Lands of the Goroka–Mount Hagen Area, Territory of Papua and New Guinea

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MAPS

PART I. SUMMARY

By H. A. Haantjens*

I. Land Systems and Geomorphology

The area surveyed comprises nearly 4300 sq miles between latitudes 5°30′ S. and 6°30′ S. in the Territory of New Guinea. Apart from the lower slopes to the Ramu valley in the north-east, it consists of valleys and hilly uplands between 4000 and 7000 ft above sea level, separated by mountain ranges to 8000–10,000 ft above sea level, with some higher peaks up to 14,800 ft above sea level.

The 39 land systems recognized and described in this report are natural landscapes with a characteristic pattern of rock, land form, soil, and vegetation, which is mappable from aerial photographs at the map scale used. Where sufficient data are available the land systems have been subdivided into units which are landscape elements of greater simplicity than the land systems, but which cannot be mapped conveniently at the scale used. The distribution of the land systems, which range in area from 3 to 1750 sq miles, is shown on a land system map at a scale of 1 : 250,000. The reference to this map, in which the land systems are briefly described and have been grouped according to their geomorphological affinities, constitutes a summary description of the survey area. Additional maps at a scale 1 : 500,000 depict the land systems grouped according to dominant lithology; ruggedness and maximum relief; associations of major soil groups; and agricultural land use capability.

Based on a complex geological history dating back to Palaeozoic time, the land systems owe their present form and distribution mainly to strong orogenesis by block-faulting and up-arching in Plio–Pleistocene time, followed by rapid weathering and strong denudation (commonly by rotational slumping and landslides) in humid climatic conditions, and accompanied by the formation of alluvial fans and lake-bed deposits in the valleys. Pleistocene volcanism was a major land-forming agent in the western part, whilst late Pleistocene glaciation affected the highest mountain summits. At present the area appears to be in a stage of relative stability.

II. Agricultural Potential

The agricultural potential of the area has been assessed in terms of modern farming methods such as permanent cultivation of annual crops, tree crop plantation agriculture, and grazing on improved pastures. The suitability of the land for traditional indigenous agricultural practices has not been considered. The land use capability of the area has been basically assessed by placing all land types recognized into 8 land classes of decreasing level of suitability for agriculture. These classes have been subdivided into 34 subclasses, indicating the nature of the limiting factors. The land classes and subclasses are described and are indicated for all land units in

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Part IV. For a regional synopsis, this information is summarized in the description of 14 land use capability groups shown on a map at scale 1 : 500,000.

The approximate areas of land of different levels of suitability for modern intensive agriculture are shown in Table 22 in Part X. Good arable land is scarce, and this may raise problems in the future in this generally densely populated area. Whilst there is much room for expansion of tree crop plantation agriculture—a development which has gained momentum for arabica coffee and tea since 1955—there is a clearly larger potential for cattle grazing on improved pastures, particularly since climatic conditions appear to be very suitable for this form of land use. Reclamation of poorly drained and swampy land could significantly increase the acreage or the productivity of land suitable for agriculture, with proportionally the greatest increase in the potential for arable cropping. Such reclamation has already begun in several basins.

Erosion hazards and difficult topography, in places together with shallow soils, are the major limitations for agricultural development. On flatter land, land use capability is commonly reduced by poor drainage and/or physically poor soils. Stoniness and flood hazards are only locally significant limitations. Climatic conditions determine in a general manner the range of crops that can be grown, but strongly limit this range above 7000 ft altitude although certain specialty crops (pyrethrum, vegetables, berries) are well adapted to the climate at elevations of 7000–9000 ft. Plant nutrient deficiencies have not been taken into account in the land use capability classification. Potash and probably sulphur deficiencies appear to be the most common for tree crops, whilst phosphate deficiencies are likely to be common for annual arable crops. Whilst crops have probably rarely failed because of nutrient deficiencies, some large yield increases due to fertilizer application have been reported, and it seems likely that in most cases sustained production over long periods will require fertilizer application, even of nitrogen which is usually not in short supply in virgin soils, as a normal management practice. Differences in the chemical composition of soils can be considerable and are discussed in Part VI.

III. Forest Resources

For the purposes of this inventory, commercial forest is defined as having a minimum of 3000 super ft per ac of standing timber from trees more than 5 ft in girth, using a form factor of 0·5, and without making allowance for internal defect. Eight types of commercial forest have been described and their distribution is shown on a map at scale 1 : 250,000. These types include 12 sq miles of lowland hill forest at an approximate stocking rate of 10,000 super ft, 65 sq miles of irregular lowland hill forest at 3000 super ft, 470 sq miles of mixed lower montane forest at 9000 super ft, 480 sq miles of degraded mixed lower montane forest at 3000 super ft, 290 sq miles of mixed–beech forest at 9500 super ft, 40 sq miles of beech forest at 11,000 super ft, 145 sq miles of beech–mixed forest at 10,500 super ft, and 8 sq miles of stunted beech–mixed forest at 3000 super ft. In addition, non-commercial montane forest covering 105 sq miles has been described and mapped because of its importance for watershed protection.

To assist in the assessment of timber extraction problems, the land systems have been divided into three access categories: I, land on which the proportion of slopes under 10° is greater than or equal to the proportion of slopes over 10°; II, land on which the proportion of slopes under 30° is greater than or equal to the proportion of slopes over 30°; III, land with dominantly slopes over 30°. The distribution of forest types over access categories and land systems is given in Table 16 in Part VIII.

IV. Climate

At altitudes of 5000 ft and higher the climate approximates the moist temperate or mesothermal climates of higher latitudes, but differs from these in its very restricted annual temperature range. Monthly mean temperature varies by only 4 degF and decreases approximately 3 degF with every 1000-ft increase in elevation from an average of 65° at 5000 ft. Ground frosts occur with increasing frequency above 6000 ft above sea level.

Regionally, rainfall distribution is controlled by the seasonal latitudinal movements of two major surface air masses: the perturbation belt of westerly-moving vortical circulations to the north (north-west season) and the south-east trade wind belt to the south (south-east season), which are separated by the intertropical convergence zone. The perturbation belt dominating the weather from December to March reaches a sufficient altitude to enter the area, resulting in high rainfall during this season. Conversely, the south-east trade winds dominant from May to October generally reach insufficient height to pass over the mountain barriers, leaving the weather, particularly in the eastern part of the area, dominated by dry zonal easterlies. The resulting seasonality in rainfall, nowhere pronounced and tempered by long transitional seasons, gradually decreases from east to west with a corresponding increase in annual rainfall in this direction. Local circulations, promoted by the large topographical differences, dominate the weather in the south-east season and remain important during the north-west season. Mean annual rainfall, measured at 14 stations over periods varying from 5 to 24 years, ranges from 68 in. at Henganofi in the east to 106 in. at Kuta in the west. Annual variability is characteristically low and ranges from 11 to 17%. Daily falls over 4 in. have not been recorded and falls over 2 in. are uncommon. On the other hand there are approximately twice as many rainy days as rainless days and rainy periods up to 44 days have been recorded. Annual evaporation at about 5000 ft is calculated to be about 42 to 51 in., and serious soil moisture stress occurs only rarely during the dry season in the driest part of the area. Mean annual relative humidity is about 87% at 0900 hr and 57–67% at 1500 hr. Mean annual cloud cover recorded at Goroka and Mount Hagen is 6 to 7 on a scale of 0–8, and mean annual sunshine recorded at Aiyura is 1850 hr. There is relatively little monthly variation in all these climatic factors.

V. Population and Land Use

The area comprises the most populated parts of the New Guinea highlands. Over a length of 200 miles and an average width of 50 miles, these highlands contain almost half of the total population of the mainland of the Territory of Papua and New Guinea. In 1962–63, the indigenous population of the survey area was 354,000, amounting to an overall population density of 80 per sq mile, and to 190 per sq mile on land used. Locally, the population density reaches 500 per sq mile on land used. About 3% of the indigenous people live in the major towns. In 1966 the non-indigenous population was 4100, of whom 44% live in the major towns. The distribution of the population over the land systems is given in Part IV, and the distribution over the area as a whole may be inferred from the distribution of the land use intensity classes on the land use map. The annual growth rate varies between 0·5 and 1·2%.

The indigenous people are mostly engaged in subsistence cultivation but there is increasing emphasis on cash cropping. In 1963–64, 8000 indigenous persons were employed outside the area, mainly as recruited labour, whilst 10,000 were employed within the area, 3000 of whom came from outside. The non-indigenous inhabitants are engaged in government, plantation, mission, and commercial work.

There is evidence that habitation dates back to at least 10,000 years B.P., whilst fairly elaborate agricultural techniques were already in use at least 2300 years B.P. The main staple crop is sweet potato, thought to have been introduced 400–500 years ago. Many other crops are also grown in subsistence cultivation, including recently introduced vegetables. Present settlement patterns vary from disperse, particularly in the western part and in rugged areas with low land use intensity, to nucleated in villages, particularly in the eastern part and on more gentle topography with high land use intensity.

The subsistence cultivation cycle ranges from long-fallow to almost permanent, short-fallow cropping systems. In the first case, the fenced-in gardens tend to be scattered, in the second they tend to be aggregated into complexes up to 3 sq miles in size. Many different types of land are used, ranging from poorly drained bottom land to slopes over 40°. Subsistence crops are generally grown below 8000 ft altitude. Garden beds are commonly prepared with a rectangular grid of shallow trenches or by making circular mounds. In the west this technique also includes composting. Gardens are prepared at a rate of 0·2–0·6 ac per head per year, with a median of 0·3 ac. The distribution of subsistence cultivation in 1955 is shown on the land use map by three main classes of land use intensity. Areas with intensive land use (> 75% anthropogenous vegetation of which > 20% is in current use) cover 251 sq miles; areas with moderate land use (> 50% anthropogenous vegetation of which 5–20% is in current use) cover 1176 sq miles; areas with light land use (< 50% anthropogenous vegetation of which < 5% is in current use) cover 397 sq miles. Large agglomerations of gardens are indicated separately on the map. Induced disclimax short grassland has been mapped as a separate category to indicate the major areas of past land use. There is little correlation between the extent and intensity of subsistence cultivation in the land systems and their land use capability rating for modern permanent agriculture. Differences in land use intensity and population distribution in six suites of areally associated land systems are described and illustrated by Figures 10–14 in Part IX. These suites are: Goroka fan suite, Minj fan suite, Bena–Kainantu hill suite, Chimbu hill suite, Hagen volcanic suite, and Wahgi alluvial suite.

According to figures published in 1967, cash cropping by indigenous persons includes 30,000 ac of arabica coffee, of which 35–50% is not yet bearing (production 5800 tons); 1500 ac of tea (not yet producing); 1000 ac of pyrethrum (production 160 tons); and 540 tons of passion-fruit pulp and juice. This commercial production takes place on small plots closely associated with subsistence cultivation. Most coffee is processed in large cooperative factories. Commercial production by non-indigenous lessees occurs on 208 holdings, mainly in the Goroka–Henganofi and Wahgi valley areas. These include 10,500 ac of coffee (1965–66 production 3500 tons), 5000 ac of other crops, mainly sweet potato, and 6000 ac of improved pastures (5600 head of cattle). Recently 16,000 ac in the western Wahgi valley have been opened up for tea plantations. Coffee yields average 965 lb/ac in the western part of the area and 1155 lb/ac in the eastern part. Maximum yields obtained are up to 3360 lb/ac. The distribution of non-indigenous holdings is well correlated with the agricultural land use capability ratings of the land systems.

VI. Soils

Fourteen major soil groups and one group of miscellaneous land types have been recognized. Thirteen of the major groups have been subdivided into 37 soil families. These have been tentatively correlated with subgroups and great groups of the 7th Approximation soil classification system of the U.S.D.A. Soil Conservation Service. Associations of major soil groups are shown on a map at scale 1 : 500,000. The major soil groups are described in alphabetical order, and the constituent soil families are described with each major group.

Humic brown clay soils are largest in extent and are found throughout the area in well-drained positions on relatively stable slopes between 3000 and 9000 ft. They are particularly well developed on volcanic ash plains and slopes and on some alluvial fans. Because of widespread slope instability various kinds of colluvial soils (regosolic soils) are common, particularly on hills and mountains. Since rocks are generally deeply weathered, lithosols are relatively rare. In comparison with other parts of New Guinea alluvial soils are also uncommon. On swampy flood-plains they are associated with organic soils. Organic soils also occur in depressions in the ash plains in the wetter western part of the area and are common on the very wet high mountain summits where they occur as alpine peat and humus soils, locally associated with rock outcrop. At the other end of the spectrum a small area of black earths (grumusols) occurs on volcanic rock in the driest part of the area. Similar, but very shallow, black soils (rendzinas) are related to limestone parent rock rather than to climate, and are commonly associated with deeper reddish clay soils. Such strongly weathered humic brown and red latosols occur also on other rock types but are comparatively uncommon. This appears to be due partly to the prevalence of unstable slopes, since they occur mostly on more gentle stable slopes, and partly to climatic factors, since they are virtually absent above 7000 ft above sea level. Impeded drainage is an important factor of soil formation, particularly in the valley lands on alluvial fans, terraces, lake deposits, and on mudstone hills. It has resulted in the development of strongly weathered meadow podzolic soils and lateritic or gleyed latosols and of less weathered meadow soils and gleyed humic brown clay soils.

The soils have mostly high organic matter and nitrogen contents (generally 3–10% organic carbon and 0·2–0·9% N), which increase from east to west and with altitude owing to increasingly wet conditions. Although the soils are mostly acid to strongly acid there are notable exceptions (pH around 6·5), particularly in alluvial soils and meadow soils but also in more weathered soils. However, only the black earths and rendzinas have consistently near neutral reaction. Although total phosphate contents are generally high (1000–3000 p.p.m.), available phosphate is commonly very low except in the alluvial soils and some meadow soils. Exchangeable potash contents vary considerably but are rarely high. The variation appears to be correlated with parent rock rather than with kind of soil. Many soils have the peculiarity that their clays are difficult to disperse. In the volcanic ash soils particularly, this is probably due to the presence of allophane. Kaolin and metahalloysite and in some cases gibbsite are the dominant clay minerals, and commonly occur in a poorly crystalline form. Illite is less common but together with montmorillonite dominates the clay composition of the black earths and probably the rendzinas.

VII. Vegetation

Apart from alpine grasslands above 12,000 ft above sea level, relatively small areas of *Phragmites* swamp, and probably also small areas of sedge bog in the valleys, the whole area was most probably originally covered with rain forest. This forest shows a marked response to climate in its structure and floristics, resulting in distinct altitudinal forest zones. Tall, structurally complex, and floristically very mixed lowland rain forest occurs below 3000 ft on the north-eastern slopes to the Ramu valley. It merges into lower montane rain forest of slightly lower stature and complexity. This forest is usually of mixed composition and in places rich in conifers, but may be dominated by oaks (*Castanopsis*, *Lithocarpus*) between 3000 and 7500 ft or by southern beech (*Nothofagus*) between 7000 and 9000 ft. At 9000–10,000 ft such forest merges into montane rain forest, which in turn gives way to subalpine forest and scrub which penetrate the alpine grassland in sheltered habitats.

In most of the valleys and hilly uplands the forest vegetation has largely disappeared as a result of clearing for shifting cultivation and subsequent burning of the grass vegetation encroaching upon the agricultural land. Of the oak forest in particular, only small remnants remain. The grasslands form a succession, apparently controlled partly by the frequency and duration of burning and partly by edaphic and climatic factors. *Miscanthus* sword grass and shrub regrowth is a tall community, developing quickly after land clearing and persisting longest in the wetter areas and on the better land. It is replaced by disclimax short grassland of the *Capillipedium* and *Themeda* type which is most extensive in drier areas and on poorer land. Generally forest clearing has proceeded to a maximum altitude of 8000 ft, since the yield of the traditional agricultural crops falls off rapidly at this altitude. As a result of the intensive interference by man, the vegetation of many lower parts of the area forms a mosaic of grassland, gardens, groves of planted trees, remnant and secondary forest, and a mixed vegetation of trees, shrubs, and tall cane grass along streams. These vegetation types are locally associated with small and large areas of swamp vegetation. In some areas, particularly the Baiyer and Wahgi valleys and in the east, the grasslands are extensive and almost unbroken.

Twenty-two vegetation communities have been recognized and described. They have been grouped into 11 broader categories. No vegetation map has been prepared but a reasonable picture of the distribution of the common communities can be obtained from the combined forest resources and land use map at the scale 1 : 250,000.

PART II. INTRODUCTION

By J. R. McAlpine* and H. A. Haantjens*

I. The Survey Area

(a) Location

The area comprises slightly less than 4300 sq miles, including a gap in the aerial photography in the east but excluding an area of overlap with the Wabag–Tari

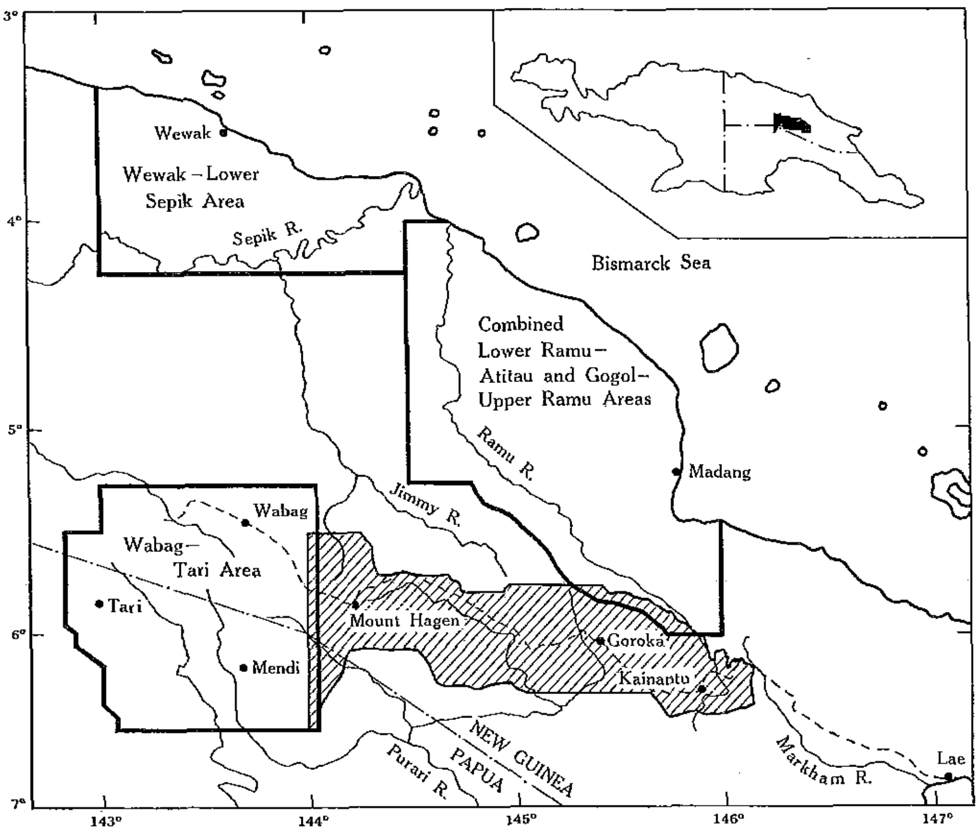

Fig. 1.—Location of the Goroka–Mount Hagen area showing major rivers and towns, the main road from Lae, and the location of adjoining and nearby survey areas.

area in the west. It is situated in the Trust Territory of New Guinea, between 144°00′ E. and 146°05′ E. and 5°30′ S. and 6°23′ S. (Fig. 1). The area comprises most of the eastern half of what are known as the Central Highlands of New Guinea.

