of Lamington land system, the true ash slopes. Where the volcanic ash has clearly been transported and sorted by the action of water, as in Bohu and Eundi land systems, the soils belong to the Sangara and Bohu families on old deposits and Ohita and Popondetta families on younger deposits. These are more like brown forest soils and prairie soils than ando soils. By inference the predominance of Higatura family in Hamamutu and Higatura land systems would indicate that the deposits of these land systems are predominantly subaerial and less "alluvial" in nature. In Awala land system the Ohita soils with their intermediate character between prairie and ando soil would indicate a true transitional stage between subaerial and waterborne ash deposits. This supports the grouping of these three land systems as lahar–glowing avalanche slopes, on which there is a general tendency for increased water action on deposition down the slope as well as sectorially, giving a radial alternation, as shown on the land system map.

The Ohita soils are generally found on little-dissected slopes, and the Higatura soils on strongly dissected slopes. Apart from the generally lower gradients of Awala land system, this may be due to a higher permeability of the sandy, water-deposited beds as compared with the more compact and slightly hardened glowing avalanche beds and ash deposits of Higatura land system.

Of the miscellaneous land types, lava rock land and volcanic ash land are restricted to the land systems of the active volcano and occur mainly in the crater area (Lamington and Hamamutu land systems).

The unweathered sandy volcanic soils with black topsoils (group *d*) are found on coarse-textured volcanic outwash fans. These deposits are probably of similar origin (though on a vastly larger scale) to those of Amboga land system, which contains the largest areas of rubble land, river wash, and alluvial land. The poorly drained Penderetta soils developed in shallow sandy deposits with a water-table perched on top of finer-textured, more weathered, buried soils of older land surfaces. As soils of this major group are also important in Eundi land system, this can be considered as being transitional between the piedmont-banjir plain and the depositional plains. Similar soils are also present on the beach ridges of Buna land system, although the sand here is less purely volcanic, finer, and better sorted.

In the sequence of land systems in Table 8 the alluvial soils of group *f* first become significant in Eundi land system, which stresses the transitional nature of this land system. They become more important in the volcanic outwash plains, especially in the lower-lying Hanau and Sananada land systems with their dominantly flood-plain character. As regards soil distribution, these land systems could well be grouped with those of the fluvial-deltaic plains and Ambi land system of the swamps, which have similar alluvial soils. But soils of purely volcanic derivation appear to have a higher pH and higher base saturation than those found in other flood-plain areas. Only in Deunia land system along the major rivers is there a large proportion of alluvial land forming an unstable deposit even younger than the alluvial soils. The coarse- over fine-textured group of alluvial soils occurs only sporadically and no clear pattern emerges in the distribution of the texture groups over the various land systems, except that the absence of fine-textured soils in Ilimo and Deunia land systems may be significant, as these are flood-plains with the steepest gradients or in the immediate vicinity (low terraces and levees) of the major rivers. The major difference between all these flood-plain land systems is in soil drainage rather than texture.

Although a few organic soils (group *g*) occur in narrow blocked valleys in Bohu land system, they are dominant only in the large freshwater swamps of Koena land system, where these soils consist of poorly decomposed peat to clayey peat of unknown depth containing wood fragments.

III. Description of Major Soil Groups and Families

In the following descriptions, colours correspond with those defined in the Munsell Colour Chart and refer to the moist condition. Other descriptive terms are used in accordance with the Soil Survey Manual of the U.S. Department of Agriculture (1951).

TABLE 9

ANALYTICAL DATA OF SAMPLE PROFILES

Major Soil Group, Soil Family, and Profile Number	Depth (in.)	Coarse Sand (2000–200μ) (%)	Fine Sand (200–20μ) (%)	Silt (20–2μ) (%)	Clay (< 2μ) (%)	Organic Carbon (%)	Nitrogen (%)	C/N Ratio	P-HCl (p.p.m.)	Cation Exchange Characteristics: Ca (m-equiv. %)	Mg (m-equiv. %)	K (m-equiv. %)	Na (m-equiv. %)	C.E.C.* (m-equiv. %)	Saturation (%)	pH-H_2O
(*a*) Strongly weathered red and brown clay soils																
Tatai (P5)	0–2	2	3	12	82	18·0	0·71	25	260	10·0	4·0	1·2	0·2	71	22	4·7
	2–11	0	2	7	88	2·0	0·10	20	60	0·1	1·1	0·2	0·1	21	7	4·8
	11–42	1	3	17	77	—	—	—	90	0·1	0·1	0·2	0·1	17	3	4·4
	42–75	—	—	—	—	—	—	—	—	0·1	0·4	0·3	0·1	—	—	4·3
	75–80	—	4	22	71	—	—	—	—	—	—	—	—	—	—	4·2
Sengi (P20)	0–6	5	14	18	64	4·8	0·37	13	320	1·5	1·0	0·7	0·1	33	10	4·8
	7–12	7	11	22	60	2·6	0·19	14	230	0·3	1·0	0·5	0·1	25	8	4·7
	13–20	7	6	16	71	0·8	—	—	100	—	—	—	—	—	—	4·6
	25–60	1	6	9	84	—	—	—	80	0·2	0·7	0·4	0·1	17	8	4·7
	72–81	3	11	19	67	—	—	—	—	—	—	—	—	—	—	4·9
(P22)	0–8	24	24	32	25	—	0·38	—	—	—	—	—	—	—	—	—
	8–12	16	18	21	42	—	0·19	—	—	—	—	—	—	—	—	—
	14–30	6	12	20	60	—	—	—	—	—	—	—	—	—	—	—
Petakiari (P11)	0–1	6	17	13	64	12·8	0·74	17	460	—	—	—	—	—	—	5·2
	2–5	4	15	14	66	4·9	0·40	12	350	0·8	1·7	0·7	0·2	30	11	5·1
	7–11	3	13	15	68	2·2	0·19	12	—	0·1	1·3	0·5	0·2	21	10	5·1
	14–23	—	—	—	—	—	—	—	—	0·1	0·5	0·5	0·2	20	6	5·0
	27–38	7	6	9	77	—	—	—	120	—	—	—	—	—	—	—
	52–58	8	15	17	59	—	—	—	—	—	—	—	—	—	—	—
Kenga (P18)	0–1	18	28	13	40	9·1	0·58	16	410	—	—	—	—	—	—	5·1
	1–4	—	—	—	—	5·3	0·38	14	300	0·4	0·9	0·8	0·1	31	7	4·8
	6–26	5	19	18	56	—	—	—	—	0·2	0·6	0·4	0·1	14	8	5·3
	30–46	6	18	14	59	—	—	—	80	—	—	—	—	—	—	5·3

(*b*) Shallow gleyed clay soils																	
Dewatutu (P4)	0–2	33†	16	23	28	3·7	0·21	18	650	9·4	5·0	0·9	0·1	—	—	6·6
	2–6	33†	12	28	27	3·4	0·15	23	—	7·3	5·8	0·3	0·1	29	46	6·1
	6–13	42†	11	18	30	—	—	—	460	—	—	—	—	—	—	6·4
	13–16	23†	17	18	41	—	—	—	—	—	—	—	—	—	—	6·2
	16–30	3	16	21	60	—	—	—	110	11·9	13·0	0·2	0·1	36	70	6·1
	33–43	2	25	19	54	—	—	—	—	—	—	—	—	—	—	—
	45–49	5	30	24	39	—	—	—	—	—	—	—	—	—	—	—
	49–54	9	39	22	27	—	—	—	410	—	—	—	—	—	—	—
(*c*) Moderately to little weathered brown ash soils																	
Sangara‡ (P3)	0–4	28	42	11	19	2·7	0·27	10	410	12·7	1·3	0·2	0·0	21	70	6·7
	4–12	32	39	9	20	1·1	0·12	9	280	7·3	1·5	0·1	0·1	14	65	6·9
	12–26	25	38	9	28	0·3	0·03	10	310	—	—	—	—	—	—	6·8
	26–34	22	34	15	29	—	—	—	—	11·5	3·8	0·4	0·4	27	59	6·8
	34–38	15	35	16	30	—	—	—	—	—	—	—	—	—	—	6·7
(P9)	0–3	—	—	—	—	8·7	0·75	12	840	33·8	4·7	1·4	0·1	57	70	7·0
	4–8	15	40	18	27	3·8	0·40	10	640	14·7	4·3	1·2	0·2	43	47	6·6
	11–13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	18–21	14	27	24	36	—	—	—	590	5·0	4·6	0·6	0·1	34	31	6·4
	29–36	17	25	20	38	—	—	—	—	—	—	—	—	—	—	6·2
(P10)	0–4	18	42	18	20	—	—	—	380	16·4	2·4	0·6	0·0	23	84	8·0
	5–9	15	42	19	22	—	—	—	250	9·3	2·7	0·4	0·0	16	80	7·3
	14–19	7	20	11	60	—	—	—	—	—	—	—	—	—	—	6·8
	26–30	6	25	17	52	—	—	—	590	7·4	6·8	0·5	0·7	28	55	6·6
Higatura§ (P8)	0–7	—	—	—	—	9·4	0·85	11	810	2·6	1·3	0·4	0·1	58	7	5·3
	7–15	23	38	22	17	3·2	0·31	10	530	1·1	0·7	0·3	0·1	31	7	5·9
	15–23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6·0
	23–30	26	35	16	23	—	0·12	—	530	0·8	0·4	0·2	0·1	26	6	6·1
	30–48	—	—	—	—	—	—	—	—	0·4	0·2	0·3	0·1	18	5	6·1
(P17)	0–6	19	55	16	10	5·9	0·59	10	640	15·6	5·5	1·3	0·1	47	48	6·2
	7–17	12	60	18	8	—	—	—	—	4·7	1·9	0·7	0·1	33	22	6·2
	22–53	15	45	22	18	—	—	—	490	2·0	1·5	0·5	0·2	27	16	5·9

TABLE 9 (*Continued*)

Major Soil Group, Soil Family, and Profile Number	Depth (in.)	Coarse Sand (2000–200μ) (%)	Fine Sand (200–20μ) (%)	Silt (20–2μ) (%)	Clay (< 2μ) (%)	Organic Carbon (%)	Nitrogen (%)	C/N Ratio	P-HCl (p.p.m.)	Cation Exchange Characteristics: Ca (m-equiv. %)	Mg (m-equiv. %)	K (m-equiv. %)	Na (m-equiv. %)	C.E.C.* (m-equiv. %)	Saturation (%)	pH-H_2O
Higatura § (P19)	0–3	42	23	18	17	18·3	0·91	20	470	—	—	—	—	—	—	4·8
	4–8	10	36	25	29	18·0	1·01	18	540	0·2	1·3	1·0	0·2	87	3	5·4
	10–20	10	33	21	37	—	—	—	—	0·1	0·6	0·9	0·2	37	5	6·3
	30–46	—	—	—	—	—	—	—	150	—	—	—	—	—	—	6·2
(P21)	1–6	13	52	17	17	6·5	0·69	9	1240	13·9	2·9	0·9	0·1	53	33	6·0
	8–14	8	63	17	12	3·4	0·35	10	940	4·3	1·2	0·6	0·1	39	16	5·9
	16–22	16	50	21	13	2·5	0·20	13	790	4·6	1·6	0·6	0·1	37	19	6·0
	24–28	19	33	16	32	1·1	0·11	10	—	4·9	1·9	0·7	0·1	28	27	6·1
	29–38	—	—	—	—	—	—	—	760	—	—	—	—	—	—	6·1
	40–50	21	35	13	31	—	—	—	—	—	—	—	—	—	—	6·2
	92–113	11	37	20	31	—	—	—	1090	—	—	—	—	—	—	5·8
Chita § (P7)	0–5	16	42	28	14	6·8	0·65	10	—	18·5	2·9	0·7	0·1	49	45	6·4
	5–9	14	40	20	24	4·9	—	—	—	8·4	1·7	0·6	0·2	40	27	6·2
	9–16	22	40	21	15	—	—	—	990	2·2	1·1	0·3	0·1	28	13	6·1
	16–31	44	39	11	4	—	—	—	—	—	—	—	—	—	—	6·1
(*d*) Unweathered sandy volcanic soils with black topsoils																
Popondetta (P2)	0–4	53	35	7	5	2·7	0·21	13	840	7·3	1·5	0·4	0·0	19	49	6·4
	6–10	43	39	12	4	1·2	0·11	10	750	5·2	1·0	0·2	0·0	12	53	6·5
	11–18	61	31	5	2	—	0·02	—	850	—	—	—	—	—	—	7·0
	21–26	56	31	9	2	—	—	—	—	—	—	—	—	—	—	7·4
	29–40	68	23	6	2	—	—	—	—	—	—	—	—	—	—	7·4
Penderetta (P1)	0–5	13	38	24	23	9·9	0·60	17	—	—	—	—	—	—	—	5·7
	6–10	12	47	29	12	4·1	0·27	15	—	—	—	—	—	—	—	6·0
	11–14	19	52	21	7	1·3	0·10	12	—	—	—	—	—	—	—	6·2
	28–34	57	27	10	4	—	—	—	—	—	—	—	—	—	—	6·5
	37–43	6	61	22	10	—	—	—	—	—	—	—	—	—	—	6·8