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It is largely between 4500 and 10,000 ft in elevation, but descends steeply to less than 1000 ft along the Ramu River in the north-east and rises higher than 10,000 ft in several peaks, the highest of which is Mt. Wilhelm (14,793 ft) (McVean 1968). In the west the area borders on the Wabag–Tari area which was surveyed in 1960 and 1961 (Perry *et al.* 1965). In the north-east it borders on the Gogol–Upper Ramu area, surveyed in 1956 and described in an unpublished report.*

(*b*) *History*† *and Government*

Extravagant speculation and bogus accounts of adventurers during the nineteenth century pictured the central highlands of New Guinea as being populated by people of material wealth. By the early twentieth century, the area was considered to be one of unrelieved ruggedness with only a very light, if any, population. Ignoring Detzner's unsubstantiated claims of 1916 (Souter 1963), the truth was not revealed until the late 1920s and early 1930s when the search for gold and souls and the concomitant need to establish the Pax Britannica led to the exploration of the area. The highlands were found to contain fairly broad and densely populated upland valleys.

The first European contact came from the east during exploration trips by the gold prospectors Rowlands, Dwyer, and the Leahy brothers. Almost simultaneously, missionaries from Madang entered the area from the north along the Chimbu valley. In 1932, the Leahys established a base camp and airstrip at Bena Bena to improve access to their gold claims. From here they explored westward, in company with J. Taylor, a government officer, as far as Mt. Hagen where another airstrip was constructed. This system of exploration on foot and subsequent leap-frogging by airstrip construction formed the basic pattern for most later exploration, contact, and control in the highlands.

During the 1930s, government stations were opened at Kainantu (Ramu police post), Bena Bena (which later was shifted to Henganofi), Kundiawa, Gogme, and Mount Hagen (which was unmanned from 1934 to 1938). Goroka was not established until 1939. Exploring missionaries either preceded the government and gold miners or followed them closely. In this initial contact period they also established many permanent mission stations, and in the west these predated the government posts. Souter (1963) provides a useful and easily accessible source of information for this period of New Guinea history.

During this early contact period, the area had its administrative headquarters on the coast at Salamaua and formed part of the Morobe District. During World War II, the area was administered by the military Australian New Guinea Administration Unit and was used to a small extent as a rest centre and provider of fresh vegetables. Civilian administration was resumed in 1946 and Goroka became the administrative centre for the highlands. Shortly after, the area was divided into the Western and Eastern Highlands Districts, with headquarters at Mount Hagen and Goroka respectively. In the first decade after the war full administrative control was established in the area surveyed, although the outliers of the two districts were still

* Lands of the Gogol–Upper Ramu area, New Guinea. CSIRO Aust. Div. Land Res. Reg. Surv. divl Rep. 57/2, 1957 (out of print).

† Prehistory is dealt with in Part IX.

uncontrolled and some areas not even contacted in the mid 1950s. In 1967, the densely populated Chimbu area was made a separate district with headquarters at Kundiawa.

Each of these districts contains a number of subdistricts (Fig. 2) and these in turn are divided for administrative purposes into census divisions. Over and above this administrative arrangement almost the whole area is now covered by local government councils, a form of representative government with gradually increasing local financial and administrative responsibilities.

European contact has also resulted in the creation of towns along the valley floors. The main towns from east to west are Kainantu, Goroka, Kundiawa, Kerowagi, Minj, and Mount Hagen (Anon. 1967*a*).

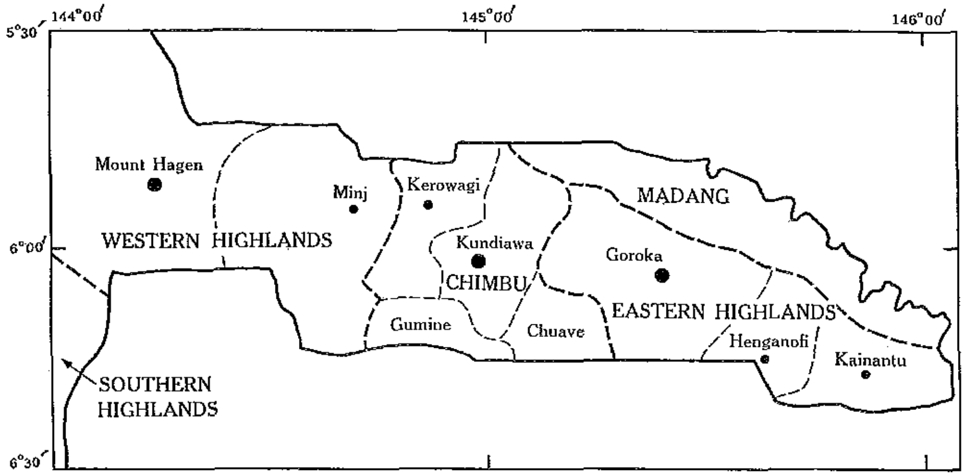

Fig. 2.—Administrative divisions. District boundaries are shown by heavy broken lines, district headquarters indicated by large dots. Subdistrict boundaries are shown by light broken lines, subdistrict headquarters indicated by small dots.

(*c*) *Transport*

As stated above, the role of aircraft was of considerable importance in the early exploration of the highlands. After World War II, government control and economic development were just as dependent on air transport for both internal and external communications.

Six main airstrips, capable of handling DC3 aircraft, were built at Kainantu, Goroka, Nondugl, Minj, Banz, and Mount Hagen soon after the war. Between these places numerous other landing grounds for light aircraft were constructed by the government, missions, and commercial interests. The result was the creation, in the major valleys, of the densest network of airstrips in New Guinea (Fig. 3). The isolation of the area from the coast was an important factor in this reliance on air transport, even when the local road network was developed. Initially, the major external air connection was to Lae, but this soon passed to Madang largely because this town is nearer and more centrally located (Fig. 1). Thus nearly all imported goods came to the highlands by air from Madang and local produce (e.g. coffee) was flown out. An indication of the magnitude of air transport is given by the fact that for the financial year 1965/66, approximately 30,000 short tons were air-freighted from Madang to the highlands (Anon. 1967*b*). Internal highland movements of freight and passengers were proportionately as large.

At the same time that airstrips and services were being extended an internal road network was being developed. Initially, construction was by local hand labour but later road construction plant was increasingly used. The first motor road was constructed from Goroka to Kainantu during the war and extension of the road network is still taking place. Each road system was commenced from a central airstrip but from the mid 1950s these separate systems were linked up, making through traffic possible. At the same time, the area was connected with Lae by a dry-weather four-wheel-drive road (Fig. 1). By mid 1966 over 2200 miles of road had been constructed (Fig. 3), of which 1300 miles were suitable for heavy to medium traffic (Anon. 1967*b*).

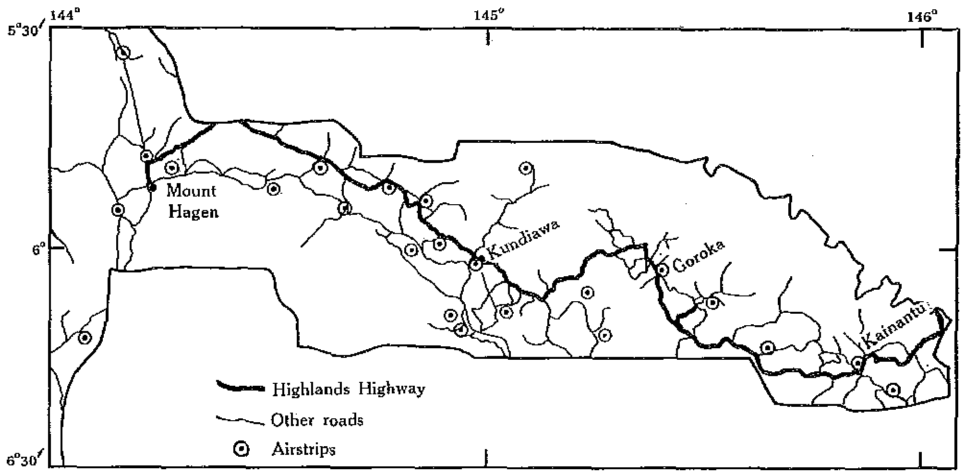

Fig. 3.—Vehicular roads according to data provided by Department of Public Works, Port Moresby; and airstrips, 1967 situation.

By 1967 the road from Lae had been upgraded to all-weather heavy-duty standards at least as far as Goroka. Thus, for the first time external road transport could compete with air services. As a result dependence on aircraft for moving goods in and out of the area has decreased markedly, but passenger traffic is still dominantly by air. The road link with Lae has greatly reduced the predominance of Madang as an external supply port; but whilst Lae now has an advantage over Madang in the central and eastern sectors of the area, this is hardly the case in the more distant western district. A direct road link from Mount Hagen to Madang is being considered to give the west a shorter outlet to the coast and simultaneously to open up the Madang hinterland, including the Ramu valley.

II. The Land Resources Survey

(*a*) *Aerial Photographs and Maps*

With the exception of a gap in the eastern part, the area is covered by vertical aerial photos taken by Adastra Airways Pty. Ltd., mostly between July and September 1955, but in September and November 1956 in the eastern part and in June 1959 in the north-western corner. The photos were taken from a height of 25,000 ft, but as a result of the great variations in altitude within the area the photo scale varies from 1 : 40,000 in the valleys to 1 : 20,000 on the summit of Mt. Wilhelm. A base map, at a scale of 1 : 250,000, mainly showing stream patterns, was prepared for this survey by the Division of National Mapping, Department of National Development, Canberra. Inadequate ground control has of necessity resulted in some loss of accuracy. Photo interpretation boundaries were transferred from the aerial photos to this base map with the aid of a Grant projector.

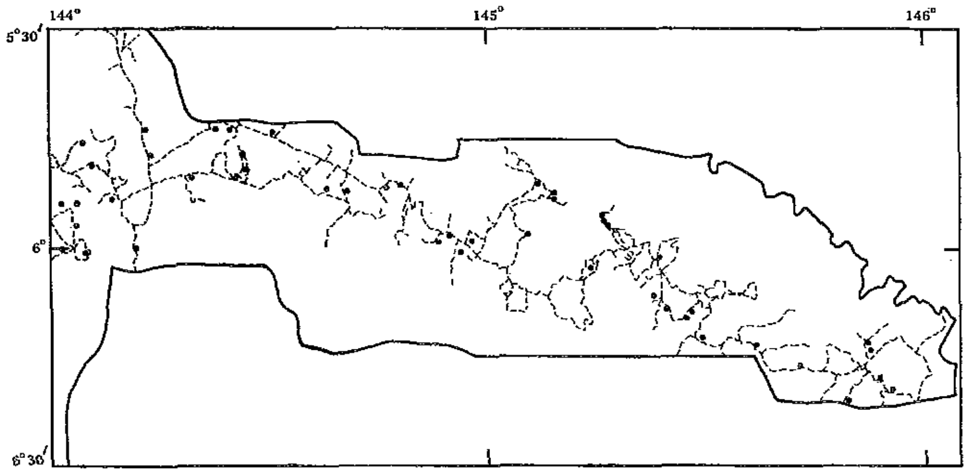

Fig. 4.—Field traverses and soil-sampling sites of the survey team.

(b) *Field Work*

The field work for the survey was carried out between June 22 and October 17, 1957, by a team consisting of a geomorphologist, pedologist, and plant ecologist, assisted by a transport officer and several indigenous field assistants. Data were collected at nearly 800 observation sites, located along the traverse lines, shown in Figure 4. Traverses were made in Land Rovers along all existing roads, which were also used as base lines for the shifting of base camps from which traverses on foot, lasting from one to seven days, were made into the more isolated parts of the area using locally recruited carriers for the transport of equipment and food. Concurrently with the main team, a forest botanist and botanical collector made a separate investigation of the principal commercial forest types in the area. The forest survey as well as the work of the plant ecologist has benefited greatly from the results of a botanical survey conducted in the area in 1956 by Dr. R. D. Hoogland, plant taxonomist, and Mr. R. Pullen, botanical collector, both of the CSIRO Division of Land Research. Mr. J. R. McAlpine revisited the area in 1965 and 1967 to collect information on population figures and present land use.

(c) *The Report*

This report replaces an interim report* that has been unavailable since 1965.

* Lands of the Goroka–Mount Hagen area, New Guinea. CSIRO Aust. Div. Land Res. Reg. Surv. divl Rep. 58/1, 1958 (unpublished).

Although survey techniques have improved in the intervening years, no attempt has been made in this report at a wholesale re-evaluation of the primary data collected during the survey or of the original photo interpretation. The differences between this report and its predecessor consist essentially of additions and editorial changes.

To bring this report in line with the published report on the adjoining Wabag–Tari area (Perry *et al.* 1965), it was necessary to carry out some remapping along the western margin and to alter the names of some land systems to those of the same land systems in the Wabag–Tari area. The western margin of the Goroka–Mount Hagen map slightly overlaps that of the Wabag–Tari map, and where boundaries do not correspond entirely those on the overlap may be considered the more reliable. Changes in the names of vegetation communities have also been introduced for the sake of uniformity with the Wabag–Tari area, whilst a table has been prepared to correlate the soil families of both areas.

The area covered in this report is larger than that covered by the interim report. The inclusion of the Baiyer River valley area in the north-west, made possible by more recent aerial photography, and the extension of the mapping to the limits of the photographic coverage in the Kubor Range area have had the effect of making the area a more natural unit.

Some mapping deficiencies in the interim report were so obvious that they had to be rectified. The most important of these is the split of the original Ogelbeng land system into four new land systems: Teiga, Ogu, Nunga, and Tari. The assistance given by Mr. J. G. Speight, CSIRO Division of Land Research, in carrying out this remapping and in providing skeleton descriptions of the four new land systems is gratefully acknowledged. Further alterations are the remapping of part of the former Hagen land system (now Nemarep land system) as Birap land system, the transfer of unit 5 of the former Astelia land system (now Giluwe land system) to Wilhelm land system, and the remapping of unit 9 of the former Ogelbeng land system, together with small parts of other land systems, as Lai land system. As a result of these modifications the number of land systems has increased from 32 in the interim report to 39 in this report.

Parts I, III, V, and IX are additions to the interim report. The text of the introduction and the land systems has been greatly revised, and up-to-date references have been added throughout the report.

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PART III. GEOLOGIC AND GEOMORPHIC HISTORY OF THE GOROKA–MOUNT HAGEN AREA

By H. A. Haantjens*

I. Introduction

The following brief account is given to provide background information and to assist the reader in assessing the significance of the land system and the lithology maps discussed in Part IV.

The geology of most of the area has been described by Rickwood (1955), McMillan and Malone (1960), Dow and Dekker (1964), and Dow and Plane (1965). Much of this information was not available when the CSIRO survey was carried out.

II. Pre-Pleistocene Geology

The oldest rocks in the area are Palaeozoic metamorphics, predominantly schists, which were intruded by large bodies of granodiorite (Wilhelm, Bismarck, Kubor, Yonki, Kwongi land systems). The intercalation of altered coral limestones with the schists suggests a reef environment of deposition (Dow and Dekker 1964). In the Mt. Wilhelm massif and the western Kubor Range (Plate 1, Fig. 1) the intrusive rocks are not overlain by the metamorphics. This suggests that the latter were removed here by erosion, thus attesting to the existence of some land masses in the distant past. Whilst Dow and Dekker (1964) indicate a Triassic to early Jurassic age for the Bismarck granodiorite, Rickwood (1955) found cappings of Permian limestone overlying granodiorite in the west, schist in the east of the Kubor Range. Since this limestone includes basal arkose sandstone derived from granodiorite in the west, and contains schist fragments in the east, he concludes that the Kubor intrusions took place in pre-Permian time. Whilst these limestones suggest that the Kubor land mass was submerged during the Permian time, the great gap in sedimentation during the Triassic and Lower Jurassic suggests that it was again a land mass in those eras. Similarly, McMillan and Malone (1960) present evidence that at least part of the Bismarck Range was land during the Mesozoic and Tertiary.

Rickwood (1955) and Dow and Dekker (1964) report uninterrupted marine deposition from Upper Jurassic to Lower Miocene time. Since the Upper Jurassic rocks increase in thickness to the east and north, and progressively younger reef limestones are found from east to west, Rickwood (1955) suggests progressive transgression of the sea from the east and north, resulting in submergence of the Kubor Range except for its western part. Similarly Dow and Dekker (1964) consider that the western Bismarck Range formed a eugeosynclinal depression after the Lower Jurassic, with its axis along the north side of the present Wahgi valley. According to these authors, there was a nearby shelf in the Wahgi valley area, as evidenced by the

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presence of reef limestone and coarse clastic sediments. These thick sequences of marine Jurassic to Miocene sedimentary rock, ranging from shales to coarse greywacke, tuff, and limestone, are dominant in Ambum, Koge, Pira, Elimbari, Korambogl, Kumun, Womei, and Okapa land systems (Plate 1, Fig. 2; Plate 2). By contrast, large amounts of terrestrial Miocene sediments (Daulo volcanics) were laid down in the eastern part of the area (McMillan and Malone 1960) where they form Limisate (Plate 11, Fig. 2) and parts of Bismarck and Okapa land systems. This change from marine to terrestrial sedimentation is reflected in the west by leaf fossils in Miocene sediments, evidence of the presence of land masses (Rickwood 1955).

Whilst the strong orogenetic movements responsible for the present topographic situation may thus have been initiated in the Miocene, resulting in relatively large land masses separated by narrow seas, there is evidence that the major uplift took place in late Pliocene and early Pleistocene times. Rickwood (1955), for instance, reports Pliocene marine deposits having been folded together with older rocks during subsequent uplift. The orogenesis was accompanied by much folding and faulting and the formation of horsts and grabens, such as the Wahgi and Goroka valley depressions. Korambogl, Womei, and Kumun land systems (Plate 2, Fig. 1) occur in such down-faulted areas and thus have lower relief than neighbouring up-faulted areas of the same rock (Plate 10, Fig. 1). McMillan and Malone (1960) report increasing amounts of uplift from SE. to NW. (Mt. Wilhelm massif). In the western part of the area, Rickwood (1955) suggests a system of roughly parallel WNW.-trending anticlines and synclines, with up-arching of the Kubor granodiorite resulting in tilting, fracturing, and erosion of the overlying Permian limestone of which only remnants now remain (Oga land system). These anticlines have gentle northern and steep southern flanks, which developed into the Bismarck and Chimbu fault zones on the southern margins of the Bismarck Range. In the east, McMillan and Malone (1960) distinguish two NW.-trending fault groups, parallel to the main structural trend and with steep NE. dips: the Asaro fault south of the Goroka valley and the Bundi–Imbrum fault along the NE. flank of the Bismarck Range. Displacement of alluvial fans in the Goroka valley indicates that the Asaro fault group is still active.

III. Geomorphology

The geomorphological history of the present landscape is almost wholly related to this orogenesis and to later events. It is suggested, however, that the accordant hilly summit areas in the Bismarck Range (Kwongi land system), and possibly also the hilly uplands of Okapa land system (Plate 2, Fig. 2), are remnants of the probably late Miocene to early Pliocene landscape as it existed before the major uplift. These surfaces gradually increase in altitude from SE. to NW., supporting the observation of McMillan and Malone (1960) of increasing uplift in this direction. Similar remnant surfaces do not exist in the western part of the area (unless Oga land system can be so considered), but they again become conspicuous further west as Nop and Silim land systems in the Wabag–Tari area (Perry 1965). It is also possible that one or two volcanic necks in Okapa land system and a crater-like feature in Yonki land system are remnants of a late Miocene or Pliocene landscape in the east.

The great increase in relief energy resulting from the orogenesis promoted vigorous down-cutting of the streams. This process was aided by the high rainfall, which led to a dense network of perennial streams and to rapid disintegration of rocks, particularly the granodiorite, by weathering. Probably because of the protection afforded by the rain forest vegetation, weathering was generally able to keep pace with erosion, as evidenced by the thick regoliths on all but the steepest slopes. These mantles of unconsolidated material probably provide favourable conditions for landslides and slumps, which are characteristic for many slopes in the area.

During this same period volcanic activity became a major land-forming factor (Plate 3) in the west of the area (Giluwe, Ialibu, Doma, Nemarep land systems). Rickwood (1955) indicates that the lava, agglomerate, and ash were poured out over a rugged landscape, similar to the present one. The gorge of the Lai River, just west of the area, was apparently well established before the major eruptions, filled with volcanic debris from Mt. Hagen, and in places later excavated to its original shape by erosion. This is evidence that the major volcanism began well after the initiation of river down-cutting, and therefore cannot be earlier than Pleistocene.

A third important geomorphic event was the Pleistocene glaciation (Plate 4, Fig. 1) of the highest mountain peaks: Mt. Wilhelm and Mt. Herbert (Rickwood 1955), Mt. Hagen and Mt. Giluwe volcanoes, and several peaks in the Kubor Range (Wilhelm and Giluwe land systems). Relicts of only one glaciation have been observed and these are extremely well preserved (Reiner 1960). This indicates that the area has been affected only by the last major glaciation, that the main volcanic centres were extinct by that time, and that the peaks of the Bismarck and Kubor Ranges may have escaped earlier glaciation simply because they had not then reached a sufficient height. This would support the suggestion that the major uplift is a very recent event in the geological history and agrees with observations of Verstappen (1952, 1960) in the Nassau and Star Mountains, West Irian. Conversely, comparisons of the Pleistocene and contemporary snow lines (Reiner 1960) show that there could not have been significant net gain or loss in height of the ranges since the late Pleistocene.

The dissection and down-wearing of the ranges and the volcanic activity had profound effects on geomorphological development in the valleys. Large alluvial and colluvial fans were formed (Moruma, Goroka, Minj, Omahaiga land systems (Plate 4, Fig. 2; Plate 11, Fig. 1)), and lacustrine beds (Plate 5, Fig. 1) were laid down in the more stable eastern parts of the area (Abiera and Aiyura land systems). Dow and Dekker (1964) attribute the deposition of fanglomerates in the Ramu valley north of the area to the glaciation of Mt. Wilhelm and Mt. Herbert. Although glaciation and periglacial processes may have contributed, it would appear that on the whole these sources of detritus were of little significance in comparison with the quantities of material made available by down-cutting streams (cf. Bik 1967).

The large supply of volcanic material caused the formation of the large ash plains of Teiga and Nunga land systems (Plate 5, Fig. 2) and hill ridges of agglomerate and lava (Ogu land system). There was subsequent partial redistribution of volcanic ash in mud flows and by stream action (Tari land system). Minor volcanic activity continued into the Recent period, mainly in the form of lava and scoria cones and explosion craters (Birap land system). Volcanic deposits blocked the Gogimp and

Kaugel valleys (Plate 6, Fig. 1), probably causing temporary lakes which were rapidly filled with alluvium, ash, and peat (Winjaka, Tambul land systems). Major rivers, such as the Kaugel, Nebelyer, and Baiyer, were able to restore normal drainage conditions by rapidly cutting gorges (Lai land system) in the poorly consolidated deposits (Plate 5, Fig. 2).

Of particular interest appears to be the history of the Wahgi River, the largest in the area. There is evidence that it replaces an earlier river, draining the Wahgi valley in the opposite direction, from east to west, into the Sepik system through the Baiyer River valley and gorge. The base of the Wahgi valley has an east–west gradient, with consolidated rocks forming the valley floor in the east (Korambogl land system). The present valley floor is almost level, due to the deposition of alluvium of decreasing age from east to west (Minj, Banz, Kinjibi, and Ko land systems). Thus the present Wahgi River passes through increasingly older deposits, has a meandering upper course, and increasing gradient and incision down stream. This is the opposite to normal river behaviour. Whilst the present river breaks out of the valley in a deep gorge through the mountains, no such obstacles existed at the wide western end of the valley before the advent of volcanism. The swampiness of the western Wahgi valley (Wahgi and Ko land systems, Plate 6, Fig. 2) appears to be caused by blocking by volcanic debris. This could not have been the case if the area had always been drained to the east. It is probable that the reversion of the drainage in the Wahgi valley took place in two steps: firstly, the capture of an early upper Wahgi in the east by a tributary of the Chimbu River (there are several instances where a similar type of capture appears imminent at present); secondly, the blocking of the western Wahgi valley, probably resulting in the formation of a lake (which may have influenced deposition in Ko, Kinjibi, and Banz land systems) followed by drainage of this lake into the vigorously down-cutting Chimbu River system. Very similar river captures, resulting in the southward diversion of originally north-west-draining rivers, have been suggested by Verstappen and Doets (1950) for the Wissel Lakes and by Verstappen (1952) for the Baliem River in West Irian.

The slowing down of the uplift, almost to a standstill in late Pleistocene and Recent times, strongly reduced the sediment supply to the rivers, thus enabling them to dissect their own Pleistocene deposits. This widespread dissection of the valley fills proceeded at different rates at different localities in the area, and alternated with periods of rest and locally renewed deposition to form series of terraces (e.g. Makuntus land system (Plate 5, Fig. 1)) related to either temporary increases in the rate of uplift or the formation of resistant nick points in the streams. At present the area appears to be in a phase of relative stability, with limited erosion, and aggradation restricted to small areas of Kinjibi, Aiyura, Kaugel, Ko, and Wahgi land systems.

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PART IV. LAND SYSTEMS OF THE GOROKA–MOUNT HAGEN AREA

By H. A. Haantjens,* E. Reiner,† and R. G. Robbins‡

I. Introduction

The 39 land systems described in this Part and shown on the accompanying land system map are natural landscapes with a characteristic pattern of rock, land form, soil, and vegetation (Robbins and Haantjens 1958) which is mappable from aerial photographs at the map scale used (Haantjens 1965). Although the land systems are primarily natural, i.e. genetic units (Mabbutt and Stewart 1963), consideration is also given in their establishment to their land use potential.

Each land system consists of one or more units. These are areas of land with a particular combination of land forms, soils, and vegetation, and are not mappable from aerial photographs or at the map scale used. A distinction is made between simple units, with only one particular type of land form, soil, and vegetation (e.g. flat terrace surface), and compound units, which have a particular sequence of land forms, soils, and vegetation (e.g. steep ridges and narrow valleys). The majority of the units in this report are compound units. They differ from land systems only in that they are not mappable because of their very intricate pattern, the absence of mappable boundaries, or small size. The concept and application of land systems and land units have been discussed in earlier papers by Christian (1952, 1958), Christian and Stewart (1953, 1968), and Christian, Stewart, and Perry (1960).

II. Grouping of Land Systems

Since land systems reflect regional variations in such different aspects of land as rock type, land form, soil, and vegetation pattern and, as a result of this, also reflect differences in land use capability, it is clear that they can be grouped in many different ways. In this report the land systems have been arranged on the land system map according to differences in gross land form type. Thus this map serves a double purpose in that it is at the same time a land system map and a geomorphological map of the area. The geomorphological grouping is twofold: a very broad subdivision into erosional, constructional, and aggradational land forms, and a narrower grouping based on slope and relief type and land-forming process. Whilst such groups are useful in analysing the landscape, they are not clear-cut and usually comprise land systems which are transitional to one or more other groups. Other ways of grouping the land systems have been followed in preparing the small-scale maps of lithology, ruggedness and maximum relief, associations of major soil groups, and

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agricultural land use capability. Table 1 has been prepared to facilitate cross reference between the land system map and the four derived maps. It should be noted that the

TABLE 1

RELATIONSHIPS BETWEEN LAND SYSTEMS AND MAPPING UNITS ON THE SMALL-SCALE DERIVED MAPS

Land System	Mapping Unit Number on Derived Map of Lithology	Ruggedness and Maximum Relief	Associations of Major Soil Groups	Land Use Capability
Wilhelm	1	1a	2	14
Giluwe	8	1b	2	14
Kubor	1	1a	3	14
Ialibu	8	1a	3	14
Bismarck	2	2a	7	12
Ambum	4	2b	7	12
Koge	3	2b	8	11
Pira	4	2b	8	11
Doma	8	2b	5	12
Oga	5	3a	10	9
Elimbari	5	2b	10	12
Suma	5	2c	10	12
Lai	8	2c	5	13
Yonki	1	2c	6	10
Nemarep	9	2c	4	9
Limisate	8	3a	1	14
Korambogl	6	2d	6	9
Abiera	10	3b	13	10
Teiga	9	3b	11	5
Kumun	6	3a	9	7
Womei	7	4b	15	6
Ogu	8	4a	11	10
Winjaka	10	3b	16	9
Kwongi	1	2d	4	12
Okapa	6	3a	9	11
Birap	9	2c	11	7
Nunga	9	4b	11	2
Tari	9	5a	12	1
Moruma	10	3b	16	7
Goroka	10	4b	12	2
Minj	10	4c	13	7
Omahaiga	10	3b	11	6
Banz	10	5b	14	4
Kinjibi	10	6	17	4
Aiyura	11	6	18	3
Tambul	11	5a	20	8
Makuntus	10	5b	17	3
Kaugel	10	6	18	3
Ko	11	6	19	8
Wahgi	11	6	19	13

separate forest resources and land use intensity map is not derived from the land system map but has been compiled from direct independent mapping on the aerial photographs.

Each of the derived maps summarizes the results of the survey on a particular subject in an overall picture, the generalization of which is directly related to the complexity of the particular subject and to the degree in which variability in the subject has influenced land system mapping. Since gross land form (geomorphology) has been used more than any other land property in the mapping of land systems, the derived maps are more generalized than the land system map and for this reason are presented at a smaller scale. The maps have been produced to enable the report user to assess rapidly the broad distribution of a number of special aspects of the

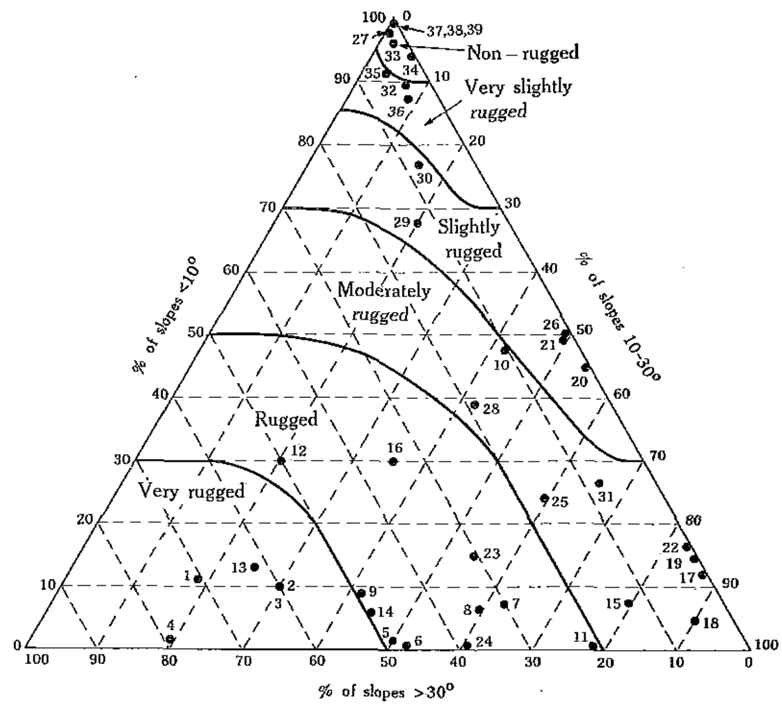

Fig. 5.—Classes of ruggedness as defined by percentages of slopes < 10°, 10–30°, and > 30°. The approximate position of each land system is shown by its number.

landscape. Thus agronomists may be particularly interested in the agricultural land use capability and land use intensity maps which are discussed in Parts X and IX respectively; civil engineers in the lithology and the ruggedness and maximum relief maps; military men in the ruggedness and maximum relief and the forest resources and land use intensity maps; foresters in the forest resources and ruggedness and maximum relief maps; and all these users may obtain useful information from the associations of major soil groups map.

The limits of the ruggedness classes, expressed in terms of percentages of very steep (> 30°), steep (10–30°), and gentle (< 10°) slopes, are shown in Figure 5 on which the approximate position of each system is also plotted.

III. Notes on Land System Descriptions

For most land systems the units have been described in a tabular form and are listed in order of decreasing size. Some land systems for which very few or no field data are available have been described in general terms, and no units have been defined. The areas of the land systems have been determined with the aid of a dot grid of 100 dots per sq in applied to the 1 : 250,000 map, and excluding the area of overlap with the Wabag–Tari area in the west. The areas of the units are estimates, arrived at during field work and photo interpretation.

In the unit descriptions soils are indicated by the name of the major soil group and the soil family. Further details on these and on the vegetation communities listed in the unit descriptions may be obtained in Part VI, where the major soil groups are described in alphabetical order, and in Part VII. The land class and subclass symbols are explained in Part X, Section II. The relationships between the land systems and commercial forest types are presented in Table 16 in Part VIII. Similarly, the relationships between the land systems and population and land use intensity are given in Part IX. The population on a land system is taken as the total of the groups and villages that occur on it. Land use intensity figures are taken from the data in Part IX.

The drainage classes listed in the soil column of the tabular descriptions are similar to those described in the Soil Survey Manual of the United States Department of Agriculture (1951), except that class 5 of the manual has been omitted. They are briefly described below.

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

II. *Well drained.*—Water is removed from the soil readily but not rapidly. It is rarely too wet and rarely too dry. There are no indications of gleying or water-table above 46 in. depth.

III. *Imperfectly drained.*—Water is removed from the soil somewhat slowly so that the soil is too wet for short but significant periods, especially in the subsoil. Distinct mottling and grey colours occur below a depth varying from 20 to 46 in.

IV. *Poorly drained.*—Water is removed from the soil slowly enough to keep the soil saturated for long periods, especially in the subsoil. Distinct mottling and grey colours occur below a depth varying from 9 to 20 in.

V. *Very poorly drained.*—Water is removed so slowly that the soil remains saturated for a large part of the year. A shallow water-table is commonly observed. Distinct mottling and grey colours occur above a depth of 9 in.

VI. *Swampy.*—Water is removed from the soil so slowly that the water-table is at or above the land surface permanently or for a large part of the year. The soil is strongly gleyed throughout; commonly it has prominent rusty mottles and/or poorly decomposed plant remains.

In the block diagrams and plans, which are drawn from single aerial photographs or are composites of segments drawn from different photos, the unit numbers are indicated but the units are not drawn proportionally to their extent in the land system. Approximate horizontal and vertical scales are given, and these should always be taken into consideration in comparing the block diagrams since it is not feasible to draw them all at one scale.

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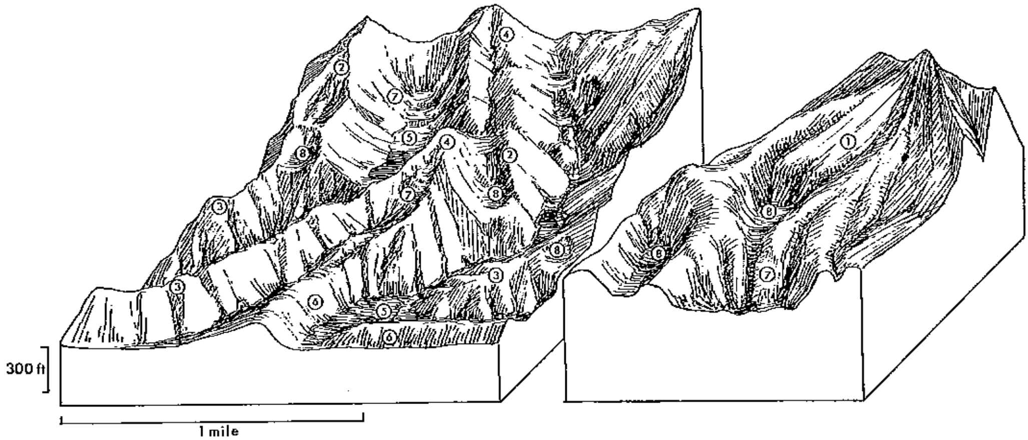
(1) Wilhelm Land System (65 sq miles)

Alpine mountains on granodiorite.

Geology.—Massive granodiorite, locally capped by Permian limestone.

Physical Features.—Massive mountain ridges and summit peaks between 10,000 and 14,800 ft. Radial pattern of U-shaped glacial valleys with stepped profiles, cirque lakes, and moraines; relief up to 2500 ft.

Population and Land Use.—Nil.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	18	**Summit peaks:** of Bismarck and Kubor Ranges, below 13,500 ft; very steep broken slopes and local scarps	Probably mainly rock outcrop and shallow alpine peat soils. Mostly excessively drained	Alpine grassland and patches of subalpine scrub	VIII
2	16	**Higher ridges:** slopes 25–60°, generally steepening in lower parts; narrow crests; relief 1000–2500 ft	Rock outcrop and alpine humus soils (Tomba). Well to excessively drained	Alpine grassland, subalpine scrub and some subalpine forest	VIII
3	10	**Lower ridges:** slopes 25–40°; narrow crests; relief 1000–1500 ft	Alpine humus soils (Pompameiri) and humic brown clay soils (Daulo). Well drained	Montane rain forest	VIIe
4	7	**Summit peaks:** of Mt. Wilhelm, above 13,500 ft; slopes 30–80°, 1000–2000 ft long	Mainly rock outcrop. Excessively drained	Sparse rock-crevice plants	VIII
5	5	**Valley floors:** slopes 3–5°, up to 400 yd wide; shallow channels with waterfalls over rock steps up to 100 ft high	Alpine peat and humus soils (Pinde, Tomba); locally rock outcrop. Poorly drained	Alpine grassland with patches of subalpine scrub; alpine peat bog	Vd
6	4	**Moraines:** straight or curved smooth ridges with rounded crests; slopes 20–45°, 50–400 ft high	Alpine humus soils (Tomba) and humic brown clay soils (Daulo). Well drained	Montane rain forest and alpine grassland with tree ferns	VIIe
7	3	**Screes:** slopes 30–45°	Rubble land. Excessively drained	Sparse alpine grasses	VIII
8	2	**Cirques:** rock basins with lakes or swamps, up to ½ mile wide	Locally raw peat. Swampy or open water	Locally alpine peat bog	VIII

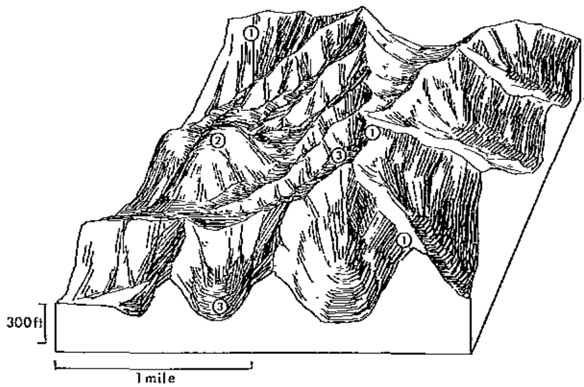
(2) Giluwe Land System (8 sq miles)

Alpine mountains on andesitic rocks.