(*f*) Alluvial soils Coarse-textured (P23)	0–3	32	33	16	17	11·3	0·86	13	—	19·2	5·0	1·8	0·1	67	39	6·4
	3–7	31	46	14	9	8·0	0·64	12	—	5·0	1·1	1·0	0·1	51	14	6·0
	9–16	13	58	23	6	—	—	—	—	0·4	0·4	0·5	0·1	26	5	5·8
	17–24	26	43	22	6	—	—	—	—	0·2	0·3	0·4	0·1	10	9	5·8
	35–42	29	49	19	2	—	—	—	—	—	—	—	—	—	—	6·0
Coarse- over fine-textured (P6)	0–3	4	64	22	10	4·5	0·33	13	—	16·0	6·7	0·4	0·1	34	68	6·3
	3–13	3	67	21	9	1·7	0·16	11	—	5·5	3·6	0·2	0·2	20	47	5·9
	13–25	1	84	11	3	—	—	—	—	—	—	—	—	—	—	6·7
	25–30	1	28	49	21	—	—	—	—	8·1	9·8	0·3	0·2	23	81	6·9
	30–37	1	31	40	26	—	—	—	—	—	—	—	—	—	—	6·9
	39–51	16	75	5	3	—	—	—	—	—	—	—	—	—	—	7·0
Medium-textured (P13)	0–3	6	36	37	21	4·7	0·38	12	—	1·6	1·0	0·7	0·1	29	12	5·5
	4–8	4	35	33	27	2·0	0·17	11	—	0·4	0·6	0·5	0·1	20	8	5·4
	12–22	3	37	29	31	—	—	—	—	0·4	0·9	0·3	0·1	12	15	5·4
	36–48	76	19	2	2	—	—	—	—	—	—	—	—	—	—	6·2
(P15)	0–2	5	43	37	14	7·1	0·61	12	—	4·4	1·2	1·2	0·1	39	23	5·3
	3–5	2	36	36	24	3·2	0·34	10	—	1·6	1·4	0·6	0·1	24	15	5·1
	7–14	0	39	32	28	—	—	—	—	0·6	1·4	0·3	0·1	15	16	5·5
	14–20	1	51	31	15	—	—	—	—	1·5	2·5	0·2	0·1	12	36	5·8
	27–39	1	45	38	16	—	—	—	—	—	—	—	—	—	—	5·7
(*g*) Organic soils Koena (P12)	0–6	—	—	—	—	45·0	2·10	21	—	—	—	—	—	—	—	—
	18–24	—	—	—	—	50·3	2·17	23	—	—	—	—	—	—	—	—
	30–42	—	—	—	—	49·5	1·72	29	—	—	—	—	—	—	—	—
(P14)	0–5	—	—	—	—	32·9	2·17	15	—	—	—	—	—	—	—	—
	20–30	—	—	—	—	45·1	1·78	25	—	—	—	—	—	—	—	—
	52–58	1	7	26	67	7·9	0·40	20	—	—	—	—	—	—	—	5·0
	68–74	1	9	31	59	2·6	0·15	18	—	0·5	2·1	0·5	0·2	28	12	4·8

* Determined by summation of exchange bases and hydrogen.

† Likely to include many very small concretions.

‡ There are many discrepancies between field and laboratory textures in this family, with laboratory results too coarse (P3) or too fine-textured (P10).

§ Many samples of this family were very difficult to disperse and some of the clay contents given could well be too low.

Soil samples collected in the field were analysed in the laboratory of the Division of Soils, CSIRO, Adelaide, under the general supervision of J. T. Hutton. These data are presented in Table 9. Data on clay mineral composition, as reported in the descriptions, are contributed by K. Norrish, Division of Soils, CSIRO, Adelaide, who carried out and interpreted X-ray analyses of samples of several important soil families.

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

These soils have the following characteristics in common. The profiles are more than 4 ft deep, unless severely truncated. The colour is strong brown to red, becoming reddish with depth. Mottles are rare except in the C horizon, where they are mainly due to weathered rock fragments. The texture is clay or heavy clay. Although there are no apparent sharp texture contrasts, the percentage of clay commonly increases considerably down the solum above the C horizon. The soils have very little visible structure *in situ*, though a strongly compound blocky structure is commonly noticed when the material is manipulated. The permeability appears to be moderately rapid and there is little plasticity in relation to the high clay content. The soils are very acid and strongly leached (Table 9), except possibly the Arumu family. The A_1 horizon is as a rule poorly to moderately developed but has a quite high content of organic matter, with a tendency to form a thin mor layer at the surface. This is confirmed by the high C/N ratios. The phosphate contents are the lowest of any soil group in the area. The exchange capacity is low in relation to clay content and the complex is highly unsaturated with a tendency for Mg to be dominant among the bases, whilst exchangeable K is commonly high. Clay minerals are dominantly kaolinite, gibbsite, or halloysite, with small amounts of goethite and quartz.

(i) *Tatai Family*.—These soils occur on ultrabasic rocks, basaltic lavas, and calcareous tuffaceous sandstones in rugged hilly and mountainous country, where the profiles are found on wider parts of spur crests. They were observed only below 2000 ft altitude. The vegetation is mostly rain forest, locally replaced by garden regrowth.

They are almost uniform heavy clays, firm to very firm in consistence and red to red-brown in colour with weak red subsoils. The A_1 horizon is poorly developed (2 to 4 in. of dark red-brown clay) or virtually absent. Rather shallow truncated profiles with a mottled or browner C horizon are common, especially on steeper slopes.

The clay content, which decreases gradually with depth, is the highest of the group, and the pH and percentage saturation are the lowest. Clay minerals are kaolinite with minor goethite.

(ii) *Sengi Family*.—These soils occur on schist and phyllite and on andesitic agglomerate and tuff in rugged hilly and mountainous country, with the deepest profiles on rounded or flat crests of spurs. Truncated profiles with the C horizon at a depth of less than 4 ft are common on steep slopes. The soils were observed only below 2000 ft altitude. The vegetation is predominantly rain forest, but locally regrowth or grassland. In the latter case the soils are commonly truncated.

The soils are characterized by a marked transition from friable or firm medium clay to firm or very firm heavy clay at a depth ranging from 10 to 20 in. The upper part of the soil is brown to red-brown in colour, the lower part yellow-red to red, but this colour change does not always coincide with the change in texture. There is usually a moderately to well-developed A_1 horizon, 5–10 in. thick and very dark grey-brown to dark brown in colour.

The analytical data clearly show the marked increase in clay content in the middle part of the profile. Although these soils are very acid, the pH is slightly higher than in the Tatai family. There is a marked dominance of Mg among the exchangeable bases and also a relatively high amount of K. No data are available on clay mineral composition.

(iii) *Mt. Green Family*.—This family is found at low altitudes on steep hills and ridges composed of andesitic lava and tuff. The best-developed profiles occur on broader crests. The vegetation is rain forest.

The soils are characterized by a marked change in colour from strong brown in the upper 15 in. to red in the deeper subsoil. This is associated with a gradual increase in texture from firm medium clay to firm or very firm heavy clay. An A_1 horizon is virtually lacking.

No analytical data are available for this family.

(iv) *Petakiari Family*.—This family occurs in the lowlands on level or dissected Pleistocene alluvial deposits, which are now well above flood levels. The vegetation is rain forest.

The soils have a uniform clay texture but in spite of this are remarkably friable. Below a 4–6 in. dark brown A_1 horizon the colour is strong brown to 12–18 in. and yellow-red below this depth. On steep slopes along dissecting streams much water-worn gravel is present in the subsoil of some profiles.

The analytical data show a consistently high clay percentage with only a minor peak in the middle B horizon. The clay fraction is dominated by halloysite, accompanied by increasing amounts of gibbsite with depth and a little goethite and quartz.

(v) *Kenga Family*.—This family occurs, possibly very locally, on steeply dissected hills and mountains in the Yodda valley area, above 1200 ft altitude. It is found mostly on steep slopes, apparently both on phyllite and basic igneous rocks. The vegetation is rain forest.

The soils are very friable uniform clay soils, which retain much of their friability even when saturated with water, which they usually are. Below a poorly developed, 4-in. brown A_1 horizon the colour is yellow-brown, merging into strong brown at about 30 in. depth.

The analytical data show a strong similarity with those of the Petakiari family, except for a significantly lower clay content. Mineralogically the clay is dominated by gibbsite, with goethite, halloysite, chlorite, and quartz as accessory minerals. The chlorite is highly weathered and different from that which is usually associated with young soils.

(vi) *Atamai Family*.—This family occurs generally on steep slopes of mountain ridges of andesitic tuff and lava, and on hills of ultrabasic rocks. It is found over a wide range of altitudes. The vegetation is rain forest.

The soils are uniform medium or light clays with a friable to firm consistence. They generally have a 6–12 in. dark brown A_1 horizon, overlying brown and, with depth, commonly yellow-brown subsoils. Profiles with a C horizon at less than 4 ft are common.

No analytical data are available.

(vii) *Arumu Family*.—This family occurs in the lowland on the lowest part of raised old alluvial deposits, on local high terraces in the Yodda–Kokoda valley, and on slight levees along major streams in the Opi–Kumusi flood-plain area. The vegetation is rain forest or garden regrowth.

These are firm or friable, brown or dark yellow-brown clay or light clay soils. The texture is clay loam or sandy clay in the subsoil of some profiles. Normally there is a 5–7 in. dark brown A_1 horizon. Slight greyish and very dark brown mottles are found below 2 ft depth in several profiles.

No analytical data are available.

(*b*) *Shallow Gleyed Clay Soils*

These are generally shallow (1–3 ft), structureless, slowly permeable, firm or plastic clay soils, which show signs of present or past waterlogging such as mottles and/or black concretions; mottling is commonly most pronounced in the upper part of the C horizon. The A_1 horizon is very dark and approximately 6 in. thick.

These soils are found on an undulating to rolling plateau land surface, under a vegetation ranging from grassland to secondary rain forest.

(i) *Dewatutu Family*.—This family represents the deepest (as much as 43 in. to the C horizon) and most mature soils of this group. The profile is characterized by a very dark grey topsoil, which merges into a dark brown clay loam overlying a yellow-brown clay with black, red, and greyish mottles. Very high amounts of iron-manganese concretions are present in the upper part of the soil, but their amount decreases rapidly and they become softer in the clay subsoil. The C horizon is strongly brown, grey, and greenish mottled, becomes rapidly less clayey with depth, and contains an increasing amount of weathered tuffaceous sandstone fragments.

Whilst the figures for the granulometric composition clearly demonstrate the texture trend in the profile, they probably give an exaggerated picture of the clay eluviation, as the large coarse sand fraction of the upper layers is likely to contain a large proportion of secondary iron concretions, thereby depressing the relative amounts of the finer fractions from which the degree of eluviation should be assessed. The soil is only slightly leached, being weakly acid and having a rather high base saturation. The exchange capacity is very high for a soil with a clay mineral composition of kaolinite and accessory goethite. The exchangeable bases are strongly dominated by Ca and Mg. Total P shows a steady decline to the B horizon and a subsequent rise in the C horizon. The rather high organic matter content is associated with a high C/N ratio, which appears to be common for strongly weathered soils.

(ii) *Siwarira Family*.—These soils are only 12–18 in. deep to the C horizon. They have a very dark topsoil with very many concretions and an olive brown and brown mottled clay subsoil with fewer concretions. The C horizon is strongly grey, greenish, and brown mottled, somewhat more sandy, but very sticky and plastic in consistence. It contains increasing amounts of weathered rock fragments.

No analytical data are available.

(iii) *Dillenia Family*.—These soils are only 9–16 in. deep to the C horizon. Below the dark topsoil the profile is dark grey-brown in colour with grey, brown, and black mottles. Only traces of iron-manganese concretions are present. The C horizon consists of plastic clay with increasing amounts of soft weathered sandstone and harder rust-stained rock fragments, creating a grey and brown mottled impression.

No analytical data are available.

(*c*) *Moderately to Little-weathered Brown Ash Soils*

This group comprises a number of soil families, which represent different stages of soil formation—mainly expressed in the depth and degree of alteration—in sandy volcanic ash parent material. Some families also show differences in the nature of the soil-forming processes: the Higatura family in its peculiar chemical properties, the Bohu family in the influence of waterlogging.

These soils occur under rain forest or garden regrowth vegetation, rarely under man-made grassland.

They are characterized by deep, very dark brown friable topsoils with low C/N ratios and by brown, porous and friable sandy clay loam to sandy clay subsoils, which are generally structureless. These merge into strongly or little-weathered sandy volcanic ash. Discrepancies between field and laboratory texture are very common, because of dispersion difficulties. The soils have a complex clay mineral composition, which is characterized by appreciable quantities of vermiculite and an amorphous material, which was not definitely identified as allophane. Hydrobiotite, hornblende, feldspars, and quartz are usually present in the clay, together with varying amounts of kaolinite or halloysite and small amounts of gibbsite or goethite.

The soils have high P, exchangeable K, and N contents, and Ca dominates the exchangeable bases more strongly than in any other group.

(i) *Sangara Family*.—This family comprises the most mature, well-drained soils of this group. They occur on level to gently sloping land below 1000 ft altitude.

They have a well-developed, dark brown to dark yellow-brown firm clay or sandy clay horizon below the slightly coarser-textured, very dark topsoil. The structure of the topsoil is subangular blocky or crumbly, of the clay subsoil weakly fine blocky, which, however, is not visible *in situ*. The yellow-brown, slightly coarser-textured, massive C horizon generally occurs at 3–4 ft depth and commonly contains brittle lumps of weathered volcanic sediment. The profiles with the finest texture have few black and greyish mottles in the subsoil.

The analytical data show a steady increase in clay with depth, but also some obvious discrepancies with the field texture. Base saturation is high and reaction is about neutral. The alkaline reaction of one topsoil sample cannot be explained. Total P is rather low for this group. The clay mineral composition is characterized by a relatively high amount of halloysite and a low amount of amorphous material in comparison with other soils in this group.

(ii) *Bohu Family*.—These soils occur only locally, on very gently sloping or level land at low altitude.