Geology.—Pleistocene andesitic lava, agglomerate, and tuff.

Physical Features.—*Eroded summits and crater walls of strato volcano with cliffs and short glacial valleys;* dissected tholoids; relief up to 1000 ft; altitude between 10,000 and 12,500 ft.

Population and Land Use.—Nil.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	6	Ridges and cliffs: 25–40°, up to 70° on lava cliffs; narrow crests; relief 500–1000 ft	Alpine peat soils (Pinde), sandy colluvial soils, and rock outcrop. Poorly to excessively drained	Alpine grassland, patches of subalpine scrub	VIII; VIIe
2	1·5	Lava domes: steep convex dissected slopes, 200–500 ft high	Probably alpine peat and humus soils. Poorly to excessively drained	Montane rain forest, subalpine scrub, some alpine grassland	VIII
3	<1	Valley floors: flats, up to 200 yd wide, with poorly developed channels	Unclassified raw peat soils. Swampy; locally open water	Alpine peat bog	VIII

(3) Kubor Land System (165 sq miles)

Mountain summit ridges.

Geology.—Granodiorite, gabbro, and minor low-grade schist.

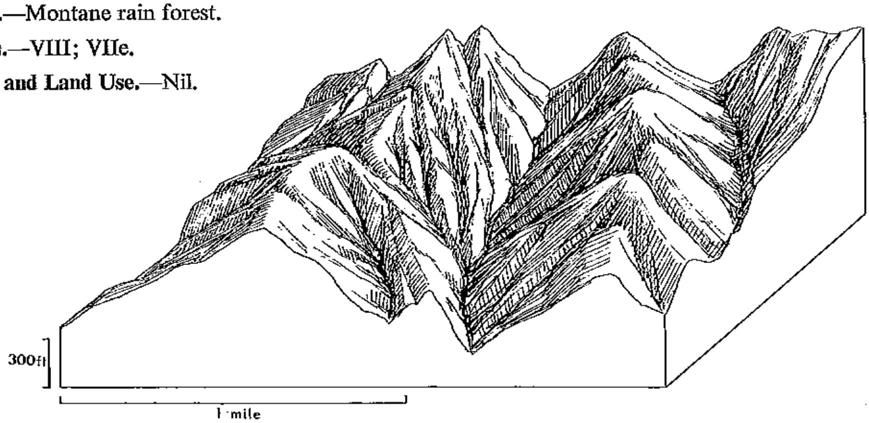
Physical Features.—Massive summit ridges, 1000–3000 ft high; long straight slopes, 25–45°; rounded crests; altitude 8000–11,000 ft.

Soils and Drainage Status.—Probably mainly alpine humus soils (Pompameiri, Tomba) with some humic brown clay soils (Daulo). Well drained.

Vegetation.—Montane rain forest.

Land Class.—VIII; VIIe.

Population and Land Use.—Nil.



(4) Ialibu Land System (65 sq miles)

Deeply dissected volcanic mountains.

Geology.—Pleistocene andesitic lava, agglomerate, and tuff.

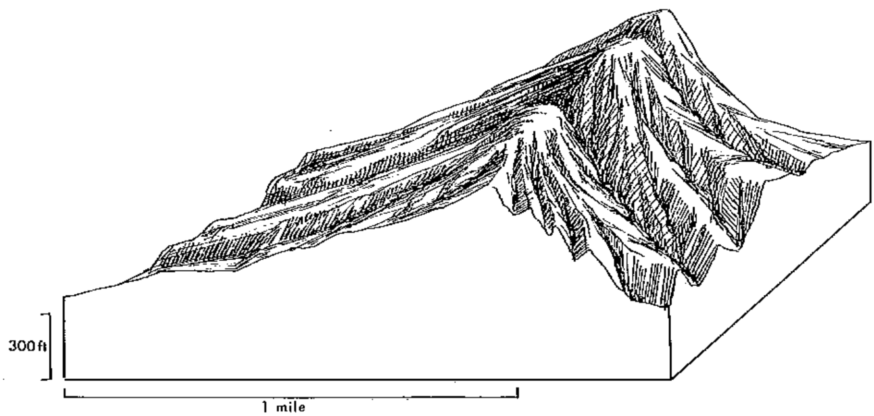
Physical Features.—Very steep mountain ridges and scarps; roughly parallel narrow-crested ridges separated by V-shaped valleys. Crest slopes 20–35°, side slopes 40–60°; relief 400–2000 ft; altitude 7500–11,000 ft.

Soils and Drainage Status.—Alpine humus soils (Tomba); lithosols on very steep unstable slopes. Well drained.

Vegetation.—Montane rain forest, some mixed lower montane forest on lower slopes.

Land Class.—VIII; VIIe.

Population and Land Use.—Less than 1 sq mile used by people on adjoining land system.



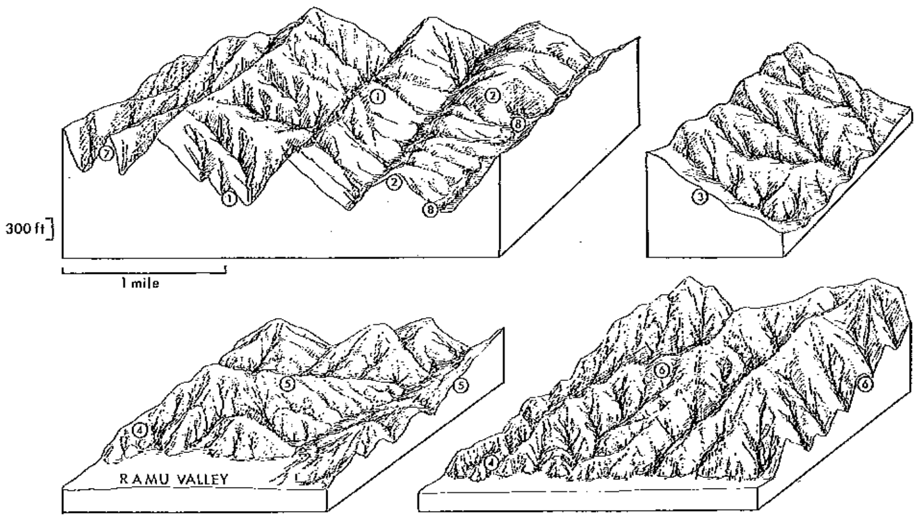
(5) Bismarck Land System (1750 sq miles)

Rugged high mountains on granodiorite and schist.

Geology.—Low-grade schists intruded by massive granodiorite (Goroka Formation); lenses of Mesozoic shale, and Miocene basalt and rhyolite (Daulo Volcanics).

Physical Features.—Extremely rugged high mountains with steep narrow ridges and a close dendritic pattern of deeply incised mountain torrents. Smaller areas of massive ridges with a subrectangular drainage pattern; relief up to 4000 ft; altitude 500–10,000 ft.

Population and Land Use.—56,000 people using 364 sq miles; 5% intensively, 72% moderately, 23% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	665	Dissected mountain ridges: long but densely dissected slopes, 17–45°; narrow crests; relief 500–4000 ft	Complex pattern of humic brown clay soils (Daulo, Ogelbeng) and brown and sandy colluvial soils; locally alpine humus soils (Pompameiri) at higher altitude, and humic brown and red latosols (Singa, Merima, Bidnimin) at lower elevations. Well drained	Mixed lower montane rain forest; locally sword grass and shrub regrowth. Succession with gardens and garden regrowth on lower slopes	VIII; VIIe
2	470	Massive mountain ridges: long straight slopes, 25–35°, decreasing to 10° near rounded crests; relief 500–2000 ft	Humic brown clay soils (Daulo, Ogelbeng), some alpine humus soils (Pompameiri) at high altitude; locally humic brown and red latosols (Singa, Merima) at lower elevation. Well drained	Mixed lower montane forest	VI–VIIe
3	260	Highland foothill ridges: densely dissected long slopes, 17–40°; narrow crests; relief 200–1000 ft	Complex pattern of brown and minor sandy and mottled colluvial soils, humic brown clay soils (Daulo, Ogelbeng) and lateritic and gleyed latosols (Ombun, minor Kerowil, Gitunu). Locally humic brown and red latosols (Singa, Bidnimin) and lithosols. Mostly well to excessively drained	*Themeda* grassland; remnant and secondary forest; shrub regrowth	VIIe; minor VIIe,so_3; VIe; VIe,so_3
4*	105	Lowland foothill ridges: densely dissected, long and short slopes, 17–35°; narrow crests; relief 200–800 ft. Some isolated hills	Shallow colluvial soils and lithosols. Excessively drained	*Themeda–Alloteropsis* short grassland; minor secondary lowland forest	VIIe,so_2; minor VIe,so_2
5*	90	Massive lower mountain ridges: long straight slopes, 25–35°, decreasing to 10° near rounded crests; relief 200–1000 ft	Reddish latosolic soils (Ainan, Baia, Bibi, Tungary) and shallow colluvial soils; locally lithosols. Mostly well drained	Lowland rain forest (*Intsia bijuga–Pometia pinnata–Celtis* association); some *Themeda–Alloteropsis* short grassland	VI–VIIe
6*	90	Dissected lower mountain ridges: long but densely dissected slopes, 17–45°; narrow crests; relief 400–2000 ft	Shallow colluvial soils and reddish latosolic soils (Baia). Well drained	Secondary lowland forest and garden regrowth	VIIe; VIII; minor VIe; VIIe,so_2
7	50	Sharp ridges: long straight slopes, 45–60°, with many landslide scars; narrow crests	Probably sandy colluvial soils and lithosols. Excessively drained	Scrubby mixed lower montane forest, commonly secondary on landslide scars	VIII
8	20	River terraces: dissected alluvial flats and hummocky colluvial aprons; slopes 5–10°; 50–80 ft above river level. Discontinuous flood-plains 50 yd wide	Humic brown clay soils (Daulo, Ogelbeng, Kwakanigl), alpine humus soils (Pompameiri), and dark colluvial soils (deep). On flood-plains medium-textured alluvial soils. Mostly well drained	Sword grass and shrub regrowth, and gardens and garden regrowth; locally remnant forest; mixed lower montane forest above Keglsugl. *Phragmites* swamp on flood-plains	I; II–IIIe; VIIe; IVe,so_3; VIII

* These units occur along the north-eastern edge of the land system along the Ramu valley and have lowland soil and vegetation types that are not described in this report. They are described in CSIRO Aust. Div. Land Res. Reg. Surv. divl Rep. 57/2, 1957.

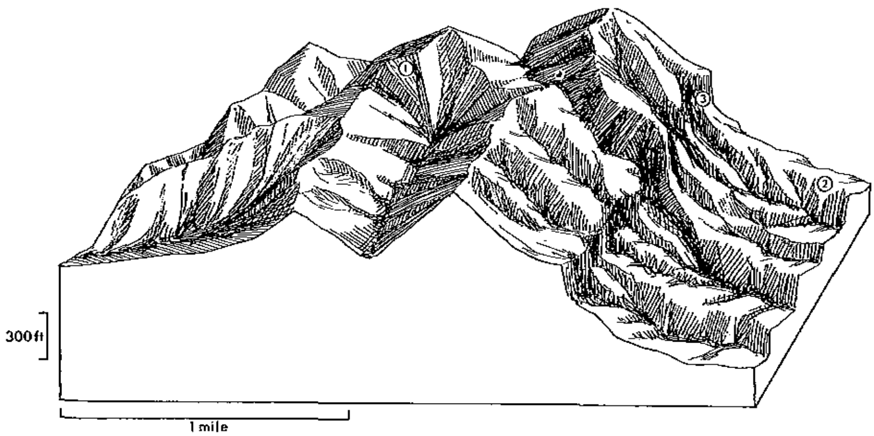
(6) AMBUM LAND SYSTEM (200 SQ MILES)

Forested rugged low mountains on greywacke and tuff.

Geology.—Moderately to steeply dipping greywacke and tuff of Cretaceous age; minor Tertiary limestone; veneer of Pleistocene volcanic ash in west of land system.

Physical Features.—Steep-sided mountain ridges with narrow crests between 7000 and 9000 ft; close dendritic pattern of streams in V-shaped valleys; minor limestone cliffs above steep, dissected, irregular foot slopes; relief up to 1000 ft.

Population and Land Use.—17,300 people using 101 sq miles; 5% intensively, 81% moderately, 14% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	160	**Mountain ridges**: irregular dissected slopes, 20–45°; undulating narrow crests; relief 100–1000 ft	Complex pattern of colluvial soils (brown, minor sandy and mottled) and humic brown clay soils (Ogelbeng). Locally alpine humus soils (Tomba) on highest ash-covered slopes and humic gleyed latosols (Ombun) on some lower spurs. Mostly well drained	Mixed lower montane forest, scrubby on some precipitous slopes; beech forest on ridges. Some sword grass and shrub regrowth on foot slopes and in wider valleys	VIIe; minor VIII VIe,so$_2$
2	30	**Foothill spurs**: ½–1½ miles long; crests up to 300 yd wide, sloping 15–25°, with hummocky surface; very steep side slopes; relief 50–150 ft	Brown, locally mottled colluvial soils; locally gleyed humic brown clay soils (Tambul). Well drained, with small poorly drained pockets	Gardens and garden regrowth; *sword grass and shrub regrowth*. Some mixed lower montane forest on higher slopes	VI–VIIe; *locally* VIe,so$_3$; VIe,so$_2$
3	10	**Limestone cliffs**: sheer rocky faces up to 300 ft high	Rock outcrop. Excessively drained	Mainly bare	VIII

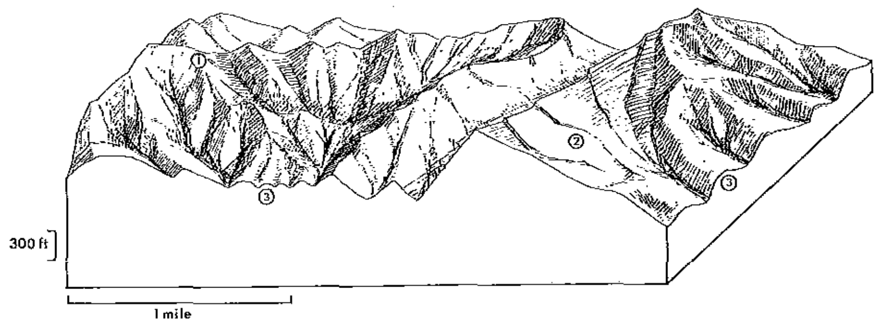
(7) Koge Land System (490 sq miles)

Mainly grass-covered rugged low mountains and hills on greywacke and shale.

Geology.—Massive Cretaceous greywacke and thin-bedded Upper Jurassic shale with moderately steep dips; smaller area of Miocene agglomerate, tuff, greywacke, and lava in the east.

Physical Features.—Irregular branching ridges with close dendritic pattern of V-shaped valleys; long strike ridges with structurally controlled, rectangular pattern of valleys; relief up to 1000 ft; altitude 5000–8000 ft.

Population and Land Use.—57,500 people using 376 sq miles; 6% intensively, 77% moderately, 17% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	295	Branching ridges: short narrow crests: gullied slopes 15–40°; relief 100–1000 ft	Complex pattern of brown colluvial soils, humic brown clay soils (Ogelbeng, Daulo), lateritic and gleyed latosols (Ombun, Kerowil, Gitunu), and lithosols (particularly in the east). Locally humic red latosols (Merima). Well to excessively drained	*Themeda* and *Capillipedium* grassland and small patches of gardens and garden regrowth. Beech forest occurs in Iliwochi hills, between Wahgi and Chimbu Rivers and west of Minj. Locally stream-bank vegetation along watercourses	VI–VIIe; locally VIIe,so_3; VIII
2	145	Strike ridges: long narrow crests; gullied slopes, 20–35° along outcrop, 15–25° along dip; relief 100–500 ft	Outcrop slopes, mostly sandy colluvial soils; dip slopes, complex pattern of brown and mottled colluvial soils, humic brown clay soils (Ogelbeng), humic brown and red latosols (Singa, Bidnimin), and lateritic and gleyed latosols (Ombun, Kerowil, Gitunu). Locally lithosols on lower ridges. Excessively to well drained	Similar to unit 1. Oak and beech forest in large high area south-east of Daulo	VI–VIIe; VI–VIIe,so_3
3	50	Colluvial aprons: short hummocky slopes, 5–15°	Various gleyed soils (Tambul, Mengendi, Banz, Kuli); sandy colluvial soils and humic brown clay soils (Daulo). Well to poorly drained	*Capillipedium* and *Ischaemum* grassland. Gardens and garden regrowth	IVe,so_3

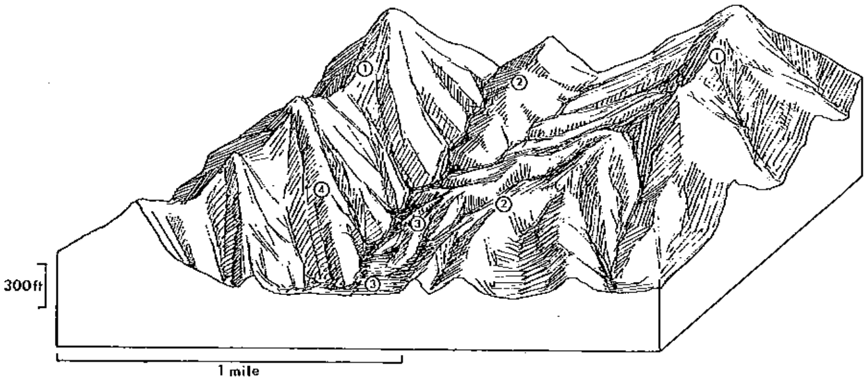
(8) Pira Land System (110 sq miles)

Mountain ridges with extensive foot slopes on sedimentary rock.

Geology.—Steeply dipping siltstone, mudstone, greywacke, and local conglomerate and limestone, of Jurassic to Miocene age; block- and thrust-faulted on E.–W. strike lines.

Physical Features.—Branching steep mountain ridges and lower E.–W. strike ridges and limestone cliffs; large valley embayments with low hill ridges and spurs; dendritic pattern of closely spaced, narrowly incised streams, locally with strike alignment; relief up to 1500 ft; altitude 4500–9000 ft.