This family is similar to the Sangara family, but differs in having generally deeper and black topsoils and olive brown or light olive brown subsoils, commonly with brown mottles. There is a well-defined clay horizon below the topsoil, merging into coarser-textured material at a depth of approximately 24–30 in.

No analytical data are available.

(iii) *Higatura Family*.—This family is found mainly on gentle to steep, strongly dissected volcanic slopes at altitudes between 500 and 4000 ft. It also occurs on the gently sloping surface of Pleistocene fan terraces in the Yodda–Kokoda valley and on the more gentle slopes and broad crests of the Ajule Kajale Range. The original forest vegetation has been destroyed on the higher slopes of Mt. Lamington by the last eruption and replaced by natural regrowth communities.

Below the very dark, fine subangular blocky, friable loam topsoil, which is normally 6–18 in. thick, the soils consist of structureless clay loam or sandy clay loam, dark brown to olive brown in the upper 2 ft, yellow-brown to light olive brown in the lower part. This material is porous and friable or brittle (hard *in situ*, very friable after manipulation, even when wet). It is strongly black speckled with mineral grains and commonly continues to a considerable depth (possibly 20 ft or more) before it merges into stratified unweathered ash. Buried profiles are common with buried topsoils mostly at depths of 18–25 in. or 20–30 in. A layer of several inches of fresh volcanic ash from the last eruption was locally found on top of these soils in the Mt. Lamington area. On steep slopes truncated profiles with very thin topsoils are common.

The analytical data show increasing clay contents with depth, at least over the first 30 in., but the laboratory texture is generally more sandy than the field texture. The clay minerals are dominated by amorphous material and vermiculite with minor kaolinite, quartz, and feldspar. Although these soils can be expected to have high exchange capacities, the very high figures calculated per 100 g clay as determined in the laboratory are probably caused by incomplete dispersion of the fine earth. The pH is generally about 6, but base saturation is very low. The Higatura soils have the most humic A_1 horizon of any mineral soil family in the area. In very organic profiles the C/N ratio is much higher than normal.

(iv) *Ohita Family*.—This family is found on coarse-textured volcanic ash on little-dissected, level to gently sloping or undulating land at altitudes of 200–600 ft.

The soils are characterized by medium-textured (sandy clay loam or clay loam) friable upper layers, which merge at a depth of about 2 ft into stratified loamy sand and coarse sand of volcanic ash, which locally contain much gravel and stones. Below the very dark organic A horizon the medium-textured layers are dark brown in colour and apparently structureless. The underlying sand has the grey-brown, strongly speckled appearance of fresh volcanic ash. Strong stratification locally causes grey and brown mottling in the finer-textured layers. Shallow buried topsoils are present in some localities. Varying degrees of surface stoniness are quite common with this family.

The analytical data are similar to those of the Higatura family, but transitional to those of the Sangara family in respect of pH and base saturation. Again there is a discrepancy between laboratory and field textures, except for the sandy subsoil. The clay minerals are dominated by vermiculite with some accessory kaolinite and amorphous material.

(*d*) *Unweathered Sandy Volcanic Soils with Black Topsoils*

These soils are deep, loose, coarse sands to loamy sands with, in many cases, sandy loam or loam topsoils. The sand consists of water-transported feldspars, dark minerals, and pumice. Soil formation has been very slight and is restricted to the development of a very friable, crumbly, black topsoil, 12–18 in. thick, with a very dark grey to dark grey transition zone to the underlying sand.

The soils are found on level to gently sloping alluvial fans and beach ridges and are normally covered with grassland.

Chemically the soils are characterized by a weakly acid reaction in the topsoil, which becomes gradually neutral in the subsoil. Base saturation is relatively low in comparison with pH, with Ca strongly dominating the low amount of exchangeable bases. Total P is moderately high.

(i) *Popondetta Family*.—This family has loamy sand to sandy loam topsoils. The sand consists of white, grey, and black uncoated grains. Slight mottling is present in the deeper subsoils of low-lying profiles. The sand of otherwise identical profiles in Sagere and Buna land systems is not directly derived from volcanic ash and is likely to be more mixed in mineralogical composition.

The organic matter content of these soils is relatively low in relation to the black colour, but is believed to be generally higher than that of the sample profile.

(ii) *Penderetta Family*.—These soils have loam to sandy clay loam topsoils and generally have higher silt and fine sand content than the Popondetta family. The subsoil is stratified with fine and coarse sandy layers. The sand is predominantly grey, with brown mottles, due to poor drainage. This is caused by the presence at depths below 6 ft of a buried, clayey, mottled soil with a thin, compacted, black topsoil. Water-tables perched on this less permeable material were observed up to 3 ft below the land surface during the "dry" season.

These soils have a high organic matter content and rather high C/N ratios.

(*e*) *Undifferentiated Soils on Consolidated Rock*

In this group are combined rather deep soils without significant horizon differentiation, and extremely shallow soils on consolidated rocks. These soils occur on very steep slopes and on sharp crests. The vegetation is generally rain forest but the shallow soils also occur in grassland and old village sites.

(i) *Slope Soils*.—These soils are brown or grey-brown, pedologically unorganized light clays or clay loams, 1–3 ft deep. They contain moderate to high amounts of angular, weathered rock fragments, especially in the lower part of the profile. The underlying material is either very stony or consists of soft, mottled, weathered rock. The soils have a very poorly developed A_1 horizon.

No analytical data are available.

(ii) *Lithosols*.—These are residual soils with less than 6 in. of soil material overlying more or less weathered parent rock. Pockets of deeper soil may occur. Rock outcrops and rock fragments are common. In some cases there is a high organic matter content.

No analytical data are available.

(*f*) *Alluvial Soils*

In this group are combined all soils that consist of more or less stratified recent alluvial deposits, which show no signs of soil formation other than a moderate development of the A_1 horizon or mottling due to impeded drainage. The vegetation is generally rain forest, locally replaced by garden regrowth or grassland. On the most poorly drained sites it is swamp forest or sago woodland.

The alluvial soils have been subdivided into four rather arbitrary families according to texture (sand to sandy loam, loam to clay loam, clay) and apparent permeability (very rapid, rapid to moderate, slow). Drainage status is used to differentiate between soils at phase level. Six drainage classes were recognized and are defined in Part III. The degree of A_1 horizon development varies considerably within all alluvial soils series. Generally it is related to drainage in that it is best developed in well-drained and least developed in very poorly drained or swampy profiles. The best-developed A_1 horizons are not more than 7 in. thick and dark grey-brown or dark grey in colour, sometimes very dark brown in the uppermost 2–3 in.

No analyses have been carried out, but the alluvial soils are likely to fall into three mineralogical groups. These groups are not related to particular textural profiles. The first is of andesitic volcanic origin and applies to soils in Bohu, Eundi, Popondetta, Penderetta, Hanau, and Sananda land systems. The second is of mixed composition, derived partly from andesitic volcanic material, partly from basic igneous rocks, and possibly partly from metamorphic rocks. It is found in Deunia, Warisota, Ambasi, Sagere, Ambi, and Buna land systems. The third is derived from schist, gneiss, and calc-silicate metamorphic rocks and restricted to Ilimo land system.

Analytical data for four profiles, one of the coarse-textured family, one of the coarse-over-fine-textured family, and two of the medium-textured family, are given in Table 9. Mineralogically profile P6 is derived from andesitic volcanic material, P13 and P15 from mixed material, and P23 from calc-silicate metamorphic material. The data have several unexpected aspects. The laboratory clay contents are generally lower than expected from the field texture, except in the most sandy samples. Except for P6, base saturation and pH are much lower than would be expected for very young alluvial soils. The soils of mixed mineralogical composition are markedly more acid than the other two. This is accompanied by low amounts of exchangeable Ca and a predominance of Mg. Exchangeable K contents, except those of P6, are high. No data are available for total P. The organic matter contents are very high, especially in relation to the poorly expressed A_1 horizons. There is a rapid decline in organic matter with depth. C/N ratios are normal.

(i) *Coarse-textured Alluvial Soils*.—These are deep very friable to loose sand to sandy loam soils with thin dark topsoils, which are commonly more loamy in texture.

The permeability is very rapid, but the drainage status* variable (from swampy to well drained). In Ilimo land system these soils are commonly stony.

(ii) *Coarse-textured Alluvial Soils with Fine-textured Subsoils or Layers*.—These are very friable to loose sand to sandy loam soils with a sharp break to a firm or plastic clay loam or clay subsoil between 20 and 40 in. depth, or with a fine-textured layer again overlying coarse-textured material. The soils are slowly to moderately permeable and very poorly to imperfectly drained.

(iii) *Medium-textured Alluvial Soils*.—Most soils in this family have loam to clay texture in the upper part which merges gradually or abruptly into coarser material at any depth between 12 and 40 in. This coarser material ranges from sandy clay loam to sand. Some soils have a uniformly medium-textured profile to 4 ft depth or more. The soils are friable or firm. Profiles occur in all drainage classes, but well to imperfectly drained soils are most common.

(iv) *Fine-textured Alluvial Soils*.—These soils have uniform, deep profiles of firm or plastic clay or silty clay, or they consist of sandy clay loam or clay loam in the upper part, which merges gradually into clay below 12 in. depth, or they are clay or sandy clay soils with a sand or sandy loam layer, at least 6 in. thick, in the middle of the profile. The soils are slowly permeable and very poorly to imperfectly drained. Some very poorly drained profiles have peaty layers or a peat subsoil.

(*g*) *Organic Soils*

(i) *Koena Family*.—This family occurs in the Kumusi–Mambare flood-plain swamps, some cut-off meanders, and small tributary valleys. The vegetation consists of herbaceous and woody swamp communities, with sago mainly along the edges and in oxbows and valleys. The water-table is at the surface in the dry season, but probably not much higher during most of the wet season.

These soils consist of a thin layer of roots, dead roots, and leaves overlying poorly to moderately decomposed very dark brown peat of very low density, mixed with many living roots. The maximum thickness of the peat could not be determined. It is generally more than 7 ft thick, except along the edges, where it is underlain at 3–6 ft by olive grey or grey, very soft clay. Much partially decomposed wood was found in the lower peat layers in some places.

Analytical data of the peat are confined to organic carbon and nitrogen and are characteristic of true peats with a high C/N ratio. The clay subsoil of one shallow peat profile has a high clay and silt content, a normal cation exchange capacity, low base saturation, and very low pH. This suggests that the peat is also acid. The exchangeable bases of the underlying clay are dominated by Mg and include a relatively high amount of K.

(*h*) *Miscellaneous Land Types*

This group comprises a number of surface materials that cannot be described and classified as proper soils. They commonly carry strongly specialized or seral vegetation communities.

* See Part III.

(i) *Rough Mountainous Country.*—This is very steeply sloping land with deep V-shaped valleys and sharp divides. Covered with forest, it is marred by landslide scars. Rock outcrop and stony land surfaces are common.

(ii) *Lava Rock Land.*—This is very rocky and stony land with jagged surfaces of lava flows and ejected boulders, mixed with volcanic ash and some soil material, which supports a forest vegetation.

(iii) *Volcanic Ash Land.*—This land is covered by more than 6 in. (probably up to 4 ft) of fresh volcanic ash and gravel.

(iv) *Rubble Land.*—This is land of which the surface is covered for more than 90% by boulders, stones, and gravel.

(v) *Stony Land.*—This is land with 15–90% gravel and stones on the surface and in the topsoil.

(vi) *River Wash.*—This consists of sparsely vegetated shifting gravel, sand, and mud bars in river beds, normally emerging above water-level.

(vii) *Alluvial Land.*—This consists of low-lying, very recent river alluvium (mainly sand and gravel) which is subject to changes due to shifting of the river channels. It is normally covered by vegetation and may vary in drainage status. Locally it is very stony.

(viii) *Dune Land.*—This comprises very recent and not fully stabilized narrow sand ridges fringing the inland side of the beach and formed by wind and wave action.

(ix) *Beach Sand.*—This is well-sorted, marine-transported sand along the coast. Normally it is very dark grey in colour because of the predominance of dark minerals. Locally it is black because of concentrates of augite, hornblende, and magnetite. The sand is locally of coral derivation.

(x) *Tidal Swamp.*—This land is inundated with sea-water at high tide and covered by mangroves. The sediments are mostly sands with layers of organic mud.

IV. References

Cline, M. G. (1949).—Profile studies of normal soils of New York: I: Soil profile sequences, involving brown forest, gray-brown podzolic and brown podzolic soils. *Soil Sci.* **68**: 259–72.

Cline, M. G. (1955).—Relationships among soils of Hawaii. *In* "Soil Survey of the Territory of Hawaii; Islands of Hawaii, Kauai, Lanai, Maui, Molokai, and Oahu". Soil Surv. U.S. Soil Conserv. Serv. No. 1939 (25): 67–88.

Kellogg, C. E. (1948).—Preliminary suggestions for the classification and nomenclature of great soil groups in tropical and equatorial regions. Tech. Commun. Bur. Soil Sci., Harpenden No. 46: 76–85.

Nygard, I. J., McMiller, P. R., and Hole, F. D. (1952).—Characteristics of some podzolic, brown forest and chernozem soils of the northern portion of the Lake States. *Proc. Soil Sci. Soc. Amer.* **16**: 123–9.

Robinson, G. W. (1949).—"Soils, their Origin, Constitution and Classification." 3rd Ed. (Thomas Murby and Co.: London.)

Swanson, C. L. W. (1946).—Reconnaissance soil survey of Japan. *Proc. Soil Sci. Soc. Amer.* **11**: 493–507.

Thorp, J., and Smith, G. D. (1949).—Higher categories of soil classification: order, sub-order and great soil groups. *Soil Sci.* **67**: 117–26.

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

United States Soil Conservation Service (1960).—"Soil Classification: A Comprehensive System. 7th Approximation." (U.S. Govt. Printer: Washington.)