Population and Land Use.—33,300 people using 78 sq miles; 57% intensively, 40% moderately, 3% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	75	Mountain ridges: gullied slopes 20–40°, locally with landslide scars; long narrow crests. Also short strike ridges with dip slopes 15–30° and outcrop slopes 20–40°; relief 400–1500 ft	Complex pattern of brown and minor sandy and mottled colluvial soils, humic brown clay soils (Ogelbeng, Daulo), and less common humic brown and red latosols (Singa, Wandi, Bidnimin). Very locally lateritic and gleyed latosols (Ombun, Kerowil) and lithosols. Mostly well drained	Upper slopes, beech forest. Lower slopes, sword grass and shrub regrowth; gardens and garden regrowth; *Capillipedium* grassland in the east	VIIe; locally VIIe,so_2; VIe
2	25	Hill ridges: short ridges and spurs up to 200 ft high; narrowly rounded crests and moderately steep slopes, 10–20°	Complex pattern of brown colluvial soils, humic brown and red latosols (Singa, Wandi, Merima), and locally gleyed latosols (Ombun). Mostly well drained, locally poorly drained	Sword grass and shrub regrowth; gardens and garden regrowth; *Capillipedium* grassland	VIe; minor VIe,so_3
3	6	Lower slopes and valley floors: short colluvial aprons with hummocky slopes up to 10°. Small alluvial terrace remnants	Mainly meadow soils (Mombol, Kuli) and meadow podzolic soils (Banz). Locally humic brown latosols (Wandi). Well to poorly drained	Similar to unit 2. *Ischaemum* grassland on poorly drained sites	IVso_3; IIIe
4	4	Limestone strike ridges: short ridges up to 400 ft high, with cliffs and steep rocky slopes	Complex pattern of rendzinas (Elimbari), humic brown latosols (Wandi), and rock outcrop. Well to excessively drained	Scrubby mixed lower montane forest, locally with stands of *Araucaria cunninghamii*	VIII

(9) DOMA LAND SYSTEM (25 SQ MILES)

Volcanic ridges and dissection slopes.

Geology.—Pleistocene andesitic lava, agglomerate, and tuff.

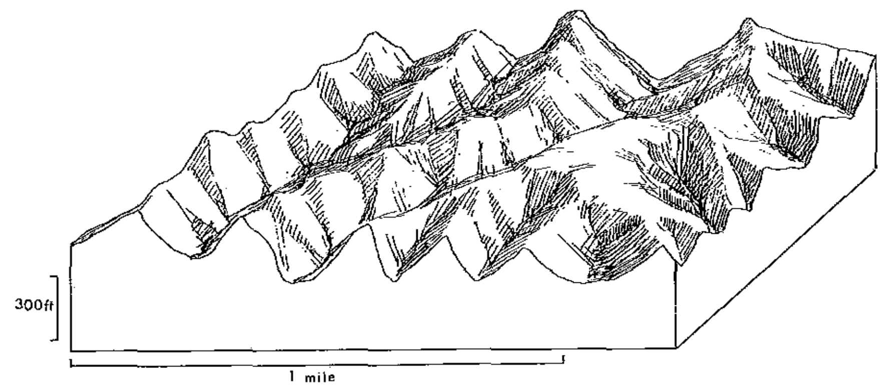
Physical Features.—Very steep irregular mountain and hill ridges with narrow crests and local undulating surface remnants. Strongly gullied very steep long dissection slopes towards major streams; slopes mostly 20–45°; relief 400–1200 ft; altitude 3500–7500 ft.

Soils and Drainage Status.—Probably mainly brown and sandy colluvial soils, locally lithosols. Locally humic brown clay soils (Daulo, Ogelbeng). Well drained.

Vegetation.—Mixed lower montane rain forest, remnant and secondary forest. Sword grass and shrub regrowth. Gardens and garden regrowth, minor *Capillipedium* grassland.

Land Class.—VIII; VIIe; minor III and VIe.

Population and Land Use.—2000 people using 23 sq miles; 9% intensively, 91% moderately.



(10) OGA LAND SYSTEM (3 SQ MILES)

Cliffed limestone plateaux.

Geology.—Permian limestone.

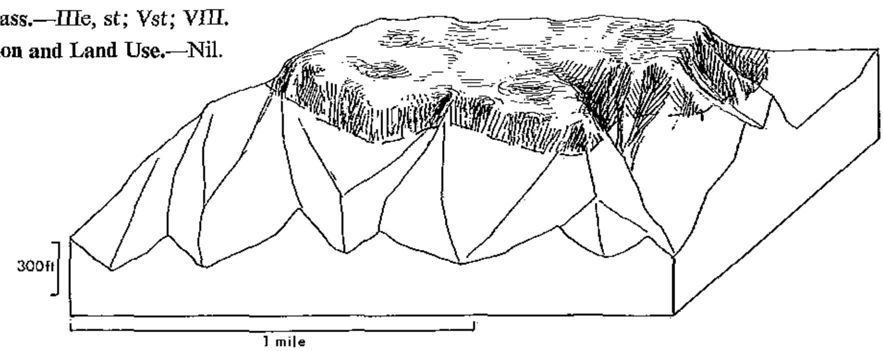
Physical Features.—Moderately to steeply sloping undissected plateau and dip slope remnants with local small dolines, surrounded by 200–600-ft cliffs with local scree slopes; altitude between 8500 and 9500 ft.

Soils and Drainage Status.—No data. Probably rendzinas (Elimbari) and stony alpine humus soils, and rock outcrop. Well drained.

Vegetation.—Beech forest.

Land Class.—IIIe, st; Vst; VIII.

Population and Land Use.—Nil.



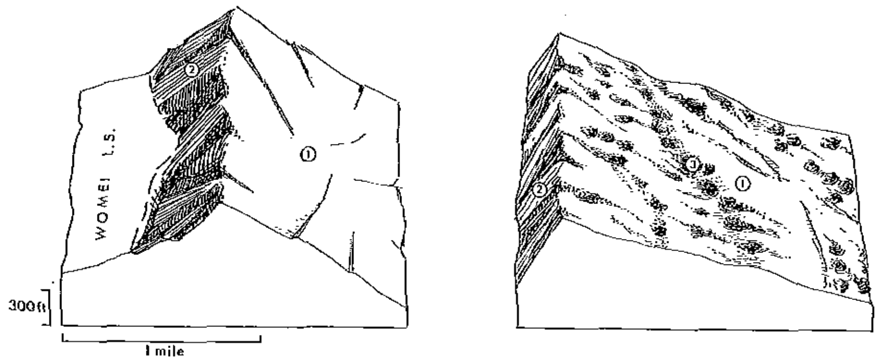
(11) Elimbari Land System (35 sq miles)

Limestone mountain ridges and scarps.

Geology.—Moderately to steeply dipping thick-bedded cavernous limestone and calcareous sandstone, mainly of Miocene age.

Physical Features.—Fault-bounded strike ridges between 5500 and 9500 ft, with prominent scarps and gentler dip slopes with rocky karren surfaces; no local surface drainage; relief up to 1200 ft.

Population and Land Use.—3000 people using 25 sq miles; 51% intensively, 31% moderately, 18% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	31	**Dip slopes:** up to 1½ miles long; sloping 10–35°; with rocky karren fields	Partly humic brown and red latosols (Wandi, Bidnimin) with moderate rock outcrop; partly rendzinas (Elimbari) with much rock outcrop. Locally humic brown clay soils (Daulo) at higher altitude. Well to excessively drained	Gardens and garden regrowth; sword grass and shrub regrowth; *Capillipedium* grassland (most prevalent in the east). Beech forest in highest and isolated areas	VI–VIIe; VI–VIIe,st; locally Vst; VIII
2	3	**Escarpments and cliffs:** 200–1200 ft high; commonly broken and cavernous	Rock outcrop with pockets of rendzina (Elimbari). Excessively drained	Mainly bare; scrubby mixed lower montane forests on least steep slopes	VIII
3	1	**Sink holes:** up to 200 ft wide, 50 ft deep; with steep concave slopes	Humic brown clay soils (Ogelbeng), humic red latosols (Bidnimin), and gleyed latosols (Ombun). Mostly well drained	Gardens and garden regrowth; sword grass and shrub regrowth	VI–VIIe

(12) Lai Land System (17 sq miles)

River gorges in volcanic deposits.

Geology.—Pleistocene andesitic agglomerate, lava, and volcanic ash; minor Cretaceous and Jurassic greywacke and tuff.

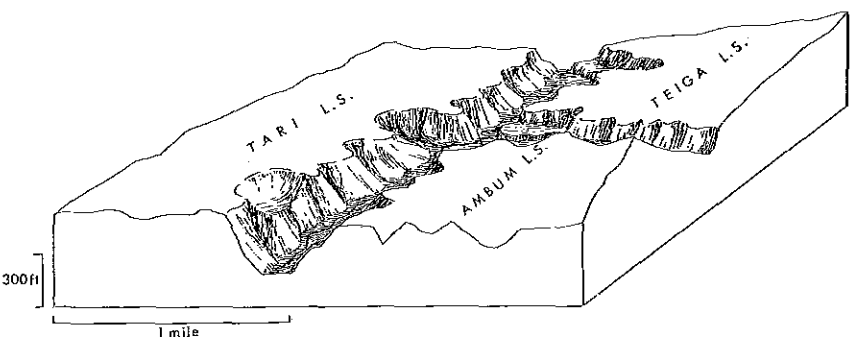
Physical Features.—Very steep to precipitous dissection slopes with salients and re-entrants along deeply entrenched streams; minor high terrace remnants and slump alcoves; flood-plains up to 100 yd wide; relief 200–400 ft; altitude 4000–7000 ft.

Soils and Drainage Status.—Mainly unclassified shallow colluvial soils and some rock outcrop; probably humic brown clay soils and gleyed humic brown clay soils on terraces and slumps; mainly alluvial land on flood-plains.

Vegetation.—Remnant and secondary forest, sword grass and shrub regrowth, stream-bank vegetation.

Land Class.—Largely class VIII with pockets of II–IIIe; IId.

Population and Land Use.—People on adjoining land systems use 12 sq miles; 5% intensively, 65% moderately, 30% lightly.



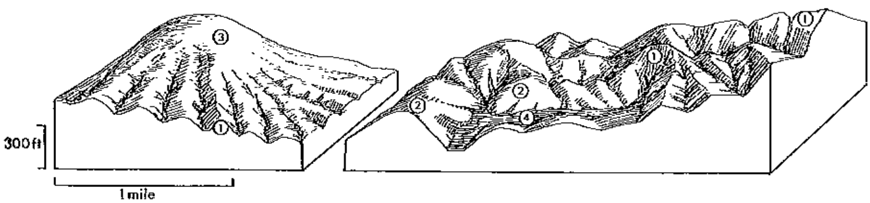
(13) YONKI LAND SYSTEM (105 SQ MILES)

Mainly grass-covered rounded and steep hills on granodiorite.

Geology.—Massive granodiorite, with minor greywacke and siltstone of mainly Tertiary age.

Physical Features.—Central dome with surrounding low-ridge spurs and hills; radial drainage pattern with narrowly incised valleys in central part and more open valleys with dendritic tributary valleys in outer part of land system; relief up to 600 ft; altitude 4600–6500 ft.

Population and Land Use.—7400 people using 54 sq miles; 80% moderately, 20% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	66	**Hill ridges:** 100–400 ft high; irregular narrow crests and closely gullied straight slopes, 20–40°. Minor colluvial lower slope sectors, 10–20°	Mostly brown colluvial soils. Locally humic brown latosols (Singa, Wandi) and lateritic and gleyed latosols (Gitunu, Ombun). Rarely lithosols. Well to excessively drained	*Capillipedium* and *Themeda* grassland. Beech forest in highest areas. Stream-bank vegetation along watercourses	VIIe; minor VIe; VIII
2	21	**Rounded hills:** 100–200 ft high; smooth convex slopes, 5–17°, leading up to rounded crests. Minor gentle foot slopes	Mostly humic brown clay soils and latosols (Ogelbeng, Singa, Wandi). Locally lateritic and gleyed latosols (Kerowil, Gitunu, Ombun). Some meadow podzolic soils (Omahaiga) on foot slopes. Mostly well drained; foot slopes locally poorly drained	*Capillipedium* grassland, with *Ischaemum* grassland on local wet sites. Locally gardens and garden regrowth	IIIe; VIe; IVe,so_2; VIe,so_2; IVe,so_3
3	16	**Summit dome:** broad convex summit with little-dissected slopes up to 30°	No data. Presumably similar to unit 2 and well drained	Beech forest; *Capillipedium* grassland on lower slopes	IIIe; VI–VIIe
4	2	**Valley floors:** up to 200 yd wide with flat floors and gently sloping margins; hummocky colluvial surfaces	Meadow soils (Kuli, Mombol) and organic soils (Gogimp, Gia) with local gravel beds. Poorly drained to swampy or artificially drained	*Ischaemum* grassland, locally *Phragmites* swamp. Mostly cleared for coffee	IIId

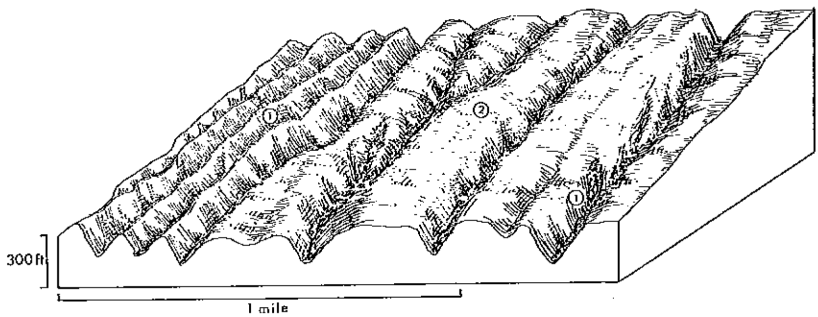
(14) Nemarep Land System (50 sq miles)

Long dissected volcanic slopes.

Geology.—Pleistocene andesitic ash, tuff, and lava.

Physical Features.—Moderate to steep concave middle-slope segments of major volcanoes, closely dissected by radial drainage into subparallel ridges, mainly less than 500 ft high; altitude 7500–9000 ft.

Population and Land Use.—1000 people using 17 sq miles; 47% moderately, 53% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	28	Narrow ridges and ravines: straight slopes, 30–50°; narrow crests with 10–20° slopes; relief 100–500 ft	Alpine humus soils (Tomba, Pompameiri) and humic brown clay soils (Daulo). Well drained	Mixed lower montane forest, locally oak and beech forest. Sword grass and shrub regrowth with gardens and garden regrowth on lowermost slopes	VIIe; VIII
2	22	Broad ridges: undulating surfaces; slopes 8–20°, locally steeper towards dissecting streams; relief 50–100 ft	Humic brown clay soils (Daulo, Ogelbeng); locally alpine humus soils (Tomba). Well drained	Sword grass and shrub regrowth with gardens and garden regrowth. Mixed lower montane forest on higher slopes	III; VIe

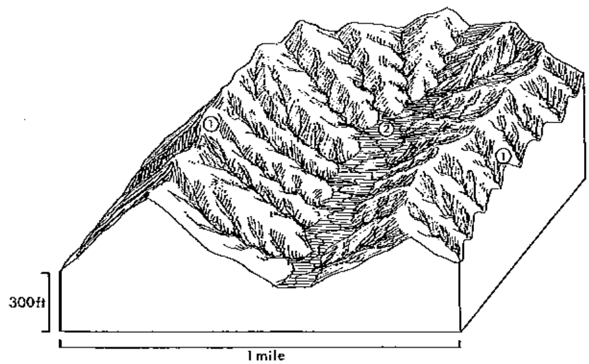
(15) LIMISATE LAND SYSTEM (17 SQ MILES)

Hummocky dry grass-covered hills on volcanic rock.

Geology.—Miocene rhyolite flows and volcanic breccia.

Physical Features.—Hill ridges with narrow and straight or undulating rounded crests; ridge flanks very closely dissected into rounded spurs with rocky mamillated profiles of moderate steepness; a close pinnate drainage pattern with small colluvial basins; relief up to 500 ft; altitude 5500–6200 ft.

Population and Land Use.—200 people using 6 sq miles; 36% moderately, 64% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	16	**Hill ridges:** 200–300 ft high; closely gullied slopes, 10–35°, broken into many convexities; irregularly rounded, locally narrow crests	Mostly lithosols and rock outcrop with mottled and sandy colluvial soils in pockets and at the base. Excessively drained	*Themeda* grassland with local patches of regrowth shrubs; little stream-bank vegetation	VIIe,so_2; VIII
2	1	**Basin floors:** up to ½ sq mile in size; gentle colluvial slopes, shallowly incised by small channels	Black earths (Limisate) and unidentified shallow rendzina-like soils. Mostly excessively drained, locally imperfectly to poorly drained	*Capillipedium* grassland; locally *Ischaemum* grassland on wettest spots	IVso_2; II–IIId

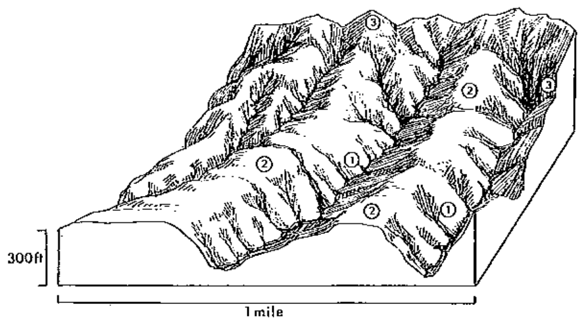
(16) Korambogl Land System (20 sq miles)

Broad convex and minor higher sharp ridges on sedimentary rock.

Geology.—Upper Jurassic mudstone, siltstone, and minor sandstone, locally steeply dipping; Miocene greywacke near Aiyura; local veneer of fine gravel near Wahgi River.

Physical Features.—Accordant ridges with gently rounded broad crests and steep, convex, slightly gullied side slopes; locally transverse higher sharp ridges; parallel narrowly incised valleys; relief up to 300 ft; altitude 4800–5500 ft.

Population and Land Use.—2400 people using 13 sq miles; 33% moderately, 67% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	12	Steep slopes: convex slightly gullied slopes, 20–40°	Brown colluvial soils. Well drained	*Capillipedium* grassland; locally remnant forest near Aiyura; some stream-bank vegetation	VI–VIIe
2	6	Ridge crests: gently rounded crests, up to 100 yd wide; convex marginal slopes up to 10°; local summit flats	Lateritic and gleyed latosols (Kerowil, Minj, Ombun). Also meadow podzolic soils (Banz) in Wahgi valley. Well to poorly drained; locally excessively drained near Aiyura	*Capillipedium* grassland with small patches of *Ischaemum* grassland	IV and VIe, so_3; IVso_2, so_3; IVe, so_3; III and VIe
3	2	Sharp ridges: very steep broken slopes, 30–45°; narrow crests	Sandy slope soils, lithosols, and meadow soils (Mengendi). Mostly excessively drained	*Themeda* grassland	VI–VIIe,so_2; some VIII

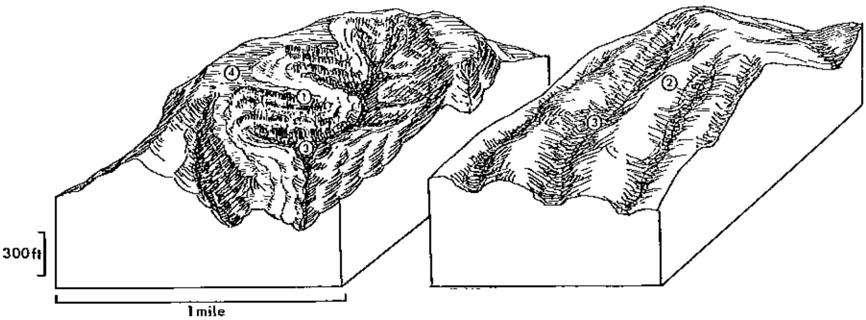
(17) Abiera Land System (130 sq miles)

Benched and rounded ridges on unconsolidated sediments.

Geology.—Bedded, little consolidated Pleistocene lacustrine clay to gravel, rich in quartz.

Physical Features.—Ridges with steep benched slopes and small flat summit remnants of weathered original depositional surface; broad convex rounded ridges; aggraded valley floors; many landslip scars; relief up to 300 ft; altitude 4800–5200 ft.

Population and Land Use.—11,300 people using 69 sq miles; 52% moderately, 48% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	62	**Benched ridges:** 100–300 ft high; alternate concave slopes, 10–20° and 50–150 ft long, and benches, 5–20 yd wide with slopes below 10°; narrow crests	Meadow soils (Kuli, Mombol), meadow podzolic soils (Banz, minor Omahaiga); mottled colluvial soils on more sandy strata; gleyed humic brown clay soils (Tambul, Winjaka) on steep slopes near crests; locally lateritic latosols (Kerowil, Gitunu) on ridge tops and gentle slopes. Mostly poorly drained; steepest slopes well to excessively drained	*Capillipedium* grassland; *Ischaemum* grassland and *Phragmites* swamp on benches; *Themeda* grassland on driest slopes	IV and VIe,so$_3$; minor VIe; VI–VIIe,so$_3$
2	52	**Rounded ridges:** 100–200 ft high; gently rounded broad crests and convex slopes, 10–20°	Lateritic latosols (Kerowil, Gitunu) and on upper slopes locally humic red and brown latosols (Bidnimin, Singa, Wandi), with sporadic humic brown clay soils (Daulo). Locally on lower slopes, meadow podzolic soils (Omahaiga) and meadow soils (Kudjil). Well to excessively drained; locally poorly drained lower slopes	*Capillipedium* and *Themeda* grassland with scattered bracken ferns. Local patches of gardens and garden regrowth. Some stream-bank vegetation with *Araucaria*	II–IVe,so$_2$; minor II–IIIe; IVe,so$_3$
3	10	**Valley floors:** up to 300 yd wide, level, hummocky, without drainage channels	Meadow soils (Kuli, Mombol), fine-textured alluvial soils, and locally organic soils (Gogimp). Very poorly drained to swampy	*Phragmites* swamp; some *Ischaemum* grassland	VI–VIId
4	6	**Summit flats:** slopes up to 5°; undissected; up to 600 yd wide	Lateritic and gleyed latosols (Minj), meadow podzolic soils (Omahaiga), and locally humic brown latosols (Wandi). Well to poorly drained, but subject to rapid drying of topsoil	Coffee plantation and gardens and garden regrowth; *Capillipedium* grassland	IVso$_3$,so$_2$; IIe

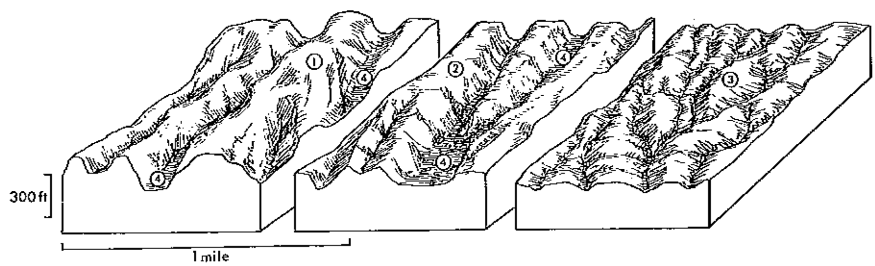
(18) TEIGA LAND SYSTEM (140 SQ MILES)

Rolling to low hilly volcanic ash plains.

Geology.—Pleistocene andesitic volcanic ash, locally underlain by agglomerate and lava.

Physical Features.—Undulating ash plain, largely transformed into low rounded hills by moderate to intensive stream dissection; common slumps on hill slopes; dense, dendritic drainage pattern of narrowly incised streams; relief up to 300 ft; altitude 5000–8500 ft.

Population and Land Use.—26,300 people using 110 sq miles; 21% intensively, 65% moderately, 14% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	63	Slumped hills: 100–300 ft high; irregular slumped slopes, 10–25°; rounded crests	Humic brown clay soils (Ogelbeng, locally Daulo on foot slopes). Well drained; small imperfectly drained depressions	Sword grass and shrub regrowth; gardens and garden regrowth; small areas of remnant forest (oak)	VIe; minor II–IIIe; IId
2	42	Dissected slopes: long, undulating, 3–10°; closely spaced steep dissection slopes, 20–35°	Humic brown clay soils (Ogelbeng, Daulo); alpine humus soils (Tomba, Pompameiri) at higher altitude. Well drained	Sword grass and shrub regrowth; areas of mixed lower montane forest at higher altitude, with much *Papuacedrus* in extreme west	II–IIIe; VI–VIIe
3	28	Low hills: 50–150 ft high; mostly smooth convex slopes, 10–30°; rounded crests	Humic brown clay soils (Ogelbeng); locally brown and red latosols (Singa, Bidnimin). Well drained	*Capillipedium* grassland, sword grass, and shrub regrowth; stream-bank vegetation; locally gardens and garden regrowth	VIe; less IIIe
4	7	Valley floors and terraces: up to 100 yd wide; including colluvial basins, up to 500 yd wide	Dark colluvial soils (deep); some humic brown clay soils (Daulo) and lateritic and gleyed latosols (Minj). Imperfectly drained	Gardens and garden regrowth; sword grass and shrub regrowth; stream-bank vegetation	IId; minor IVso$_3$

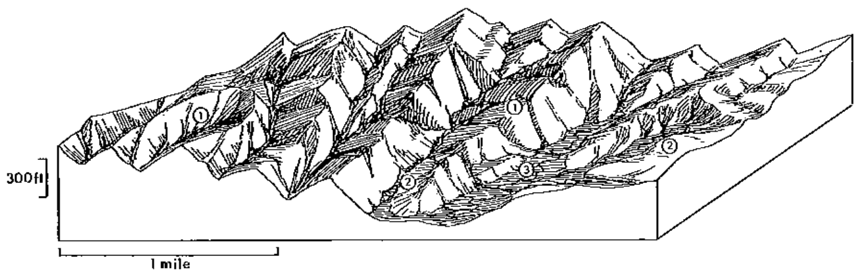
(19) Kumun Land System (85 sq miles)

Low hill ridges with slumped slopes on mainly fine-grained sedimentary rocks.

Geology.—Gently dipping interbedded mudstone, siltstone, and greywacke of Jurassic and Cretaceous age.

Physical Features.—Closely spaced short ridges with irregular slopes; numerous slump scars and hummocky colluvial aprons; very dense dendritic drainage pattern with small gullies and swampy larger valleys; relief up to 500 ft; altitude 4500–6000 ft.

Population and Land Use.—24,900 people using 84 sq miles; 55% intensively, 43% moderately, 2% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	73	**Hill ridges**: short ridges, 100–400 ft high; irregular slopes 15–30°; crests generally rounded, narrow where underlain by greywacke	Complex pattern of meadow soils (Mengendi), lateritic and gleyed latosols (Ombun, locally Gitunu), and brown colluvial soils. Very locally humic brown clay soils (Ogelbeng, Daulo) and humic brown latosols (Wandi) on greywacke and flat ridges. Mostly imperfectly drained, partly well drained	*Capillipedium* grassland and small areas of *Themeda* grassland in the east. Locally many gardens and garden regrowth. Stream-bank vegetation	IV and VIe, so_3; less II–IIIe; VIe,so_2
2	11	**Colluvial aprons**: short hummocky slopes, up to 10°	Medium and fine-textured alluvial soils, probably meadow soils (Mombol). Some brown colluvial soils and rubble land on large landslides. Locally organic soils (Gia). Mostly very poorly drained	Gardens and garden regrowth; patches of *Ischaemum* grassland and *Phragmites* swamp	IVso_3; IVe,so_3; minor IIId
3	2	**Flood-plains**: flats up to 150 yd wide	Medium-textured alluvial soils. Swampy	*Phragmites* swamp	IIId

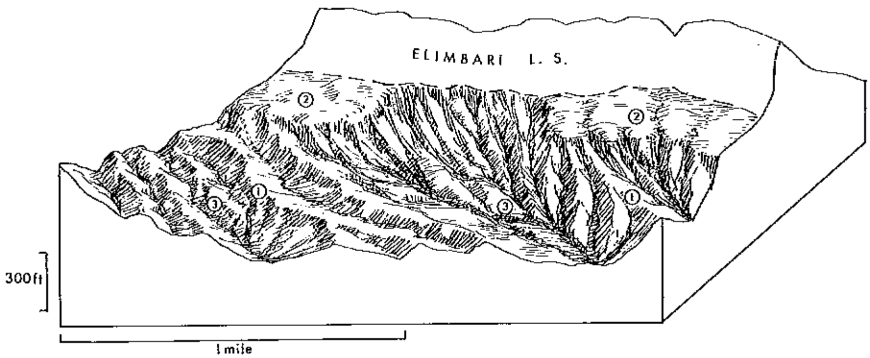
(20) Womei Land System (45 sq miles)

Very low dissected and slumped foothills.

Geology.—Gently dipping but strongly contorted and displaced Upper Cretaceous mudstone and minor calcareous sandstone; rock-fall debris from adjacent limestone cliffs.

Physical Features.—Complex pattern of very closely spaced low ridges and hills; hummocky lower slopes due to slumping; dissected colluvial aprons at foot of limestone cliffs of Elimbari land system; very dense dendritic pattern of narrowly incised valleys; relief up to 200 ft; altitude 5000–6500 ft.

Population and Land Use.—11,200 people using 37 sq miles; 62% intensively, 32% moderately, 6% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	19	**Hill ridges:** short, 100–200 ft high; irregular gullied slopes, 15–30°; slightly rounded crests	Complex of meadow soils (Mengendi) and meadow podzolic soils (Banz); locally gleyed latosols (Ombun). Poorly to imperfectly drained; locally well drained	Gardens and garden regrowth; many small areas of *Capillipedium* grassland	IV and VIe, so_3; little IIIe; VIe,so_2
2	13	**Colluvial aprons:** hummocky slopes, up to 10° and 300 yd long; steep dissected margins up to 25° and shallow rounded drainage depressions	Humic brown clay soils (Ogelbeng, Daulo) and brown and red latosols (Singa, Wandi, locally Merima); commonly stony. Well drained	Remnant forest; sword grass and shrub regrowth; gardens and garden regrowth	II–IIIe; II–IIIe,st; VI–VIIe; Vst
3	13	**Lower slopes:** hummocky concave slopes, up to 15° and 300 yd long; dissected by small streams	Meadow soils (Mombol, Kuli, locally Mengendi) and meadow podzolic soils (Banz). Poorly to very poorly drained	Gardens and garden regrowth; small areas of *Ischaemum* grassland and *Phragmites* swamp. Stream-bank vegetation	IVso_3; IVe,so_3; little IIId

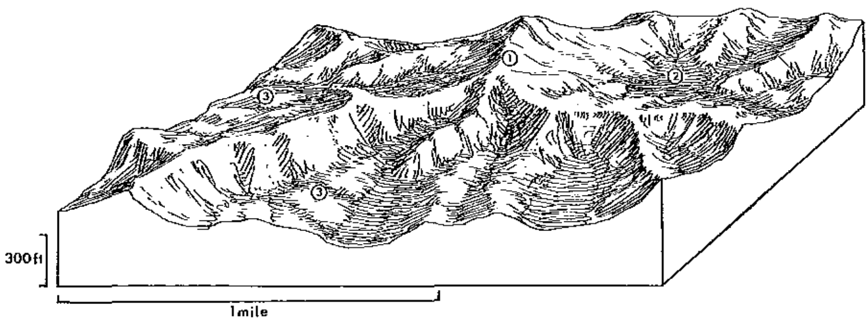
(21) Ogu Land System (20 sq miles)

Slumped low ridges and colluvial slopes on volcanic agglomerate.

Geology.—?Pleistocene andesitic agglomerate and minor volcanic ash.

Physical Features.—Network of ridges with irregular slumped and benched slopes, separated by broad colluvial slopes and depressions; coarse-textured pattern of streams; relief up to 400 ft; altitude 5200–7600 ft.

Population and Land Use.—1400 people using 14 sq miles; 44% moderately, 56% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	11	**Hill ridges:** 100–400 ft high; irregular, commonly benched slopes, 10–30°; narrow crests	Humic brown clay soils (Ogelbeng) commonly with dark, locally with pale subsoil. Mostly poorly developed topsoil; locally stony. Well drained	Mostly *Capillipedium* grassland with scattered *Miscanthus*	VI–VIIe
2	5	**Enclosed depressions:** up to 500 yd wide; almost level; occurring at various levels	Organic soils (Gogimp). Swampy	Sedge bog	VIId; VIII
3	4	**Colluvial fans:** slopes up to 5°, up to 200 yd long; locally dissected by gullies	Gleyed humic brown clay soils (Tambul); some lateritic and gleyed latosols (Minj) and deep dark colluvial soils. Imperfectly to very poorly drained	*Ischaemum* grassland; gardens and garden regrowth; some *Leersia* swamp and *Phragmites* swamp	II–IIId; locally VId

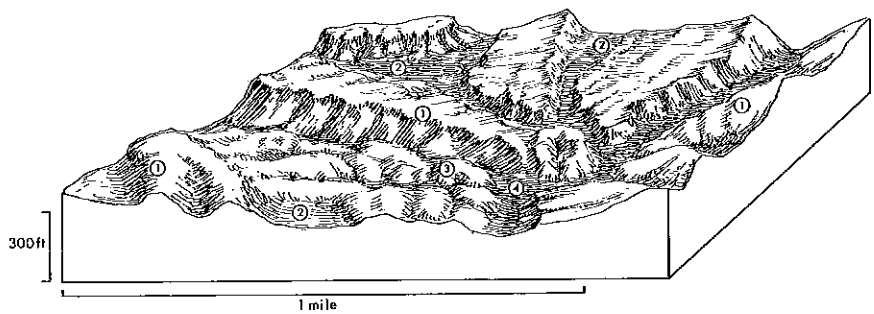
(22) WINJAKA LAND SYSTEM (5 SQ MILES)

Low hills and ridges with slumps on unconsolidated sediments.

Geology.—Bedded unconsolidated Pleistocene to Recent fluviatile clay to gravel; minor cover of volcanic ash.

Physical Features.—Short broken narrowly rounded ridges and boulder mounds; small depressions and flood-plains; relief up to 200 ft; altitude 6800–7300 ft.

Population and Land Use.—People on adjoining land systems use 5 sq miles; 88% moderately, 12% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	3·5	Short broken ridges: 100–200 ft high; slumped and gullied concave slopes, 15–20°; short colluvial toes; narrowly rounded crests	Gleyed humic brown clay soils (Tambul, Winjaka), humic brown clay soils (Ogelbeng), and meadow soils (Kudjil); locally alpine humus soils (Tomba) on volcanic ash, and deep dark colluvial soils. Imperfectly to well drained	Sword grass and shrub regrowth; gardens and garden regrowth; some stream-bank vegetation	VI–VIIe; some IId; IIIe
2	1	Depressions: up to 100 yd wide; enclosed or blocked valley floors	Organic soils (Gogimp). Swampy	Sedge bog; *Leersia* swamp	VIId
3	<1	Mounds: 50–100 ft high, up to 150 yd wide; convex slopes up to 25°	No data. Stony. Well drained	Sword grass and shrub regrowth	VIe,st
4	<1	Flood-plains: up to 8 ft above streams; up to 100 yd wide	No data. Presumably alluvial land and alluvial soils. Poorly drained	*Phragmites* swamp	VId

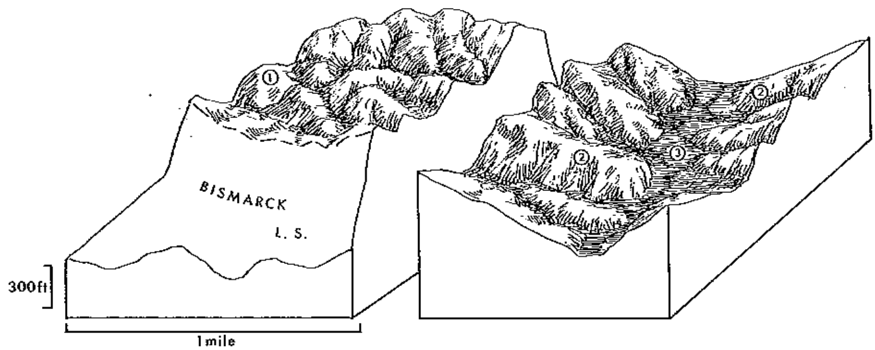
(23) Kwongi Land System (45 sq miles)

Hilly mountain summit plateaux and basins.

Geology.—Granodiorite and locally low-grade schist.

Physical Features.—Hilly uplands adjoining mountain summits; low rounded hills with close dendritic stream pattern, and more open major valleys with terraced alluvial floors; relief up to 300 ft; altitude 8000–10,000 ft.

Population and Land Use.—Nil.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	26	**Hills:** short straight slopes, 20–40°; rounded accordant crests; relief 100–300 ft	Probably alpine humus soils (Pompameiri) and humic brown clay soils (Daulo). Well drained	Mixed lower montane forest	VIIe
2	6	**Ridges:** short irregular slopes, 10–30°; rounded crests **Colluvial slopes:** long, hummocky, 5–15°; dissected, with sharp breaks at lower end	Alpine humus soils (Pompameiri) and humic brown clay soils (Daulo). Well drained	Mixed lower montane forest; much montane grassland and sparse subalpine scrub on lower slopes	VI–VIIe
3	3	**Valley floors:** up to 500 yd wide; terraced flats up to 20 ft above river level; colluvial aprons, slopes 3–7°; locally microrelief of trenches 1–2 ft deep along contour	Lower flats: organic soils (Gogimp) and unclassified alluvial soils. Higher flats and colluvial slopes: organic soils (Gia) and alpine humus soils (Pompameiri). Poorly to very poorly drained	Montane grassland and some alpine peat bog	Mainly VId

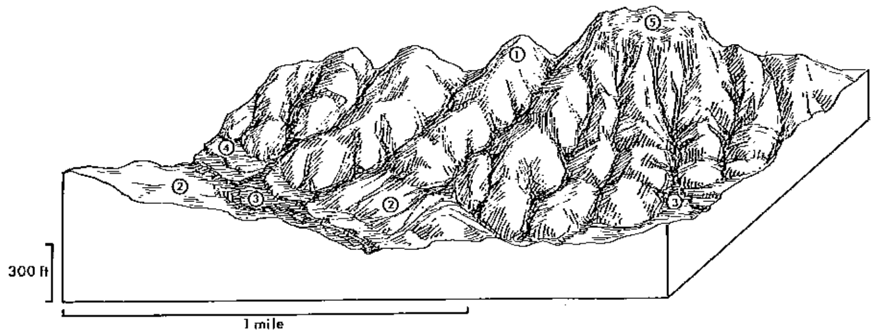
(24) OKAPA LAND SYSTEM (50 SQ MILES)

Hilly uplands on sedimentary and volcanic rocks.