PART VIII. VEGETATION OF THE BUNA–KOKODA AREA

By B. W. Taylor*

I. Introduction

This report is confined to a short description of the vegetation types present in the Buna–Kokoda area.

The vegetation consists of rain forest and garden regrowth, swamp communities, disclimax grasslands, and seral communities following the eruption of Mt. Lamington in 1951.

A major difficulty encountered in this vegetation study was the identification of species. The flora of New Guinea is very rich in species, especially of tall trees. At the time of writing there was no published flora, and no enumeration of those species which have been recorded. The identification of the numerous species of tall trees is made more difficult because flowers are infrequent and only such leaves, flowers, and fruits as fall to the ground are readily available for field identification. However, the local indigenes have names for a large number of trees. In many cases these names correspond to a single species and are an extremely useful aid. Difficulties arise where different species, generally belonging to the same genus or family, have the same native name.

The method of field identification adopted was to note the names given to each tree by native tree experts and at the same time to make brief notes on field characters, and to collect wood and bark samples. A rapid cross check was then possible when the native name was again encountered. The native names were also recorded for the collections made by the systematic botanist, and a considerable number of these have been identified. Duplicates of specimens have been sent to the following herbaria: Lae, Leiden, Arnold Arboretum, Kew, British Museum, U.S. National, and Melbourne. Although several languages were noted, all native names quoted in the text are in the Orokaiva language.

Field observations generally consisted of an enumeration of species present on either side of a traverse line, together with notes on their abundance and height and on the overall structure of the community. In rain forest communities the floristic enumeration was largely confined to the upper two tree layers.

Classification of the various communities presents some difficulty as no fully satisfactory system has been recorded in the literature. The system adopted for structural classification follows that of Beard (1944), but the establishment of additional formations has been necessary. The floristic classification of rain forest is more difficult and the system used will undoubtedly need modification. Floristic groupings of different stands of rain forest were made mainly on the basis of the more abundant species but sometimes on the radical differences in the floristic list of rarer species. The units so recognized have been called associations but these do not

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correspond to associations as described from temperate regions, although there are superficial resemblances. Groups of related associations have been placed in alliances following the system of Beadle and Costin (1952).

An important feature of the vegetation is the large extent of regrowth on abandoned native gardens. After the felling of an area of forest, burning, and planting, native gardens are kept clear of weeds for a period of approximately 10 months. The crops, amongst which taro (*Colocasia esculenta*) is prominent, are then harvested and the area abandoned to a bush fallow of at least 5 years and generally a much longer period. A dense mass of trees soon springs up and a succession is initiated which leads up to a mature forest. The actual course of the succession varies not only with the habitat of the site but also with its cultural history.

Another important feature of the Buna–Kokoda area is the presence of many extensive stands of grassland.* Apart from a few stands which are stages in a natural sere, all these appear to have been formed as a result of native gardening and are maintained as a disclimax by regular hunting fires.

II. Description of Vegetation Types

The vegetation communities described in the following pages, as well as their distribution over the land systems, are given in Table 10.

(*a*) *Rain Forest Formation*

This formation is an evergreen hydrophilous forest, at least 100 ft high, usually taller, with at least three layers of trees. It is rich in thick-stemmed lianes and in woody as well as herbaceous epiphytes.

(i) Anisoptera kostermansiana–Pometia pinnata *Association.*—Important species in the mature forest are *Anisoptera kostermansiana, Dracontomelum mangiferum, Alstonia scholaris, Dysoxylum* sp. ("kase"), and *Baccaurea papuana.* Garden regrowth covers large areas. In early regrowth stages *Timonius timon, Alphitonia incana, Canarium acutifolium, Macaranga* sp. ("pambata"), *Ficus calopilina,* and *Leucosyke javanica* are common. In advanced regrowth stages common species are *Evodia* sp. ("sera") and *Sterculia* sp. ("ageni").

(ii) Pometia pinnata–Chisocheton *Sp. Association.*—This association is of very mixed floristic composition, and although a few species may be locally abundant, no one species is abundant in any large stand. The most frequent species are *Pometia pinnata, Chisocheton* sp. ("asawa"), *Polyalthia* sp. ("adidionga"), *Dracontomelum mangiferum, Ficus hesperidiiformis,* and *Ficus* spp. ("korsena"). Garden regrowth is widespread in the area of this association. *Alphitonia incana, Ficus pungens, Ficus calopilina, F. gul, Geunsia cumingiana,* and *Pipturus argenteus* are frequent species in the early stages, followed by *Evodia* sp. ("sera") and *Sterculia* sp. ("ageni"). In more advanced stages the community is dominated by *Pometia pinnata* or occasionally by *Tristiropsis subangula.*

(iii) Pometia pinnata–Alstonia scholaris–Octomeles sumatrana *Association.*—This community is of widespread distribution on the alluvial plains, generally on

* The distribution of these grasslands is indicated on the accompanying map.

areas with poor drainage. In mature forest *Pometia pinnata* may make up 25% of the dominant trees. Other important species are *Alstonia scholaris*, *Syzygium* sp. ("dara"), a Sapotacea ("dipapa"), and *Planchonia timorensis*. *Octomeles sumatrana* also occurs in mature forest but is more frequently an indicator of advanced stages of a succession following devastation by floods. Garden regrowth successions cover very large areas and are of two types, one on coarse and one on fine-textured soils. On sandy soils regrowth up to a height of 80 ft is dominated by *Kleinhovia hospita*. In early stages *Macaranga* sp. ("pambata"), *Callicarpa* sp. ("olinga"), *Ficus calopilina* and *F. pungens*, *Voacanga papuana*, *Semecarpus* sp. ("homiga"), and *Hibiscus tiliaceus* are common, followed by *Alphitonia incana*, *Timonius timon*, *Macaranga tanarius*, and *Ficus* sp. ("junga"). Communities over 80 ft in height are dominated by many species including *Pterocarpus indicus*, *Neonauclea* sp. ("tiga"), *Planchonia timorensis*, *Vitex cofassus*, *Dysoxylum* sp. ("ondoto"), *Endospermum formicarum*, and *Elaeocarpus* sp. ("korina"). On heavier soils *Kleinhovia hospita* is not abundant and primary species become predominant at an early stage.

(iv) Pometia pinnata–Dillenia quercifolia–Palaquium *Sp. Alliance*.—This alliance is composed of the *Pometia pinnata–Dillenia quercifolia* association, the *P. pinnata–D. quercifolia–Palaquium* sp. association, and the *Palaquium* sp. association. The small stands in Sananada and Warisota land systems are restricted to the *Palaquium* sp. association. There is a general tendency for the sequence of associations from the *Pometia pinnata–Dillenia quercifolia* association to the *Palaquium* sp. association to occupy progressively more poorly drained sites. Many tall trees are present in the alliance. Usually *Pometia pinnata*, *Dillenia quercifolia*, and *Palaquium* sp. make up over 50% of the trees in the dominant layer in any one stand. Other common species are *Vitex cofassus*, *Alstonia scholaris*, *Anisoptera kostermansiana*, *Ficus hesperidiiformis*, and *Ficus* spp. ("korsena").

(v) Anisoptera kostermansiana–Intsia bijuga *Association*.—*Anisoptera kostermansiana* and *Intsia bijuga* constitute up to 50% of the trees present in the dominant layer. Other important species are *Hopea papuana*, *Syzygium* sp. ("gasara"), *Eucalyptopsis papuana*, *Calophyllum* spp. ("ango"), and *Podocarpus neriifolius*. Small societies of palms and *Pandanus* spp. are common in the lower storeys.

Native gardens are now rare in the area of this association but were apparently much more frequent in the past, as secondary forest now covers large areas. Species common in regrowth communities are *Macaranga* sp. ("pambata"), *Albizia falcata*, *Leucosyke* spp., and *Euroschinus papuanus*. In secondary forest *Tristiropsis subangula* is the most abundant species and *Dracontomelum mangiferum*, *Canarium* spp., and *Pometia pinnata* are common. A community dominated by *Eucalyptus tereticornis* is also presumed to be secondary. This community occurs on steep hills with badly eroded soils and these hills are presumed to have been originally covered by the *Anisoptera kostermansiana–Intsia bijuga* association.

(vi) Anisoptera kostermansiana–Eucalyptopsis papuana–Dillenia nalagi *Association*.—The most abundant species in mature forest are *Anisoptera kostermansiana* and *Eucalyptopsis papuana* with *Dillenia nalagi*, *Intsia bijuga*, *Hopea papuana*, *Gmelina* sp. ("pwa"), *Syzygium* sp., and *Podocarpus neriifolius* common. Secondary regrowth communities cover large areas particularly in the southern section of the association.

TABLE 10

DISTRIBUTION OF VEGETATION TYPES OVER LAND SYSTEMS ARRANGED BY GEOMORPHOLOGICAL UNITS AND SUBUNITS

Occurrence of communities is indicated as *D* (dominant, > 50% of land system area), S (subdominant, 50-20%), m (minor, < 20%)

Vegetation	Complex Mountains				Simple Fold Mountains and Hills			Extinct Volcano	Active Volcano							Depositional Plains														
	Metamorphic Mountains	Igneous Mountains	Hills						Summit and Adventive Features	Lahar–Glowing Avalanche Slopes			Piedmont-banjir Plains		1951 Eruption Products	Piedmont Terraces		Volcanic Outwash Plains				Fluvial-deltaic Plains					Swamps		Strand Plains	
	Misima	Botue	Oivi	Komondo	Hegahorte	Mt. Green	Iauga	Hydrographers	Lamington	Hamamutu	Higatura	Awala	Bohu	Eundi	Amboga	Kokoda	Ioma	Popondetta	Penderetta	Hanau	Sananada	Ilimo	Deunia	Warisota	Ambasi	Sagere	Ambi	Koena	Buna	Killerton
Rain forest formation																														
Anisoptera kostermansiana–Pometia pinnata																		S*		m*										
Pometia pinnata–Chisocheton sp.										S	*D**	*D**	*D*	S*			*D*													
Pometia pinnata–Alstonia scholaris–Octomeles sumatrana								m					m	m*				S*	S*	S*	*D**	*D**	*D*	S*	*D**	S*			S*	
Pometia pinnata–Dillenia quercifolia–Palaquium sp.																					m			*D*		S				
Anisoptera kostermansiana–Intsia bijuga		S?			*D*?	*D*		*D*	S?																					
Anisoptera kostermansiana–Eucalyptopsis papuana–Dillenia nalagi							*D**																							
Syzygium sp.–*Flindersia* spp.	S	S	*D*	*D*												*D**														
Barringtonia asiatica–Pterocarpus indicus																				m	m				m*			m	m	
Lower montane rain forest formation																														
Lithocarpus molucca–Castanopsis acuminatissima	S?	S?						S																						
Swamp forest formation																														
Campnosperma auriculata–Syzygium sp.													m														m	S		

Mangrove forest formation														
Heritiera littoralis												m		S
Bruguiera gymnorrhiza														S
Rhizophora mucronata														S
Fluctuating swamp forest formation														
Planchonia timorensis–Metroxylon sagu												m	S	
Swamp woodland formation														
Campnosperma auriculata–Metroxylon sagu													m S	
Mangrove woodland formation														
Ceriops tagal														m
Avicennia marina														m
Fluctuating swamp woodland formation														
Metroxylon sagu								m				m	S m	m
Swamp savannah formation														
Campnosperma auriculata–Thoracostachyum sumatranum													S	
Herbaceous swamp formation														
Thoracostachyum sumatranum–Hanguana malayana								m					S	
Grassland														
Saccharum spontaneum–Imperata cylindrica								m S			*D D* S m	m m m m		*D*
Themeda australis–Imperata cylindrica–Coelorhachis rottboellioides					m									
Imperata cylindrica–Apluda mutica				S										
Seral communities of the blast area														
Herbaceous communities						S	m m m		m					
Trema orientalis associes						S								
Euroschinus papuanus communities						m	*D* S m							
Lamington banjir sere									*D*		m			
Bare ground						m			m		m m		m	m m

? No field checks carried out. * A large proportion is garden regrowth.

The most abundant species in early stages are *Dillenia nalagi*, *Alphitonia incana*, *Macaranga* sp. ("pambata"), *Timonius timon*, *Pittosporum ferrugineum*, and *Glochidion* sp. ("ahura"). In later stages *Dillenia nalagi* is abundant, and *Evodia* spp. ("ser surindi" and "hama") and *Elaeocarpus* sp. ("korina") are common.

(vii) Syzygium *Sp.*–Flindersia *Spp. Association*.—The most important species are *Syzygium* sp. ("kartsaira"), *Flindersia* spp. ("notha" and "peromumbura"), *Sloanea* sp. ("orhe"), Indet. ("ahu"), and *Lithocarpus molucca*. A feature of this association is that individual stands are commonly dominated by a single species. Secondary forest is of widespread occurrence and the predominant species are *Pometia pinnata*, *Ficus hesperidiiformis* and *Ficus* spp. ("korsena"), *Pygeum* sp. ("angeri"), *Dracontomelum mangiferum*, cf. *Xanthophyllum* sp. ("koena"), *Alstonia scholaris*, and *Chisocheton* sp. ("asawa"). Important species in garden regrowth are *Albizia falcata*, *Pimeliodendron amboinicum*, *Litsea* spp., and *Evodia* spp. in advanced stages, and *Albizia falcata*, *Glochidion* sp., *Ficus* spp., and *Macaranga* spp. in young stages.