Geology.—Miocene siltstone, sandstone, tuff, agglomerate, and lava.

Physical Features.—Upland areas with closely set steep-sided low hills; minor areas of rounded hills and undulating slopes; fine-textured dendritic pattern of short incised valleys tributary to perched upland valleys with slightly terraced alluvial flood-plains; relief up to 400 ft; altitude 5500–7000 ft.

Population and Land Use.—7200 people using 42 sq miles; 4% intensively, 87% moderately, 9% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	38	**Steep hills:** 100–300 ft high; steep concave slopes, 15–35°; relief up to 400 ft along edges of land system	Mostly brown colluvial soils and gleyed latosols (Ombun). Locally humic brown clay soils (Ogelbeng) and humic brown and red latosols (Singa, Bidnimin). Mostly well drained; locally excessively drained crests	Beech forest; *Capillipedium* grassland merging into *Themeda* grassland on dry ridges. Some gardens and garden regrowth	VI–VIIc; minor VIIe,so_2
2	8	**Colluvial aprons:** short hummocky slopes	Lateritic and gleyed latosols (Gitunu, Ombun). Imperfectly to poorly drained	Gardens and garden regrowth, stream-bank vegetation; *Capillipedium* grassland	VIe,so_3
3	2	**Valley floors:** flat or gently sloping, unincised, up to 100 yd wide	Ranging from meadow soils (Kuli) to organic soils (Gumanche). Poorly drained to swampy	*Ischaemum* grassland and *Phragmites* swamp; some gardens and garden regrowth on higher ground	II–IIId; VIII
4	1·5	**River terraces:** discontinuous remnants, 20–50 ft above stream bed	Meadow soils (Kudjil), lateritic latosols (Gitunu), and humic red latosols (Bidnimin). Poorly to well drained	*Capillipedium* grassland with scattered gardens and garden regrowth	IIc; IVso_3
5	<1	**Dome:** lava plug with basal scree slopes; 300–400 ft high	No data. Presumably rock outcrop and sandy colluvial soils. Excessively drained	*Themeda* grassland and bare ground	VIII

(25) BIRAP LAND SYSTEM (5 SQ MILES)

Conical volcanic hills.

Geology.—Pleistocene to Recent andesitic lava, scoria, and ash.

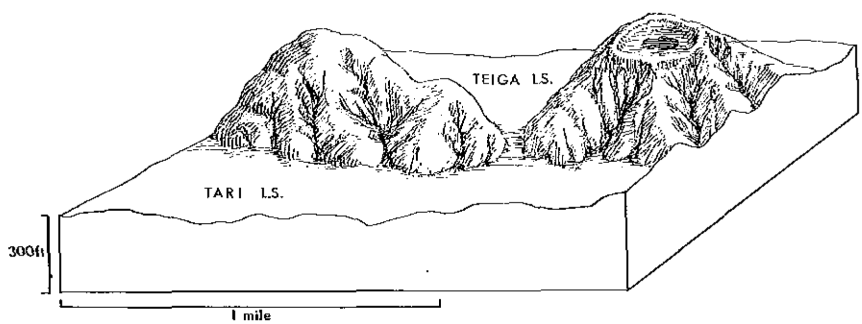
Physical Features.—Ash and scoria cones, lava domes, minor dykes and crater lakes; partly dissected by small streams; slopes 10–45°, height 100–800 ft; altitude 5000–8000 ft.

Soils and Drainage Status.—No data. Probably humic brown clay soils (Daulo, Ogelbeng) and alpine humus soils (Tomba) at highest elevations. Mostly well drained.

Vegetation.—Mixed lower montane forest; sword grass and shrub regrowth.

Land Class.—IIIe; VI–VIIe.

Population and Land Use.—500 people using 3 sq miles; 100% lightly.



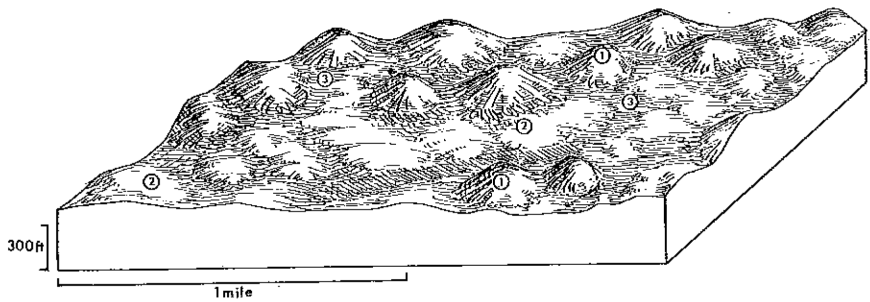
(26) Nunga Land System (25 sq miles)

Undulating volcanic surface with numerous conical hills.

Geology.—Pleistocene andesitic volcanic ash and agglomerate.

Physical Features.—Undulating constructional surface with narrow shallow valleys and hollows; numerous small conical hills up to 200 ft high; altitude 5000–5600 ft.

Population and Land Use.—2500 people using 15 sq miles; 3% intensively, 42% moderately, 55% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	13	Conical hills: 60–200 ft high; commonly in interlocking groups; steep smooth slopes, 15–30°	Humic brown clay soils (Ogelbeng, locally Daulo), commonly with dark subsoil. Well drained	*Capillipedium* and locally *Themeda* grassland	VI–VIIe
2	10	Undulating surfaces: up to 400 yd wide; local slope up to 7°	Humic brown clay soils (Ogelbeng); gleyed humic brown clay soils (Winjaka) and lateritic and gleyed latosols (Minj) in local slight depressions. Mostly well drained; locally imperfectly drained	*Capillipedium* grassland; sword grass and shrub regrowth	IIe; minor IId
3	2	Depressions: narrow linear, and isolated rounded	Organic soils (Gogimp). Swampy	Sedge bog	VIId

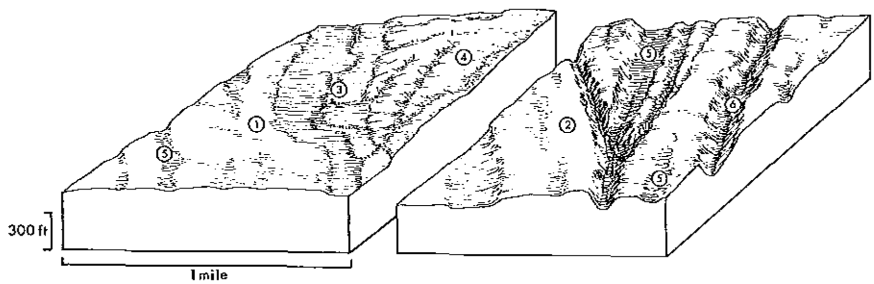
(27) Tari Land System (120 sq miles)

Volcanic ash plains, fans, and alluvial plains.

Geology.—Pleistocene volcanic ash, partly alluvial, commonly overlying agglomerate and lava.

Physical Features.—Gently sloping, smooth to undulating, alluvial, ash-flow, and mud-flow surfaces; little dissected; coarse subparallel drainage pattern, with some larger rivers in deeply incised steep-sided valleys; relief up to 200 ft; altitude 4500–7000 ft.

Population and Land Use.—*14,500 people using 82 sq miles; 12% intensively, 56% moderately, 32% lightly.*



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	48	**Upper alluvial plains:** 30–80 ft above widely spaced dissecting streams; slopes up to 2°	Lateritic latosols (Minj, Gitunu); locally meadow podzolic soils (Omahaiga) and humic brown clay soils (Ogelbeng). Imperfectly drained	*Capillipedium* grassland with scattered *Miscanthus*	$IVso_3,so_1$; IId
2	36	**Ash plains:** 50–100 ft above streams; little dissected; slopes up to 5°; locally terraced	Humic brown clay soils (Ogelbeng); locally alpine humus soils (Tomba) in highest parts and humic brown latosols (Singa) in lowest parts. Well drained	Gardens and garden regrowth; sword grass and shrub regrowth	I; IIe
3	16	**Lower alluvial plains and terraces:** below 5000 ft; 15–30 ft above streams; undissected, almost level	Meadow podzolic soils (Korn, Omahaiga, Banz); locally lateritic latosols (Gitunu), humic brown latosols (Singa), and dark colluvial soils (deep). Poorly to imperfectly drained	*Capillipedium* grassland, frequently with much bracken fern, locally with scattered *Miscanthus*; locally *Ischaemum* grassland. Scattered areas of gardens and garden regrowth	II–IIId; $IVso_3$
4	14	**Ash-flow and mud-flow fans:** long hummocky slopes, 4–10°; closely dissected	Complex of humic brown clay soils (Ogelbeng), gleyed humic brown clay soils (Tambul), meadow soils (Mombol), humic red latosols (Bidnimin), and locally sandy colluvial soils. Imperfectly, well, and excessively drained	*Capillipedium* grassland; sword grass and shrub regrowth; some gardens and garden regrowth and stream-bank vegetation	II–IIIe; *minor* II–IIId; II and $IVso_2$
5	4	**Depressions:** inactive gully floors and rounded areas up to 600 yd wide; at various levels	Dark colluvial soils (Kerebiji, Kummel); organic soils (Gogimp); very locally gleyed humic brown clay soils (Winjaka) and meadow podzolic soils (Omahaiga)	Grass–sedge bog; sedge bog; *Ischaemum* grassland; *Phragmites* swamp	IIId; VId
6	2	**Terrace scarps and flood-plains:** along entrenched streams: scalloped slopes 30–60°, up to 300 ft long; flood-plains up to 50 yd wide	Unclassified shallow colluvial soils and rock outcrop; alluvial land	Remnant and secondary forest	VIII

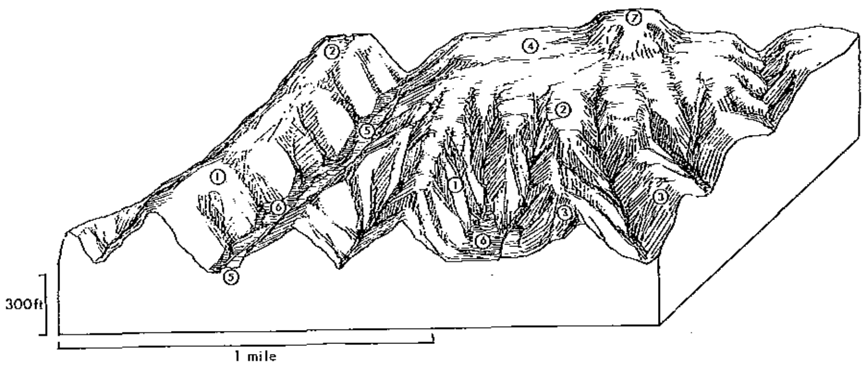
(28) Moruma Land System (55 sq miles)

Strongly dissected high alluvial fans.

Geology.—Unconsolidated Pleistocene fluviatile clay, sand, and boulder gravel, mainly derived from granodiorite; minor exposures of Cretaceous mudstone and shale.

Physical Features.—Dissected alluvial fans with small remnant fan surfaces grading radially into flat-crested spurs, narrow steep-sided ridges, and irregularly slumped ridges with gentler slopes; few small mudstone hills protruding above fan level; dense subparallel to radial drainage pattern, with narrow terraces and flood-plains along through-going streams; relief up to 300 ft; altitude 5000–5700 ft.

Population and Land Use.—12,000 people using 49 sq miles; 20% intensively, 50% moderately, 30% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	25	**Steep ridges**: 100–300 ft high; irregular slopes, 20–45°; sharp or narrow flat crests. Includes steep slopes marginal to unit 2	Few data. Unclassified colluvial soils and meadow soils (Kuli, Kudjil), gleyed humic brown clay soils (Tambul), and on upper slopes also humic red latosols (Bidnimin) and meadow podzolic soils (Banz). Variable drainage due to slope and seepage	Remnant and secondary forest; sword grass and dense shrub regrowth	VI–VIIe; VIII; minor VIe,so_3; IVso_2
2	15	**Dissected fan surfaces**: flat with steep gullies, or rounded linear rises and depressions; slopes up to 10°; relief up to 60 ft	Humic brown clay soils (Ogelbeng) and humic red latosols (Bidnimin) in upper parts; lateritic and gleyed latosols (Kerowil, Minj, minor Gitunu) in lower parts. Meadow podzolic soils (Banz), medium- and fine-textured alluvial soils and organic soils (Gogimp) in depressions and gullies. Well to excessively drained; locally poorly drained. Depressions imperfectly drained to swampy	Gardens and garden regrowth; sword grass and dense shrub regrowth; *Capillipedium* grassland with sedges, particularly in the west; *Ischaemum* grassland and *Phragmites* swamp in depressions	II–IIIe; II and IVso_2; some IVso_3,so_2; minor III and VId
3	9	**Slumped ridges**: 100–200 ft high; dissected broken upper slopes, 15–25°; hummocky benched lower slopes, 5–15°; narrow crests	Gleyed humic brown clay soils (Tambul), meadow soils (Kuli), meadow podzolic soils (Banz), and locally unidentified colluvial soils on upper slopes; also humic red latosols (Bidnimin) and lateritic and gleyed latosols (Gitunu). Imperfectly to poorly drained; steepest slopes excessively drained	*Capillipedium* and locally *Ischaemum* grassland; some gardens and garden regrowth and stream-bank vegetation	IV and VIe,so_3; some IVso_3; IVso_2; VI–VIIe, so_2; VIII
4	3	**Fan surfaces**: flat to gently undulating; slopes up to 3°; slightly dissected by gullies	Humic brown clay soils (Ogelbeng) and humic brown latosols (Singa). Well drained	*Capillipedium* grassland, improved pasture, and some gardens and garden regrowth	I
5	1·5	**Terraces**: narrow, up to 100 ft above streams; discontinuous	Meadow soils (Kuli, Kudjil); gleyed humic brown clay soils (Tambul). Probably alluvial soils on lower terraces. Mainly poorly drained	*Capillipedium* and *Ischaemum* grassland; gardens and garden regrowth; *Phragmites* swamp in local seepage areas	IVso_3; II–IIId
6	1	**Flood-plains**: up to 100 yd wide; less than 8 ft above streams; discontinuous	No data. Probably alluvial land. Excessively to poorly drained	Stream-bank vegetation; *Phragmites* swamp	VIII
7	<1	**Mudstone hills**: emerging 20–50 ft above general land surface; moderate to steep slopes	No data. Presumably similar to unit 2 of Koge land system. Well to excessively drained	*Capillipedium* grassland	IVe,so_2

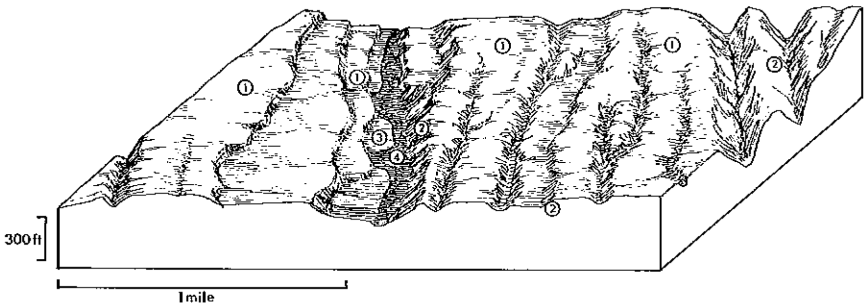
(29) Goroka Land System (50 sq miles)

Terraced and moderately dissected high alluvial fans.

Geology.—Unconsolidated Pleistocene fluviatile clay, sand, and boulder gravel, derived from granodiorite and schist.

Physical Features.—Gently undulating alluvial fans with regional slopes up to 3°; low steps separating three levels; closely and steeply dissected along margins; narrow flood-plains and terraces along through-going streams; relief up to 250 ft; altitude 5000–5500 ft.

Population and Land Use.—14,500 people using 50 sq miles; 46% intensively, 43% moderately, 11% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	30	**Fan surfaces:** flat to gently undulating; slopes 1–3°; at three levels, separated by steep steps of 20–50 ft; 100–250 ft above streams	Lateritic and gleyed latosols (Kerowil, less Minj) grading to meadow podzolic soils (Omahaiga) in slight depressions. Humic red and brown latosols (Singa, Wandi, Bidnimin) and humic brown clay soils (Daulo), mainly in upper parts. Well to excessively drained; locally imperfectly to poorly drained	Gardens and garden regrowth with much *Saccharum*; coffee plantations; *Themeda* and *Capillipedium* grassland	$IIso_2$; IIe; less I and $IVso_2$
2	16	**Steep slopes:** irregular slumped dissection slopes, 15–40°; along fan margins or meeting to form sharp ridges	Few data. Truncated brown and red clay soils (Ogelbeng, Bidnimin, Singa) and meadow soils (Kudjil) on upper slopes; unclassified colluvial soils on lower slopes. Variable drainage due to slope and seepage	Remnant and secondary forest; patches of *Capillipedium* and *Ischaemum* grassland	VI–VIIe; VIe,so_2; $VIIe,so_2$
3	2	**Terraces:** level to gently sloping; up to 300 yd wide, 20–40 ft above streams; discontinuous	Meadow podzolic soils (Omahaiga) and humic brown clay soils (Ogelbeng). Poorly to well drained	*Themeda intermedia* tall grassland; gardens and garden regrowth	$IVso_2$; I
4	2	**Flood-plains:** up to 200 yd wide, up to 8 ft above streams; short backing colluvial slopes	Meadow soils (Mombol), coarse medium-textured alluvial soils; minor unclassified organic soils, alluvial land. Mostly very poorly drained to swampy	*Phragmites* swamp; streambank vegetation	IIId; Vd; IVf; VIII

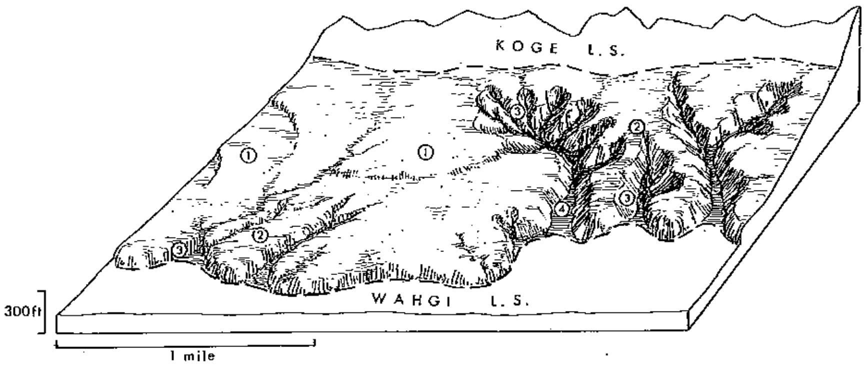
(30) MINJ LAND SYSTEM (13 SQ MILES)

Undulating partly dissected intermediate alluvial fans.