(viii) Barringtonia asiatica–Pterocarpus indicus *Association*.—This association is found on coastal sand ridges. It is a mixed rain forest with *Pterocarpus indicus*, *Barringtonia asiatica*, and *Intsia bijuga* common. On recent coastal deposits there are many seral communities in which *Ipomoea pes-caprae*, *Calophyllum inophyllum*, and *Casuarina equisetifolia* are dominant in various stages. All these seres develop towards a climax of the *Barringtonia asiatica–Pterocarpus indicus* association.

(*b*) *Lower Montane Rain Forest Formation*

This formation is an evergreen rain forest with two layers of trees with leaves predominantly simple.

(i) Lithocarpus molucca–Castanopsis acuminatissima *Association*.—This community was examined in the field only in Hydrographers land system. Thus little is known of it except that *Lithocarpus molucca* and *Castanopsis acuminatissima* are common, and that many species are shared with the *Anisoptera kostermansiana–Intsia bijuga* association. However, both *A. kostermansiana* and *I. bijuga* are rare.

(*c*) *Swamp Forest Formation*

This formation is an evergreen forest with two layers of trees and with sparse shrub and ground layers. Prop roots and pneumatophores are common.

(i) Campnosperma auriculata–Syzygium *Sp. Alliance*.—Many species are found in the dominant layer including *Campnosperma auriculata*, *Syzygium* sp. ("gasarabwing"), cf. *Garcinia* sp. ("batue"), and *Neuburgia* sp. The common species in the lower tree layer are the sago palm (*Metroxylon sagu*), *Pandanus* spp., and *Schuurmansia henningsii* as well as species common in the upper tree layer.

(*d*) *Mangrove Forest Formation*

This formation is an evergreen forest, generally below 70 ft in height, and has usually only one layer of trees. Prop roots and pneumatophores are abundant. Other layers may be present, generally a sparse layer of tree seedlings, a shrub layer, or a layer of small trees.

(i) Heritiera littoralis *Association*.—This association occurs on the landward edge of the mangrove forest formation. *Heritiera littoralis* is predominant but *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, and *Xylocarpus* sp. are common.

(ii) Bruguiera gymnorrhiza *Association*.—This community occurs as a belt in somewhat wetter sites than those occupied by the *Heritiera littoralis* association. *Bruguiera gymnorrhiza* is predominant but a few other mangrove species occur.

(iii) Rhizophora mucronata *Association*.—This association occupies the zone of mangrove forest with the largest period of inundation and fringes tidal creeks and lagoons. It consists of an almost pure stand of *Rhizophora mucronata* but other mangrove species occur occasionally.

(*e*) *Fluctuating Swamp Forest Formation*

This formation has two well-defined tree layers at 80 and 30 ft. The upper layer consists of evergreen trees, the lower layer is predominantly palms, and the ground layer is very sparse.

(i) Planchonia timorensis–Metroxylon sagu *Association*.—The upper tree layer is of very mixed floristic composition. Common species are *Planchonia timorensis*, *Alstonia scholaris*, and *Neonauclea* sp. ("tiga"). The ground layer is predominantly *Metroxylon sagu*.

(*f*) *Swamp Woodland Formation*

This formation is an evergreen woodland generally with a single layer of evergreen trees; occasionally a lower tree layer is present. The ground layer of hydrophytes varies from sparse to dense.

(i) Campnosperma auriculata–Metroxylon sagu *Alliance*.—The most common species are *Campnosperma auriculata*, *Syzygium* sp. ("gasarabwing"), and *Metroxylon sagu* in the tree layers, and *Thoracostachyum sumatranum*, *Hanguana malayana*, and many fern species in the ground layer.

(*g*) *Mangrove Woodland Formation*

Mangrove woodland is an evergreen woodland with a single layer of trees. Pneumatophores or prop roots are often abundant. The formation is restricted to a single headland south of Oro Bay.

(i) Ceriops tagal *Association*.—This association fringes mangrove forest and grows in the open sea. It consists of an almost pure stand of *Ceriops tagal*.

(ii) Avicennia marina *Association*.—A single stand of this association was noted surrounded by mangrove forest. It consisted of a pure stand of *Avicennia marina*.

(*h*) *Fluctuating Swamp Woodland Formation*

This formation has a layer of palms, 25–35 ft high. Other layers are absent or very sparse.

(i) Metroxylon sagu *Association*.—The community consists almost entirely of *Metroxylon sagu* though scattered trees may occur. The ground is littered with dead palm fronds and except for rare trailing plants the ground layer is absent. Stands occurring in the Koena land system form rounded clumps surrounded by swamp savannah or herbaceous swamp.

(*i*) *Swamp Savannah Formation*

Swamp savannah has a dense, tall ground layer of hydrophytes with an open or very scattered tree layer.

(i) Campnosperma auriculata–Thoracostachyum sumatranum *Alliance.*—The composition of the ground layer is identical with the *Thoracostachyum sumatranum–Hanguana malayana* alliance described below, and the scattered trees, 12–45 ft in height, belong to relatively few species including *Campnosperma auriculata* and *Syzygium* sp.

(*j*) *Herbaceous Swamp Formation*

This formation consists of a densely packed mass of leaves and stems of herbaceous hydrophytes 6–12 ft in height, with occasional twining plants binding the mass together.

(i) Thoracostachyum sumatranum–Hanguana malayana *Alliance.*—*Thoracostachyum sumatranum* and *Hanguana malayana* occur as local dominants but more frequently are co-dominants. Additional species are rare or common and include several tall species of Cyperaceae, ferns, and, very rarely, grasses.

(*k*) *Grassland*

Three different disclimax grassland alliances have been recognized. Scattered trees are found in all three types, the most common species being *Antidesma ghaesembilla, Nauclea orientalis,* and *Timonius timon.* Over 100 other tree species have been seen in these grasslands but these are generally of rare occurrence.

(i) Saccharum spontaneum–Imperata cylindrica *Alliance.*—After the regular yearly burning the dominant grass species *Saccharum spontaneum, Imperata cylindrica, Ophiuros exaltatus,* and *Coelorhachis rottboellioides* rapidly regenerate. Any combination of these four species may be locally dominant but *Saccharum spontaneum* is the most abundant species. Other grass species common in this alliance are *Apluda mutica, Sorghum nitidum,* and *Hymenachne amplexicaulis.* The occurrence of other herbaceous species is more variable and tends to be more frequent in drier areas where up to 30 species have been recorded from a small area. In a mature stand, which may exceed 10 ft in height before the annual firing, generally only a few species are present, including *Pueraria* spp., *Merremia hirta, Passiflora foetida,* and a fern ("kukusa"). Common species in a recently burnt stand include *Pygmaeopremna sessilifolia* and *Uraria lagopodioides.* In addition to the three tree species common in grasslands, *Ficus calopilina* is also a common tree in this alliance.

(ii) Themeda australis–Imperata cylindrica–Coelorhachis rottboellioides *Alliance.*—This alliance consists of a sequence of communities probably depending on the intensity of burning. It varies from a community dominated by *Imperata cylindrica* or by *Saccharum spontaneum* to a community dominated by *Themeda australis* and *Coelorhachis rottboellioides.* At this later stage the community rarely exceeds

3 ft in height, and the floristic composition may vary greatly over a few yards. A few stands include scattered trees of *Albizia procera* and *Eucalyptus tereticornis*, exceeding 60 ft in height.

(iii) Imperata cylindrica–Apluda mutica *Alliance*.—This community is dense grassland less than 5 ft high with occasional scattered trees. Species are few in number compared with other grassland. *Imperata cylindrica* may be dominant or co-dominant with *Apluda mutica*, the only other common species. The tree species include common grassland species and a few species common in the surrounding regrowth, notably *Dillenia nalagi*.

(*l*) *Seral Communities of the Blast Area*

These communities arose on the eruption deposits and on sites where the original vegetation was destroyed by the eruption of Mt. Lamington in 1951. The limit of this destruction is shown on an inset to the accompanying map. They are here described in the stage at which they were examined in August 1953. A more detailed account of these communities as well as a discussion of the survival of species and the future course of the successions is given by Taylor (1957).

(i) *Herbaceous Communities*.—Three main groups of herbaceous communities occur.

(1) A continuous range of communities from scattered moss and ferns to a dense closed stand of *Saccharum spontaneum*, 14 ft in height, is found on the lahar–glowing avalanche deposits in Avalanche valley.

(2) A second group of communities occurs in areas covered by more than 6–9 in. of volcanic ash. These communities are also dominated by *Saccharum spontaneum* but scattered trees, notably *Euroschinus papuanus*, occur where the ash cover is thinnest.

(3) A third group of herbaceous communities occurs on steep eroded slopes in the blast area of Mt. Lamington. These communities range from an almost pure stand of tussocks of *Saccharum spontaneum* separated by a dense mat of moss or *Lycopodium cernuum* to almost bare ground with a scattered cover of moss and *L. cernuum*.

(ii) Trema orientalis *Associes*.—This community consists of a single layer of trees, 15–25 ft in height. The dominant tree is *Trema orientalis*. Other species are rare and include *Ficus pungens*, *F. calopilina*, *F. berhaysii*, and *Leucosyke javanica*. The ground layer is predominantly *Imperata cylindrica*.

(iii) Euroschinus papuanus *Communities*.—Two communities, the *Euroschinus papuanus* associes and the *Euroschinus papuanus–Musa* spp. associes, occur. The *Euroschinus papuanus* associes is a woodland, 20–40 ft in height, *Euroschinus papuanus* predominating and with *Ficus pungens*, *F. calopilina*, *Ficus* sp. ("mumbura"), *Trema orientalis*, *Octomeles sumatrana*, and *Omalanthus* sp. ("ugaho") occasionally found. Under the dominant layer there is frequently a sparse subordinate tree layer and a dense ground layer of *Saccharum spontaneum*, *Imperata cylindrica*, and many herbs. This associes occurs on sites with an ash cover less than 6 in. deep or where little of the topsoil has been eroded. The *Euroschinus papuanus–Musa* spp. associes is very similar to the *Euroschinus papuanus* associes but is somewhat lower in height, 12–22 ft, and species of Musaceae ("hura" and "hubibi") are co-dominants with the tree species. This associes occurs on sites where erosion has removed most of the topsoil.

(iv) "*Lamington Banjir*" *Sere*.—The beds of all streams draining from Mt. Lamington are filled with deposits of volcanic material. In the upper reaches these consist of coarse sand or gravels which are only occasionally flooded and this area is dominated by scattered tussocks of *Saccharum spontaneum* or mixed stands of small trees, *Pipturus argenteus*, *Trema orientalis*, and *Albizia falcata* being common. In the lower reaches, the deposits are of fine sand and may be flooded frequently. These deposits bear dense stands of *Saccharum spontaneum* or *Phragmites karka* or a mass of water-loving herbaceous species. Most of the original vegetation on these areas has been killed but a few individual trees have survived.

III. References

Beadle, N. C. W., and Costin, A. B. (1952).—Ecological classification and nomenclature. *Proc. Linn. Soc. N.S.W.* **77**: 61–82.

Beard, J. S. (1944).—Climax vegetation in tropical America. *Ecology* **25**: 127–58.

Taylor, B. W. (1957).—Plant succession on recent volcanoes in Papua. *J. Ecol.* **45**: 233–43.

PART IX. LAND USE POTENTIAL OF THE BUNA–KOKODA AREA

By H. A. Haantjens* and G. A. Stewart*

I. Problems in assessing Potential Land Use

Assessing potential land use in this area must necessarily be mainly based on inductive methods as only limited indications can be obtained from the study of existing land use.

The only form of agriculture which is widespread throughout the area is shifting cultivation (Plate 5). Site quality is undoubtedly a major factor to the Papuan in the selection of land but the standards differ from those that would apply to European-type agriculture and its importance is often overridden by other considerations. For instance, coastal villages will use land in the coastal area, whether it is suitable or not. Villages in the mountains, originally situated for defence and health purposes, have to use poor land in those areas. Also, inherently poor land is not a serious obstacle to gardening, when the temporary fertility of cleared forest is combined with the ease of clearing of steeply sloping land. In shifting cultivation flood risks in the wet season can be avoided by short occupations and they are not considered as seriously as they would be by European settlers. Stoniness of the land is hardly an obstacle in native gardening. Some native crops are very tolerant to adverse conditions and yield levels have only a vague meaning to the native, who is not producing for a market.

For these reasons the intensity of gardening in a particular area is not always an indication of the suitability of the land for agricultural purposes, but in some cases it may support the conclusions reached on the basis of other considerations.

Naturally the apparent quality of the native crops has been considered during the survey. The large tolerance, the indeterminate nature of the root crops with no clearly defined stages of development, the complexity of varieties, and the lack of knowledge of the history and management of the individual gardens strongly limited the value of the observations. Only the extremes gave clear confirmatory evidence on site quality.

European-type agriculture in the area is too scarce, too limited in scope, and in most cases too recent to be of much value in determining the land use potentialities.† However, where possible, plantations were visited and crops inspected. Discussions with managers added to the information thus obtained.

One way of indicating the land use potential is to name, for each individual land unit, the crops that could be grown. Following this system one immediately meets with many difficulties. The number of potential crops is so large that it would not be easy to consider them all. For several areas the lists of suitable crops would be very long and confusing rather than enlightening.

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† This was written in 1954. Now much more could probably be learnt from subsequent experience with tree crops.

Another problem is that very little documentation exists on the precise environmental requirements of tropical crops. In the absence of local experience to use as a guide, such detailed assessment would result in an intolerable amount of guesswork and create a false impression of reliability.

Finally, detailed assessment would inevitably entail discussion of such matters as possible types of farming, size of farms, production methods, etc., which are beyond the scope of this report.

II. System of Assessment used in this Report

In order to avoid the difficulties outlined above and yet to give as precise technical information as the available data will allow, the agricultural potential of all units has been assessed (in the land system descriptions of Part III) in terms of eight land classes, adapted from the standard land classification system of the United States Soil Conservation Service.* Only minor alterations have been made to suit the local environment.

The land classes, denoted by Roman figures, indicate the *level* of suitability of land for different types of crop production. This level is determined by the nature and intensity of a number of limiting factors, of which chemical soil fertility is only a relatively minor one. These land classes should therefore not be considered as productivity or fertility classes in a narrow sense.

Land is placed in a particular class on the basis of what individual producers or small groups of producers will be able to achieve in neutralizing the limiting factors in this class. This should be kept in mind particularly where drainage or flooding is the limiting factor. Large-scale reclamation projects would be necessary to raise the potential of some land which cannot be properly drained or safeguarded against floods by the individual producer and which therefore ranks low in the classification in this report.

Except in class I the land classes are subdivided into subclasses, denoted by letter symbols indicating the nature of the limiting factors that affect the suitability of the land for various agricultural purposes.

When the land use potential is limited by two or more factors, the most important is given first, but the capability class is determined by the combined effect of all factors listed. Thus land with a moderate degree of erodability (e) would not necessarily be ranked still lower because of a limited degree of stoniness (st).

Only subclasses occurring in the area are described in Section IV.

In view of the high and well-distributed rainfall in the area, irrigation agriculture has not been considered when grouping the land into suitability classes, with the exception of paddy rice growing. Apart from this aspect, climate has not been considered in the classification but is discussed in relation to crop production in Part IV.

* A manual on conservation of soil and water. U.S.D.A. Soil Conserv. Serv. Agric. Handb. No. 61, 1954.

III. Limitations of the Assessment by Land Classes

As the subclasses are based on the nature of the limiting factors for land use as observed in the field, the assignment of subclass symbols such as e for erosion hazard, d for poor drainage, to various kinds of land can be considered as fairly definite and unquestionable. But the placing of land into the various classes (I–VIII) indicating the severity of the limitations is subject to more uncertainty, particularly because of the scarcity of present land use and experimental data that could have served as a guide. For example, land now classified as IIId may, as a result of further work done in the area, have to be reclassified as class IId land. But it is unlikely that land now classed as IIe will ever be reassessed as class IId. The only limiting factor that was difficult to assess not only in its severity, but in some cases also in its occurrence, is flooding. No floods were experienced during the field work in the dry season and this factor had to be assessed from indirect observations and limited information provided by local residents.

A different kind of limitation of the land classification is that it is based on present normal agricultural practices. The development of new techniques or crop varieties could well necessitate alterations in the present classification. Thus, in this report, the statements on land classifications are of a less definite and less lasting nature than the description and classification of the basic physical characteristics of the land. As new technical agronomic know-how becomes available and can be applied, this basic information can be reinterpreted for a new land classification with different criteria.

IV. Description of Land Capability Classes

Land classes I–IV are all suitable for cultivation but in decreasing order, class IV being marginal for this form of land use. Land classes V–VIII are not suitable for cultivation.

Class I land is very good land that can be cultivated safely with ordinary farming methods. It is nearly level, has deep productive soils, is well drained, and is not subject to damaging floods. It is suited to most types of land use, but paddy rice growing would generally involve special water supply measures.

Class II land is good land which is not subject to damaging floods but which requires simple special practices to maintain or reach optimal productivity when cultivated. It can be used without special limitations for other forms of land use, but tree crops require simple special measures where drainage is imperfect. Some areas are in particular suitable for paddy rice growing.

Subclass IIe.—The degree of erodability requires simple erosion control measures when the land is cultivated. These measures may be contour planting, strip cropping, short rotations with legumes or cover crops, mulching, simple terracing, etc.

Subclass IIst.—This land is sufficiently stony to interfere with cultivation of row crops, but stones can be cleared without undue effort.

Subclass IIso.—The soils are of very low fertility, or of moderately low fertility and sandy with low moisture-holding capacities. The improvement and maintenance of soil productivity require more than normal attention.

Subclass IId.—This land requires improved drainage to reach optimum productivity, especially for tree crops and arable crops, but this can be achieved by simple means such as a small number of drainage trenches.

Subclass II (padi) d.—This is IId class land but its topography and soil texture are particularly suitable for paddy rice cultivation with simple water control measures.

Class III land is moderately good land which requires intensive special measures to improve and maintain its productivity when it is cultivated. It can generally be used without special limitations for other forms of land use, but when the land is imperfectly drained intensive measures are required for tree crops. Some areas are particularly suitable for paddy rice growing.

Subclass IIIe.—The erosion hazards are such that intensive erosion control measures are necessary when the land is cultivated. Crops which are very susceptible to erosion should not be grown, and frequent rotations with grasses or legumes or intensive terracing are necessary.

Subclass IIIst.—This land is too stony for row crops and the removal of stones requires a major effort.

Subclass IIIe,st.—This land requires simple or intensive erosion control measures when cultivated. Stones interfere with operations but can be removed rather easily.

Subclass IIIe,so.—This land requires intensive erosion control measures when cultivated and has chemically poor, acid soils.

Subclass IIIso.—The soils are of moderately low to low fertility and very sandy with very low moisture-holding capacity. The improvement and maintenance of the productivity of this land when cultivated require intensive special measures such as frequent rotations with grasses or legumes, mulching, frequent application of fertilizers. The choice of crops is limited by the low availability of moisture.

Subclass IIId.—This land requires much improved drainage by intensive measures such as the establishment of a network of drainage ditches, tile drainage, or, locally, mechanical disposal of excess water to reach and maintain optimum productivity of tree crops and arable crops.

Subclass III (padi) d.—This is IIId class land but its topography and soil texture make it particularly suitable for paddy rice cultivation with simple water-control measures. For the same reasons it is inherently less suitable for many tree crops.

Subclass III (padi) d,f.—This is III (padi) d class land which is subject to frequent flooding, but control of this limiting factor is possible by relatively simple means such as low levee banks and improvement of natural drainage channels.

Class IV land is fairly good land that is best maintained in perennial vegetation but can be cultivated occasionally or in a limited way, if handled with great care.

Subclass IVe,so.—The degree of erodability is such that this land should be left in perennial vegetation for most of the time. It can be cultivated once in several years. The soils are very shallow and make the land unsuitable for most tree crops and for terracing.

Subclass IVf.—This land is liable to moderate flood hazards, whilst flooding cannot be controlled by local measures. Thus arable farming is restricted to quick-maturing crops in the drier season. The land is suitable for grazing and probably for some kinds of tree crops.

Subclass IVd,f.—This land is poorly drained and liable to flooding. Flood control and drainage are very difficult. It can be used for cultivation only during a short period of the year, and the choice of crops is therefore limited. It is unsuitable for tree crops. Pastures and forestry are the types of land use best adapted to it.

Subclass IV (padi) d,f.—This is IVd,f land with finer-textured soils which could be used occasionally for paddy rice growing.

Class V land is nearly level, not subject to erosion, and has productive soils, but it is unsuitable for cultivation because of other factors. It is productive grazing or forestry land and may be suitable for tree crops or paddy rice cultivation.

Subclass Vst.—This land is too stony for cultivation and the stones are too numerous to be removed. It is suitable for grazing and tree crops and very suitable for forestry.

Subclass Vf,st.—This land is liable to floods, which are very difficult to control. It is also moderately stony. For these reasons it is only suitable for pastures and forestry.

Subclass Vd,f.—This land is subject to serious flooding, which prevents cultivation throughout the year. Drainage improvement is not feasible. The land is stony in many places. This land is unsuitable for tree crops but suitable for pastures or forestry.

Subclass V (padi) d,f.—This is Vd,f class land with finer-textured soils and without stones which could be used for paddy rice growing under primitive irrigation conditions.

Class VI land is subject to moderate limitations for pastures or forestry. Some subclasses are also moderately suitable for tree crops.

Subclass VIe.—This land has so many erosion hazards that it is suited to grassland or forest only under careful management. It is also suitable for tree crops, provided that intensive measures are taken to prevent erosion.

Subclass VIst.—This land is so stony that it is only moderately suitable for pastures. It is difficult land for tree crops but quite usable for forestry.

Subclass VIe,st.—This land is less steep than subclass VIe and less stony than subclass VIst and can therefore be more easily used for pastures and tree crops.

Subclass VIe,so.—The combination of moderately steep slopes and shallow or very infertile soils makes this land suitable for pastures and forestry with only moderate limitations, but it is not very good for tree crops.

Subclass VIf,d.—This land is liable to severe flood hazards and in addition it is poorly drained. Thus potential land use is virtually restricted to rather extensive grazing or forestry.

Subclass VIf,st,so.—The combination of flooding, stoniness, and infertile sandy soils makes this land unsuitable for tree crops and of limited value for pastures. It is suitable for forestry.

Class VII land is subject to severe limitations for pastures or forestry. Some areas could also be used for tree crops.

Subclass VIIe.—The limitations of this subclass are similar in nature but more severe than those of subclass VIe. It is very difficult land to manage, even for forestry.

Subclass VIIe,so.—The combination of steep slopes and very shallow or very infertile soils makes this land unsuitable for tree crops and severely limits its suitability for pastures and forestry.

Subclass VIIso,st,f.—The combination of very coarse-textured infertile soils, high degree of stoniness, and flooding prevents the use of this land except for extensive grazing and for forestry.

Subclass VIIps.—This is swampy land, which is difficult to reclaim and which is only suitable for sago or paddy rice, grown under primitive irrigation conditions.

Class VIII has such unfavourable characteristics that it is unsuited for cultivation, tree crops, grazing, and forestry. In many cases it is important for watershed protection. Much of this land is covered by tall forest, but its exploitation would be very difficult.

Class VIII land has also been subdivided into subclasses, according to the nature of the limiting factors. In this case these are merely of academic interest and do not require further explanation and definition.

V. Regional Land Use Potential

The assessment of the potential land use, based on the system outlined above and applied to the land systems and units in Part III, marks the general limit of detail in land classification to be expected from this type of broad survey.

To permit the reader to obtain at a glance an impression of the regional land use potential within the survey area, the land systems have been grouped into a number of broad land use groups (Table 11) shown on the inset to the accompanying map and described below. Owing to the small scale of the map, the boundaries are very generalized and several of the smallest land systems are reproduced only in part or not at all.

(a) *Land with High or Moderately High Land Use Potential*

(i) *Uplands*.—These have a large proportion of very good land, although it is generally broken by numerous stream channels of varying width and depth. This land is suitable for many types of agricultural production, but not for wet rice-growing. Extensive good forests occur in Bohu and Awala land systems.

(ii) *Alluvial Plains*.—Much land in Ilimo land system has only few restrictions on choice of crops and cultivation practices, but it is locally stony or poorly drained.

To achieve its high potential productivity Sagere land system requires much improved surface draining. This is not likely to meet with serious technical difficulties. This land has good possibilities for paddy rice-growing and would, in general, be more suitable for arable farming and pastures than for tree crops. Good forest covers the upper portions of this land system.

TABLE 11
GROUPING OF LAND SYSTEMS INTO LAND-USE GROUPS

Land-use Groups		Component Land Systems	Principal Land Classes
Agricultural Potential	Nature of Terrain		
High to moderately high	Uplands	Awala, Bohu, Bundi	I–III
	Alluvial plains	Ilimo, Sagere	
Moderate	Uplands	Higatura, Kokoda, Ioma	IV–V or mixtures of I–II and VI–VII
	Alluvial plains	Popondetta, Penderetta, Hanua, Sananända, Deunia, Warisota, Ambasi, Buna	
Low	Hills	Komondo, Mt. Green, Iauga	VI
Very low to nil	Mountains	Misima, Botue, Oivi, Hegahorte, Hydrographers, Lamington, Hamamutu	VII–VIII
	Swamps and plains	Amboga, Ambi, Koena, Killerton	

(b) Land with Moderate Land Use Potential

(i) *Uplands*.—These have a considerable portion of good land with reasonably fertile or infertile (Ioma land system) soils, suitable for many arable or tree crops as well as pasture. However, the land use potential is significantly reduced because the land is broken by many ravines or by large, densely dissected areas. Therefore, land of this group appears generally most suitable for tree crops with, locally, forest plantations or grazing land. Some land in Higatura land system would be liable to damage to crops in case of renewed eruption of Mt. Lamington.

(ii) *Alluvial Plains*.—Although topographically these are eminently suitable for agriculture, the potential for arable crops is rather limited by flood risks or droughty, very sandy soils, and that for tree crops by poor drainage. It is difficult to improve the drainage when flooding cannot be controlled and this seems normally to be the case. Some of this land appears suitable for paddy rice growing. Cropping must be restricted to the drier part of the year, when flood hazards are smallest. With careful management and crop rotation permanent crops could possibly be grown on the very sandy soils, but these are expected to be more suitable for certain tree crops. Virtually all land of this group seems suitable for grazing or forestry. Good stands of forest occur in Hanau and Deunia land systems.

(c) *Land with Low Land Use Potential*

(i) *Hills.*—The slopes of this land are too steep and the soils too infertile for cultivation, whilst the general ruggedness makes it rather unattractive for tree crop plantations, although these could possibly be introduced on a small scale. This land could be cleared for extensive grazing but its most natural use appears to be forest exploitation. Extensive stands of forest are present.

(d) *Land with Very Low or No Land Use Potential*

(i) *Mountains.*—Although there would be local possibilities for tree crops and grazing (mainly on gentler slopes of Botue and Hegahorte land systems) this land is generally so rugged that it is virtually useless for agricultural settlement. Forest exploitation may be possible in some foothill areas, notably in Hydrographers and Hegahorte land systems. The maintenance of a protective forest cover is important as this group constitutes the most important catchments in the area. It includes the summit area of Mt. Lamington with its eruption hazards.

(ii) *Swamps and Plains.*—This land has no land use potential except for sago or paddy rice growing with very little water control in Ambi land system. The possibility of reclaiming the swamp lands is extremely remote and the peat soils of Koena land system are, moreover, very infertile. Parts of Amboga land system may eventually be used for timber extraction. The mangrove resources of Killerton land system are too small for serious exploitation.

APPENDIX I

Petrography and Petrology

By S. J. Paterson* and P. Green†

The results of microscope examination of thin sections of rock specimens are tabulated in Tables 12 and 13.

(a) *Owen Stanley Metamorphics*

In the specimens examined, stress minerals—muscovite, chlorite, plagioclase, clinozoisite, epidote, and glaucophane—are dominant, but in samples 95 and 96 both stress and anti-stress minerals—clinozoisite, glaucophane, and cordierite—occur.

According to the metamorphic facies and grade concepts of Eskola (1920) and Tilley (1924), which were extended by Turner and Verhoogen (1951), the rocks may generally be assigned to facies ranging from the greenschist facies (muscovite–chlorite subfacies) to the albite–epidote–amphibolite facies (chloritoid–almandine subfacies), indicating metamorphism under conditions of low to moderate temperature, mostly low hydrostatic pressure, and moderate to high directed pressure. The extent of the Owen Stanley metamorphics and the localized nature of the Ajule Kajale complex intrusions substantiate the conclusion that the metamorphics are dominantly the result of low- to medium-grade regional metamorphism, though within the sphere of influence of the intrusions contact or local metamorphic features are seen in rocks that may be assigned to the actinolite–epidote–hornfels subfacies.

The high proportion of calcite plus actinolite in samples 92, 93, and 94, which are garnetiferous calc-silicate, calc-silicate, and calc-schist rocks, is indicative of metamorphism of limestones or highly calcareous rocks.

(b) *Igneous Provinces*

The Ajule Kajale complex, Iauga formation, Hydrographers Range volcanics, and Mt. Lamington volcanics belong to petrographic provinces that are dominated by a calc-alkali kindred of rock types. The mineralogical characteristics of the provinces are the occurrence throughout of plagioclase within the labradorite–andesine–oligoclase range, the presence of ordinary augite and hornblende, and a serial variation in the occurrence of the orthorhombic pyroxene and hypersthene in both time (probable pre-Tertiary to Recent) and space (plutonic to volcanic). Quartz and the alkali–feldspar orthoclase occur only in one specimen (sample 53) in the Iauga formation, and feldspathoids do not occur, while biotite is present only in the Pleistocene to Recent volcanics.

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TABLE 12
PETROLOGY OF METAMORPHIC AND PLUTONIC ROCK SAMPLES

	No.	Name	Classification	Crystallinity and Texture	Minerals* Quartz (%)	Feldspars (%)	Amphiboles (%)	Pyroxenes (%)	Olivine (%)	Chlorite Group (%)	Fe Oxides (%)	Calcite (%)	Others (%)	Grain Size (mm)
Palaeozoic(?) Owen Stanley metamorphics	91	Quartz-muscovite-chlorite gneiss	Metamorphic	Crystalloblastic, gneissose	55	5 Pl				10 Cl	10 Mg		20 M	0·05–1·0
	92	Garnetiferous calc-silicate rock	Metamorphic	Crystalloblastic, granulose	5		10 Ac					60	24 G 1 Ep	0·02–1·5
	93	Calc-silicate rock	Metamorphic	Crystalloblastic, granulose	48	2 Pl	1 Ac				2 Mg	46	1 Ep	0·25–1·0
	94	Calc schist	Metamorphic	Crystalloblastic, schistose	40		10 Ac					50		0·25–1·0
	95	Garnetiferous cordierite-actinolite schist	Metamorphic	Crystalloblastic, schistose			30 Ac						40 Co 20 Cz 10 G	0·25–1·0
	96	Glaucophane-cordierite schist	Metamorphic	Crystalloblastic, schistose			50 Gl			5 Cl		1	23 Co 20 Cz	0·01–1·0
	141	Actinolite-schefferite schist	Metamorphic	Crystalloblastic, schistose	20		40 Ac			10 Cl	10 Il		20 Sc	
	142	Garnetiferous actinolite schist	Metamorphic	Crystalloblastic, schistose		10 Pl	82 Ac				7 Il		1 G	
	59	Dunite	Ultramafite	Holocrystalline, hypidiomorphic					75	24 An			1 Cr	3·0–8·0
	122	Peridotite	Ultramafite	Holocrystalline, hypidiomorphic					60	39 An	1 Mg			0·05–3·5
	123	Augite peridotite	Ultramafite	Holocrystalline, hypidiomorphic				60 Au	40					1·0–4·0

Mesozoic or early Tertiary Ajule Kajale complex	124	Peridotite	Ultramafite	Holocrystalline, hypidiomorphic					75	24 An	1 Mg			0·05–4·0
	125	Peridotite	Ultramafite	Holocrystalline, hypidiomorphic					50	49 An	1 Mg			0·05–4·0
	126	Serpentinized augite peridotite	Ultramafite	Holocrystalline, hypidiomorphic				10 Au	10	60 An	20 Mg			0·05–4·0
	127	Peridotite	Ultramafite	Holocrystalline, hypidiomorphic					95	4 An	1 Mg			0·05–4·0
	128*a*	Olivine-hypersthene gabbro	Calc-alkali basic plutonic	Holocrystalline, hypidiomorphic		1 La		91 Au 3 Hy	3	1 An	1 Mg			0·05–4·0
	128*b*	Olivine gabbro	Calc-alkali basic plutonic	Holocrystalline, hypidiomorphic		60 La		15 Au	23	1 An	1 Mg			0·05–4·0
	129	Hypersthene dolerite	Calc-alkali basic hypa-byssal	Holocrystalline, hypidiomorphic		50 La		25 Au 25 Hy						0·5–2·0
	130	Augite norite	Calc-alkali basic plutonic	Holocrystalline, poikilitic		24 Pl		14 Au 60 Hy		1 Cl	1 Mg			0·3–4·0
	133*a*	Hypersthene dolerite (micronorite)	Calc-alkali basic hypa-byssal	Holocrystalline, hypidiomorphic		60 Pl	3 Ac	17 Au 20 Hy						0·5–1·0
	133*b*	Hypersthene dolerite (microgabbro)	Calc-alkali basic hypa-byssal	Holocrystalline, hypidiomorphic		60 Pl	15 Ac	5 Hy 20 Di						0·5–1·0
	134	Augite norite	Calc-alkali basic plutonic	Holocrystalline, hypidiomorphic		50 Pl		20 Au 25 Hy		5 Cl	1 Mg			2·0–3·0
	136	Hornblende gabbro	Calc-alkali basic plutonic	Holocrystalline, hypidiomorphic		60 Pl	10 Hb 15 Ac	15 Au						2·0–3·0

* Ac, actinolite; An, antigorite; Au, augite; Ca, calcite; Cl, chlorite; Co, cordierite; Cr, chromite; Cz, clinozoisite; Di, diopside; Ep, epidote; G, garnet; Gl, glaucophane; Hb, hornblende; Hy, hypersthene; Il, ilmenite; La, labradorite; M, muscovite; Mg, magnetite; Pl, plagioclase; Sc, schefferite.

TABLE 13
PETROLOGY OF VOLCANIC ROCK SAMPLES

	No.	Name	Classification	Crystallinity and Texture	Phenocrysts* Feldspars (%)	Amphiboles (%)	Pyroxenes (%)	Biotite (%)	Chlorite Group (%)	Fe Oxides (%)	Others (%)	Grain Size (mm)	Ground Mass*	Composition Phenocrysts (%)	Ground Mass (%)
Lower Tertiary Iauga formation	34	Hypersthene andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	70 Pl		10 Au 15 Hy			5 Mg		0·5–2·5	Pl, Au, and Mg microlites and glass	60	40
	35	Augite andesite	Calc-alkali intermediate volcanic	Merocrystalline, trachytic	75And		15 Au			10 Mg		0·5–1·0	Pl, Au, and Mg microlites and glass	50	50
	36	Basalt	Calc-alkali basic volcanic	Merocrystalline, hyalopilitic	70 La		20 Au			8 Mg	2 Ze	0·2–1·0	Pl, Au, and Mg microlites and glass	20	80
	41	Olivine basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic	24 La		70 Au		1 An 1 Cl		4 O	0·25–2·0	Pl, Au, O, and Mg microlites and glass	40	60
	42	Basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic	70 La		28 Au		2 Cl		2 U	0·5–1·5	Pl, Au microlites and glass	40	60
	43	Olivine basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic	70 La		20 Au			5 Mg	5 O	0·5–1·5	Pl, Au, and Mg microlites and glass	40	60
	53	Quartz microdiorite	Calc-alkali intermediate hypabyssal	Holocrystalline, hypidiomorphic	5 Or 33 La	50 gHb				2 Mg	10 Q	0·5–1·5			
	55	Chloritized basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic	60 La				1 An 35 Cl	1 Mg	1 O 1 Ze 1 Ep	0·5–1·0	Pl, Cl, and Mg microlites and glass	40	60
	62	Olivine basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic					18 An	2 Mg	80 O	0·5–1·0	Pl, Au, and Cl microlites and glass	20	80
	74	Basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic	50 La		45 Au			5 Mg		1·0–3·5	Pl, Au, and Mg microlites and glass	80	20
	76	Basalt	Calc-alkali basic volcanic	Merocrystalline, porphyritic			98 Au				2 Ze	1·0–3·5	Glass stained by haematite and Pl microlaths	45	55
	79	Olivine basalt	Calc-alkali basic volcanic	Merocrystalline, variolitic	44 La		50 Au				1 O 5 Ze	0·25–1·0	Glass stained by haematite and Pl microlites	50	50
	106	Augite andesite	Calc-alkali intermediate volcanic	Holocrystalline, trachytic	10 La		5 Au		60 An 2 Cl		23 Ze	0·25–1·0	Pl, Cl, and Mg microlites	50	50
Pleistocene Hydrographers volcanics	110	Biotite-hypersthene andesite	Calc-alkali intermediate volcanic	Merocrystalline, hyalopilitic	77 And		3 Au <1 Hy	15		5 Il		0·25–1·0	Glass and Au, B, and Il microlites	50	50
	112	Lamprobolite andesite	Calc-alkali intermediate volcanic	Merocrystalline, hyalopilitic	60 And	30 L	5 Au			5 Il		0·25–1·0	Pl and Il microlites and brown glass	60	40
	112*a*	Hypersthene andesite	Calc-alkali intermediate volcanic	Merocrystalline, hyalopilitic	70 And		5 Au 24 Hy			1 Mg		0·25–2·0	Glass and Pl and Au microlites	40	60
	112*b*	Augite-hypersthene andesite	Calc-alkali intermediate volcanic	Merocrystalline, hyalopilitic	90 And		9 Au <1 Hy	<1		<1 Il		0·25–1·0	Glass and Pl, Au, and Il microlites	40	60
	113	Augite andesite	Calc-alkali intermediate volcanic	Merocrystalline, hyalopilitic	80 And		18 Au			2 Il		0·2–2·0	Glass and Pl, Au, and Il microlites	30	70

1	Beach sand	Sedimentary (volcanic derivation)			20 bHb 15 gHb 5 L				60 Mg					
5	Andesitic volcanic ash	Calc-alkali intermediate ejectamenta	Merocrystalline, porphyritic	30 And	25 bHb		3		2 Mg		0·2–3·5	40% fragmentary andesitic material		
8	Augite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	40 And	1 bHb	20 Au	4		35 Mg		0·2–1·5	Pl laths, Mg and Au microlites and glass	30	70
17	Augite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	40 And		20 Au			40 Mg		0·05–1·0	Pl, Au, and Mg microlites and glass		
19	Hornblende andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	45 And	45 gHb		5		5 Mg		0·02–1·5	Pl, gHb, and Mg microlites and glass	40	60
19*a*	Lamprobolite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	55 And	40 L				5 Mg		0·05–2·0	Glass and Pl, L, and Mg microlites	60	40
20	Enstatite anthophyllite schist	Metamorphic (from serpentinite and peridotite)			20 Anp	80 En					0·05–2·0			
21	Lamprobolite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	45 And	50 L				5 Mg		0·05–1·5	Glass and Pl, L, and Mg microlites	50	50
21*a*	Lamprobolite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	40 Ol-And	40 L				20 Mg		0·1–1·5	Glass and L and Mg microlites	60	40
22*a*	Hornblende andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	55 Ol-And	38 bHb	1 Au	1		5 Mg		0·1–1·5	Glass and bHb, Pl, and Mg microlites	60	40
22*b*	Hornblende andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	55 Ol-And	9 bHb		1		35 Mg		0·1–2·0	Glass and bHb, Pl, and Mg microlites	60	40
23	Gedrite-enstatite schist	Metamorphic (from serpentinite and peridotite)			60 T 35 Ge	5 En					0·05–2·0			
27	Hornblende-augite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	40 Ol-And	5 bHb	15 Au			40 Mg	<1 O	0·1–1·5	Pl, Au, and Mg microlites and glass	40	60
28	Hornblende andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	50 And	44 bHb	2 Au	1		3 Mg		0·1–3·0	Glass and Pl, bHb, and Mg microlites	60	40
30	Hornblende-biotite andesite	Calc-alkali intermediate volcanic	Merocrystalline, porphyritic	30 And	50 bHb	5 Au	10		5 Mg	<1 O	0·1–1·5	Glass and Pl, bHb, Au, and Mg microlites	40	60
33	Hornblende-biotite andesite	Calc-alkali intermediate volcanic	Holocrystalline, porphyritic	45 And	30 gHb	5 Au	10		3 Mg	7 U	0·25–3·0	Pl, Au, and Mg microlites	50	50
52	Hypersthene-biotite andesite	Calc-alkali intermediate ejectamenta	Merocrystalline, hyalopilitic	70 And		5 Au 15 Hy	5		5 Il		0·25–1·0	Glass and Pl, Hy, and Au microlites	50	50
60	Andesitic volcanic ash	Calc-alkali intermediate ejectamenta	Merocrystalline, porphyritic	20 And	15 bHb 5 gHb 20 L	6 Au	6		3 Mg		0·5–1·5	25% fragmentary andesitic material		
61	Andesitic volcanic ash	Calc-alkali intermediate ejectamenta	Merocrystalline, porphyritic	25 And	20 gHb		1		4 Mg		0·20–1·0	50% fragmentary andesitic material		

* An, antigorite; And, andesine; Anp, anthophyllite; Au, augite; Cl, chlorite; En, enstatite; Ep, epidote; Ge, gedrite; bHb, brown hornblende; gHb, green hornblende; Hy, hypersthene; Il, ilmenite; L, lamprobolite; La, labradorite; Mg, magnetite; O, olivine; Ol, oligoclase; Or, orthoclase; Pl, plagioclase; Q, quartz; T, tremolite; U, uralite; Ze, zeolite.

The constant characteristics of the kindred are zoning of the plagioclase within the labradorite–andesine–oligoclase range and a high proportion of magnetite. The serial characteristics of the kindred, which are shown in Table 14, are, from the oldest plutonic to the youngest volcanic rocks, a regular variation in the labradorite/andesine ratio, a gradual decline in the proportion of augite, hypersthene, and olivine, and an increase in the proportion of hornblende. Hornblende, dominantly green in the Lower Tertiary volcanics, is green-brown in the Pleistocene to Recent volcanics and brown (basaltic) in the most recent volcanics.

TABLE 14
SERIAL CHARACTERISTICS OF THE IGNEOUS PROVINCES

	Province			
	Ajule Kajale (Mesozoic or Lower Tertiary)	Iauga Formation (Lower Tertiary)	Hydrographers Range Volcanics (Pleistocene)	Mt. Lamington Volcanics (Pleistocene to Recent)
Plagioclase	Predominantly labradorite	Predominantly labradorite	Predominantly andesine	Predominantly andesine
Common augite	Very common	Common	Moderate	Moderate
Hornblende (green, brown, and basaltic)	Rare	Rare	Rare	Common
Hypersthene	Common	Moderate	Moderate	Rare
Olivine	Very common	Common	Not found	Rare

The Mt. Lamington volcanics may be divided into four distinctive groups. The first group (samples 8, 17, 27, 52) is characterized by a high proportion of pyroxenes, the second (samples 22*a*, 22*b*, 28, 30) by brown hornblende, the third (samples 19, 33) by green hornblende, and the fourth (samples 19*a*, 21, 21*a*) by lamprobolite and magnetite. The groups are arranged above roughly from the oldest to the youngest, though considerable intermingling occurs.

It can be seen from the above that the rocks of the provinces belong to the ultrabasic, basic, and intermediate groups of the common granodiorite–andesite kindred, which has been formulated as the typical example of the calc-alkali igneous series. Tyrrell (1948) states that the "plutonic members (of the series) range from peridotite, olivine gabbro to gabbro, and thence through diorite, quartz-diorite, and granodiorite to granite. The commonly associated volcanic rocks are andesite, dacite, and rhyolite". Tyrrell further states that "the granodiorite–andesite kindred is typically associated with fold-mountain ranges, and appears to be in genetic connection with the movements which have produced them. Thus the more deeply-worn central parts of the fold-mountain chains that girdle the Pacific Ocean, and those of the Alpine-Himalayan system, often expose cores of plutonic rocks of this kindred, whilst the volcanoes which exist on or near the mountain chains erupt mainly andesitic lavas. At the present day many of the active volcanoes in the above-mentioned regions are erupting a very characteristic hypersthene–andesite lava". The remarks are particularly appropriate to the igneous occurrences in the Buna–Kokoda area.

(*c*) *References*

ESKOLA, P. (1920).—Mineral facies of rocks. *Norsk. Geol. Tidsskr.* **6**: 143–94.

TILLEY, C. E. (1924).—Facies classification of metamorphic rocks. *Geol. Mag.* **61**: 167–71.

TURNER, F. J., and VERHOOGEN, J. (1951).—"Igneous and Metamorphic Petrology." (McGraw-Hill: New York.)

TYRRELL, G. W. (1948).—"The Principles of Petrology: An Introduction to the Science of Rocks" 9th Ed. (Methuen and Co. Ltd.: London.)

INDEX TO LAND SYSTEMS, SOILS, AND VEGETATION COMMUNITIES

(*Photo: Australian News and Information Bureau*)

Fig. 1.—Large parts of the area are steep hills and rugged mountains covered by rain forest. The Owen Stanley Range with its massive, parallel spurs (Misima land system) is particularly steep. It has an abrupt fault-controlled boundary with the intramontane Kokoda valley, at 800–1500 ft altitude. In this populated valley, which is almost wholly covered with secondary vegetation, remnants of old terraces covered with weathered ash from Mt. Lamington volcano (Kokoda land system) rise above the younger flood-plains of Ilimo land system.

Fig. 2.—The active volcano, Mt. Lamington, is a dominating feature in the region. In the summit area (Lamington land system), an active dome rose to more than 5000 ft after the 1951 eruption. The main force of the disastrous blast came through the gap of Avalanche valley (Amboga land system) between old domes on the left and lava flows on the right. The original vegetation was destroyed within a large area and in 1953 the regeneration on slopes covered with fresh volcanic ash was still in a herbaceous stage, dominated by cane-grass.

(*Photo: Royal Australian Air Force*)

Fig. 1.—During earlier stages of activity, viscous lava poured over the upper western slopes of Mt. Lamington to form convex ridges (Lamington land system) lying on top of the dissected volcanic slopes of Hamamutu (severely dissected) and Higatura (moderately dissected) land systems. Adventive cones, like that in the top left-hand corner, are a characteristic feature of the volcano. The photo, taken in February 1951, clearly shows the effect of the eruption on the rain forest vegetation. Paired with Mt. Lamington is an older extinct volcano, the Hydrographers Range. Dissection has turned it into very broken, mountainous country (Hydrographers land system) but from a distance the outline of the original concave, volcanic slopes is still evident.

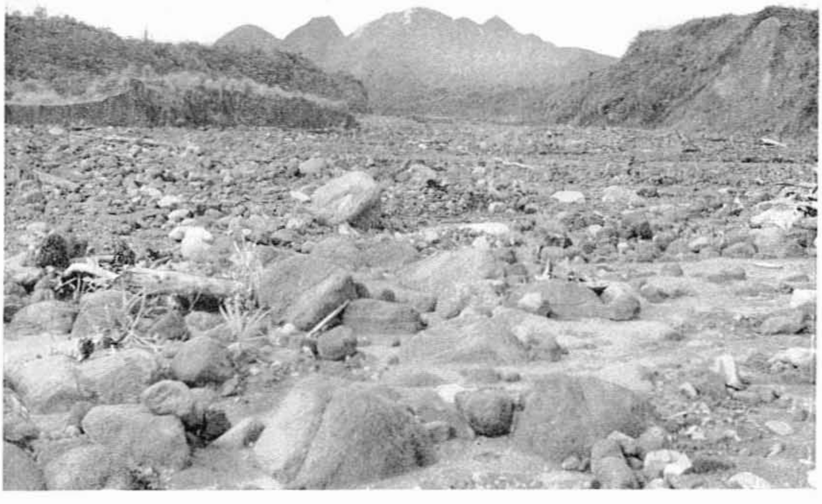


Fig. 2.—Laharic deposits such as these filled up the channels of many rivers originating on Mt. Lamington (summit area in background). In most cases this happened several months after the eruption. Such deposits were mapped in Amboga land system.

Fig. 1.—*Imperata–Ophiuros* grassland, here in a rather early stage of regeneration after burning, occupies nearly all the higher parts of the volcanic out-wash plains of Popondetta land system with their black, sandy soils (sample in auger). Fire-resistant trees locally give these grasslands a savannah character. The plains are slightly dissected and rain forest covers the lower-lying flood-plains (background).

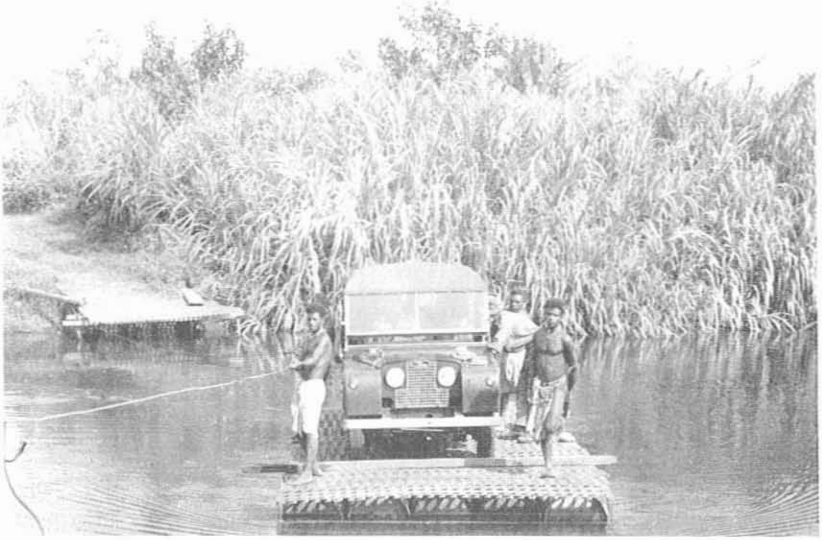
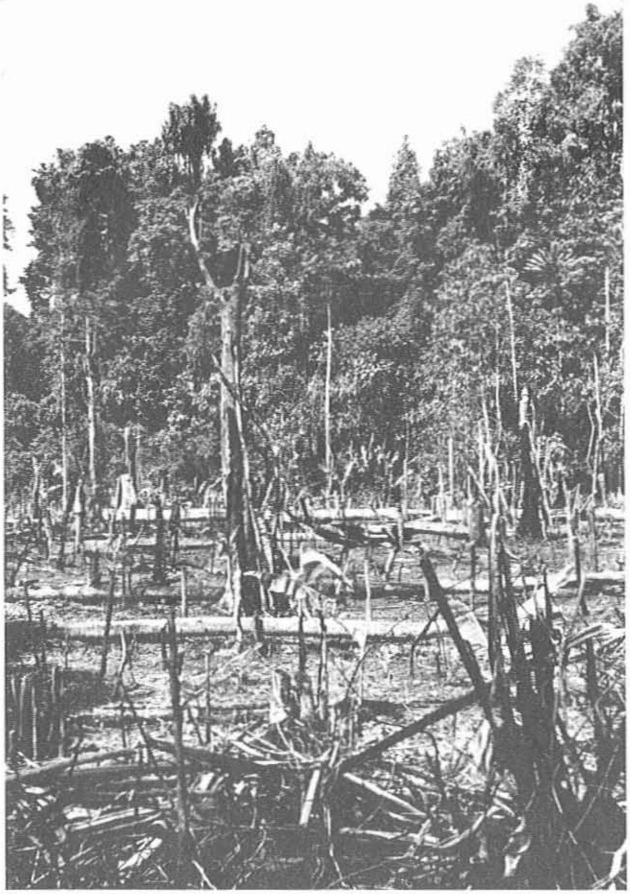


Fig. 2.—Flood-plains with young alluvial soils cover a considerable proportion of the area. A bridge now spans the lower Embogo River on the road linking the agriculturally most productive areas near Popondetta with Oro Bay, the best natural harbour in the area. The lower courses of the larger rivers are fringed by tall *Saccharum spontaneum*. The rarely flooded alluvial plains (Warisota land system) are here covered with regrowth following shifting cultivation.

Fig. 1.—After the eruption, fine sandy sediments were deposited as flood-outs close to the coast by several rivers originating on Mt. Lamington. Stream channels were blocked and very wet conditions prevailed with many rivulets flowing over the surface. The deposits (Amboga land system) were rapidly covered by a dense mass of *Saccharum spontaneum* or *Phragmites* sp. and many water-loving herbaceous species.

Fig. 2.—Taro (*Colocasia esculenta*) is the most important subsistence crop of the indigenous population. It is particularly well adapted to poorly drained land, but this excellent crop of nearly 4 ft is in a clearing on fertile volcanic soils in Bohu land system.



In shifting cultivation clearings are maintained for about 10 months for the main crops (such as taro), then allowed to revert to forest regrowth, although crops like bananas and papaw may continue to be harvested for another year or so. The same site may be cleared again after 5 years, but commonly there is a longer period of recovery to secondary forest. In this new forest clearing on volcanic soil in Awala land system the garden has been subdivided with logs into small family plots.

Flood-plains have their own characteristic types of rain forest, particularly on poorly drained sites such as this in Hanau land system. This forest, rich in pandanus palms, is intermediate between well-drained rain forest and swamp forest. It belongs to the *Pometia pinnata–Alstonia scholaris–Octomeles sumatrana* association.

Fluctuating swamp woodland, dominated by sago (*Metroxylon sagu*), occurs typically on periodically inundated gleyed alluvial soils of Ambi land system.

In the northern part of the area extensive peat swamps of Koena land system are covered with swamp savannah vegetation, dominated by *Thoracostachyum sumatranum* with scattered trees of *Campnosperma auriculata* and *Syzygium* sp. The figure in foreground is 6 ft 6 in. tall but ankle deep in water which is permanently at or over the surface of the poorly decomposed organic soils.