Geology.—Unconsolidated Pleistocene fluviatile clay, sand, and boulder gravel.

Physical Features.—Alluvial fans sloping up to 2°; partly gently undulating and slightly stepped; partly immaturely dissected into flat- or round-crested spurs; rather open branching drainage pattern; relief up to 150 ft; altitude 5000–5400 ft.

Population and Land Use.—2500 people using 11 sq miles; 62% moderately, 38% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	7	Fan surfaces: gently undulating to flat; locally benched or terraced; slopes up to 2°	Lateritic and gleyed latosols (Minj); meadow podzolic soils (Omahaiga) in slight depressions. Poorly drained, but mostly subject to rapid drying of topsoil	*Capillipedium* grassland	$IVso_3,so_2$; minor $IVso_3$
2	3	Dissected fan surfaces: flat to rounded or undulating; up to 500 yd wide	Lateritic and gleyed latosols (Minj) and meadow podzolic soils (Omahaiga, Gitunu). Mainly excessively drained		II and $IVso_2$; $III–IVe,so_2$
3	2	Steep slopes: along margins of units 1 and 2; 150–250 ft long; irregular, slumped, 10–40°	Few data. Unclassified colluvial soils, meadow soils (Kuli, Kudjil), and very locally humic brown latosols (Wandi). Variable drainage due to slope and seepage	*Capillipedium* and *Ischaemum* grassland; sword grass and shrub regrowth; remnant and secondary forest	VI–VIIe; IV and VIe, so_3; VIII
4	1	Valley floors: up to 100 yd wide	No data. Probably alluvial land	Stream-bank vegetation; *Phragmites* swamp	VIII

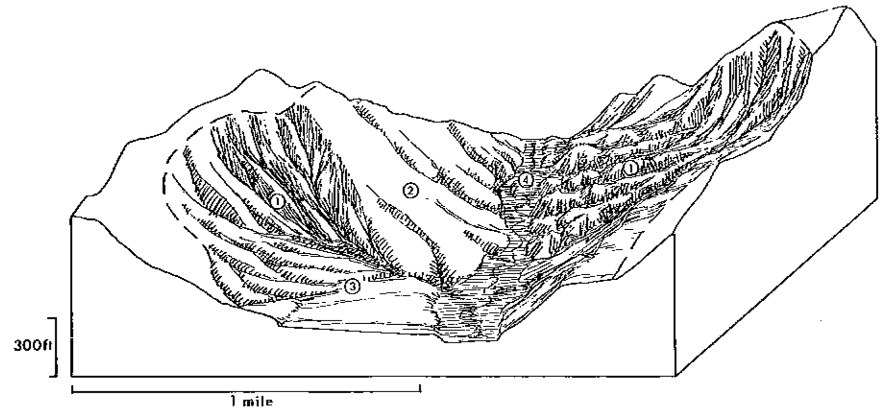
(31) Omahaiga Land System (55 sq miles)

Mostly steep moderately weathered dissected colluvial fans.

Geology.—Colluvium derived from schist and granodiorite.

Physical Features.—Steep hummocky colluvial fans, closely dissected into broad to narrow ridges; steeper colluvial heads of alluvial fans, with undulating surfaces, including few gently sloping, terraced lower fan surfaces. Subparallel drainage, narrowly incised and with branching tributaries in upper part; relief up to 200 ft; altitude 5500–7000 ft.

Population and Land Use.—15,000 people using 48 sq miles: 15% intensively, 67% moderately, 18% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	30	**Steep slopes and ridges:** long irregular concave slopes, 17–30°; dissected locally to form flat-topped or narrow ridges with very steep slopes, 20–40°, relief 50–200 ft	Humic brown clay soils (Daulo, less Ogelbeng); locally humic brown latosols (Singa), gleyed latosols (Ombun), and brown colluvial soils. Dark colluvial soils (Kerebiji) occur in local depressions and gleyed humic brown clay soils (Tambul, Winjaka) and meadow soils (Mombol) locally on schist-derived material. Mostly well drained; locally imperfectly to poorly drained	Sword grass and shrub regrowth; locally many gardens and garden regrowth. Some remnant forest on upper slopes and near streams	VI–VIIe; minor IVe,so$_3$; IIId
2	22	**Moderate slopes:** long, irregularly undulating, 5–17°; rounded gullies, very steep margins to incised streams	Humic brown clay soils (Daulo, Ogelbeng); near Bena Bena lateritic latosols (Kerowil) and meadow podzolic soils (Banz), with sandy and mottled colluvial soils and fine-textured alluvial soils in lower parts. Well drained but locally poorly drained	Sword grass and shrub regrowth; gardens and garden regrowth, including much *Saccharum*	II–IIIe; minor IVe,so$_3$; VIIe
3	3	**Colluvial toes and terraces:** long slightly undulating slopes, 2–3°; with shallow drainage depressions; terraces along eastern margin	Humic red and brown latosols (Bidnimin, Singa) and meadow soils (Kudjil); organic soils (Gogimp) in depressions. Well to imperfectly drained. Depressions very poorly drained to swampy	Gardens and garden regrowth; some *Capillipedium* grassland; *Phragmites* swamp in depressions	IIe; IId; minor IIId
4	1	**Flood-plains:** level, with minor terraces, up to 200 yd wide	Probably medium-textured alluvial soils. Probably poorly drained	*Phragmites* swamp; streambank vegetation	IVf,d

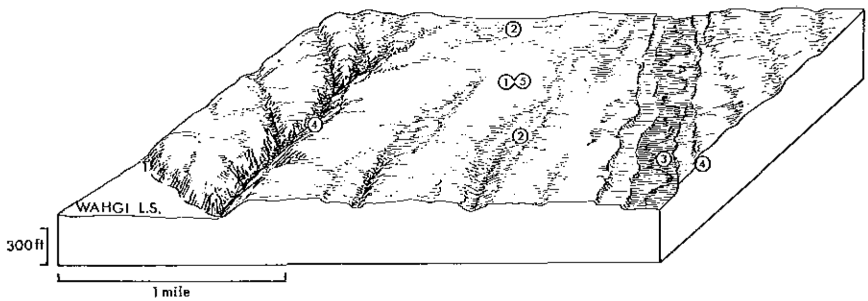
(32) Banz Land System (30 sq miles)

Undissected intermediate fan plains.

Geology.—Sub-Recent fine-textured alluvium, derived from shale and greywacke.

Physical Features.—Coalescing alluvial fans sloping up to 2°; flat to gently undulating with shallow drainage depressions; minor remnants of older fan surface; widely spaced dissecting minor streams and major through-going streams with flood-plains and terraces; sharp break to Wahgi valley flood-plain; relief up to 100 ft; altitude 5000–5400 ft.

Population and Land Use.—3600 people using 17 sq miles, 11% intensively, 61% moderately, 28% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	21	**Fan surfaces**: flat to gently undulating; slopes up to 3°	Meadow podzolic soils (Banz); very locally meadow soils (Mombol). Poorly drained; locally shallow water-table	*Capillipedium* and *Ischaemum* grassland; locally grass–sedge bog	$IVso_3$
2	5	**Drainage depressions**: seepage zones up to 200 yd wide, merging into linear drainage depressions up to 50 yd wide; up to 10 ft below unit 1; slopes up to 3°	Meadow soils (Mombol, Kuli). Very poorly drained; commonly shallow water-table	*Phragmites* swamp	IIId
3	2	**Flood-plains and terraces**: up to 400 yd wide; discontinuous narrow terraces, 10–30 ft above streams	Medium-textured alluvial soils, locally stony; alluvial land; higher terraces, meadow podzolic soils (Banz). Well to poorly drained	Flood-plains: *Phragmites* swamp; stream-bank vegetation Terraces: *Capillipedium* grassland; gardens and garden regrowth	VIf; VIII I; II–IIIst; IId; $IVso_3$
4	1	**Very steep slopes**: along margins and dissecting streams; 50–150 ft long, up to 40°	No data. Probably colluvial soils	Remnant and secondary forest	VIII
5	1	**Rounded ridges and low rises**: 10–30 ft high, 50–100 yd wide	Lateritic and gleyed latosols (Minj, Gitunu); commonly gravelly. Well to excessively drained	*Capillipedium* grassland; locally gardens and garden regrowth	II and $IVso_3$; minor IIe

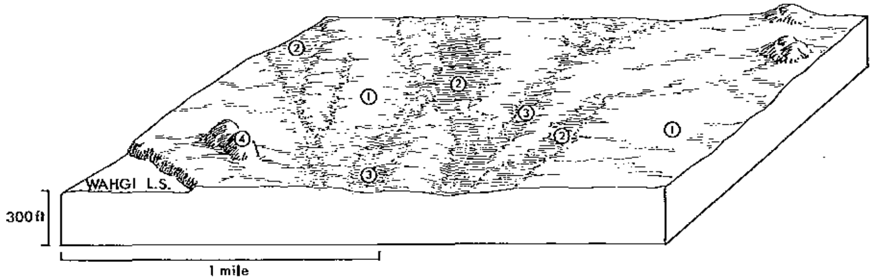
(33) Kinjibi Land System (40 sq miles)

Undissected low fan plains.

Geology.—Recent alluvial clay with minor sand and gravel; minor outcrops of Mesozoic shale and greywacke.

Physical Features.—Coalescing alluvial fans sloping less than 1°; almost level with shallow drainage depressions; sharp break of 20–40 ft to flood-plains of Wahgi River and through-going major tributaries; few small hills of protruding bed-rock; altitude 5100–5300 ft.

Population and Land Use.—1700 people using 16 sq miles; 31% moderately, 69% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	30	**Alluvial plains:** flat to very gently undulating; steep margins, 20–40 ft high	Meadow soils (Mombol, Kuli) very locally with gravelly subsoil; less meadow podzolic soils (Banz). Imperfectly to poorly drained; locally shallow water-tables	*Capillipedium* and less *Ischaemum* grassland; some remnant and secondary forest on steep margins	IVso$_3$; II–IIId
2	7	**Drainage depressions and flood-outs:** seepage zones up to 300 yd wide, and linear shallow depressions up to 50 yd wide. Flood-outs slope up to 3°	Meadow soils (Mombol) and dark colluvial soils (Kummel); some alluvial land on flood-outs. Very poorly drained to swampy	*Phragmites* swamp, commonly with *Saccharum* and regrowth shrubs	IIId; minor VIIf,d
3	2·5	**Flood-plains:** up to 50 yd wide	No data. Probably alluvial land and alluvial soils	Stream-bank vegetation; *Phragmites* swamp	IVf,d
4	<1	**Low hills:** 20–50 ft high; moderately steep slopes	No data. Presumably similar to unit 2 of Koge land system. Well to excessively drained	*Capillipedium* and *Themeda* grassland	IVe,so$_3$

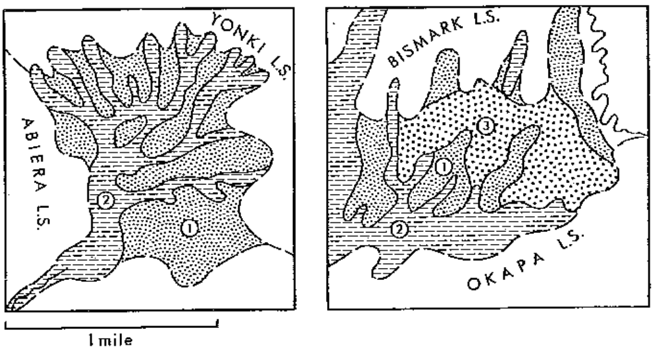
(34) Aiyura Land System (16 sq miles)

Poorly drained alluvial and colluvial basins.

Geology.—Sub-Recent and Recent alluvial and colluvial clay with some peat.

Physical Features.—Hummocky and undulating valley plains; swampy flats and tributary drainage tracts; relief up to 30 ft; altitude 5000–5500 ft.

Population and Land Use.—4200 people using 13 sq miles; 61% moderately, 39% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	10	Colluvial slopes: undulating very gentle slopes, 1–6°; relief 5–30 ft	Meadow soils (Mombol, Kuli, Kudjil); meadow podzolic soils (Banz, minor Omahaiga), particularly on higher areas together with local lateritic latosols (Kerowil) and humic brown clay soils (Daulo). Poorly drained; locally well drained	Gardens and garden regrowth; *Capillipedium* and *Ischaemum* grassland; minor stream-bank vegetation	IVso$_3$; IVe,so$_3$; minor I; IIe
2	5	Drainage depressions: flat, up to 300 yd wide; with ill-defined channels	Medium- and fine-textured alluvial soils. In narrow valleys organic soils (Gia), dark colluvial soils (Kerebiji), and meadow soils (Mombol). Swampy	*Phragmites* swamp	IIId
3	1	Higher flat surfaces: slightly below unit 1 and above unit 2	Organic soils (Gogimp). Swampy	*Ischaemum* grassland and grass–sedge bog	VId

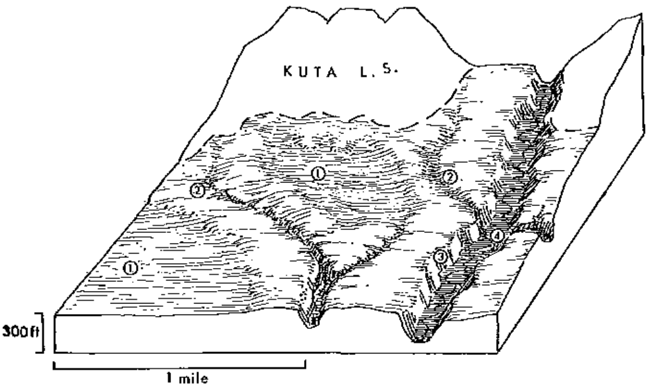
(35) TAMBUL LAND SYSTEM (8 SQ MILES)

Mostly swampy high level plains.

Geology.—Unconsolidated Pleistocene to Recent fluviatile deposits, covered with peat and thin volcanic ash.

Physical Features.—Slightly but deeply dissected valley plains, flat to undulating; few narrowly but deeply entrenched valleys; relief up to 200 ft; altitude 6800–7000 ft.

Population and Land Use.—1500 people using 5 sq miles; 50% moderately, 50% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	5	Flat surfaces: up to 2 miles wide; slopes up to 2°	Organic soils (Gogimp, Gia, some Gumanche in centre of large area). Swampy	Sedge bog; grass–sedge bog; minor *Phragmites* swamp, minor *Leersia* swamp	VI–VIId
2	2	Undulating surfaces: up to 800 yd wide; slopes 2–8°	Gleyed humic brown clay soils (Tambul, Winjaka); locally meadow podzolic soils (Banz) in depressions, and humic brown clay soils (Ogelbeng, commonly with pale subsoil) on steeper slopes and near edges. Imperfectly to poorly drained; locally well drained	Sword grass and shrub regrowth; locally *Capillipedium* grassland and gardens and garden regrowth	II–IIId; minor II–IIIe
3	<1	Very steep slopes: along margins of unit 2; 100–300 ft long; irregular slopes, 20–50°	No data. Probably colluvial soils	Remnant and secondary forest; sword grass and shrub regrowth	VIIe; VIII
4	<1	Flood-plains and terraces: flood-plains up to 150 yd wide; terraces up to 50 yd wide, 20–40 ft above streams, slopes up to 2°	No data. Probably organic soils (Gia) and alluvial soils. Well to very poorly drained	*Phragmites* swamp; stream-bank vegetation	IVf; IVf,d; Vd

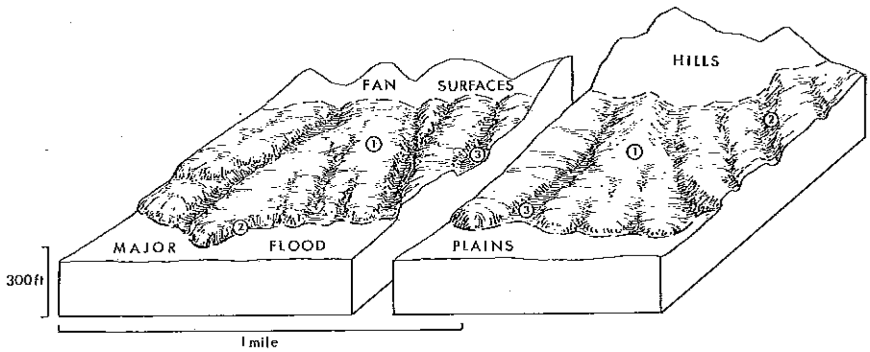
(36) Makuntus Land System (35 sq miles)

Intermediate river terraces.

Geology.—Sub-Recent to Recent alluvial clay with minor sand and gravel.

Physical Features.—Terrace surfaces, locally backed by small colluvial aprons; locally dissected; steep marginal slopes; relief up to 50 ft; altitude 4000–5000 ft.

Population and Land Use.—900 people using 8 sq miles; 24% moderately, 76% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	31	Terrace surfaces and colluvial aprons: up to 500 yd wide; slopes 1–3°	Meadow podzolic soils (Banz, in east much Omahaiga), meadow soils (Mombol, minor Kuli); locally dark colluvial soils (Kummel) in slight depressions. Poorly drained: locally shallow water-tables	*Capillipedium* grassland, commonly with sedges; *Ischaemum* grassland; in east much *Themeda intermedia* tall grassland; locally many gardens and garden regrowth, and plantations	$IVso_3$: less IId
2	2	Steep slopes: 40–80 ft long; irregular slopes of margins and gullies	No data. Probably colluvial soils	Remnant and secondary forest; *Capillipedium* grassland	VIIe; VIII
3	2	Flood-plains: up to 50 yd wide	Fine-textured alluvial soils. Poorly drained	Stream-bank vegetation; *Phragmites* swamp	IIId

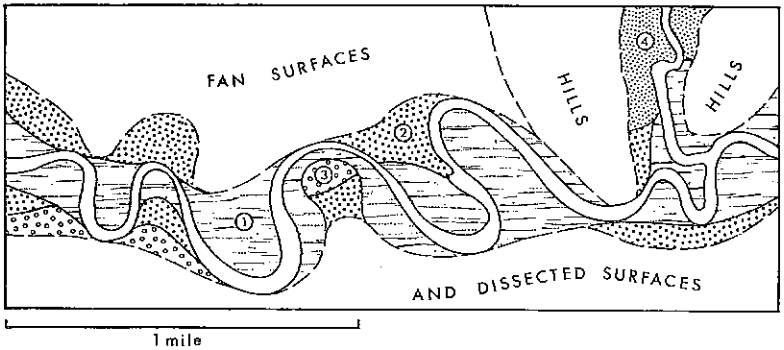
(37) Kaugel Land System (50 sq miles)

Flood-plains and terraces.

Geology.—Recent fluviatile clay, sand, and gravel; minor peat.

Physical Features.—Narrow flood-plains and discontinuous low terraces along major meandering streams; locally small backing colluvial aprons; altitude 4800–7800 ft.

Population and Land Use.—12,500 people using 38 sq miles; 1% intensively, 77% moderately, 22% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	28	**Flood-plains:** flat or hummocky; up to 5 ft above low stream level; up to 450 yd wide	Few data. Alluvial land; various alluvial soils; locally organic soils (Gia). Variable drainage	Stream-bank vegetation, commonly with much *Saccharum*; *Phragmites* swamp	IVf; Vf,d; VIII
2	13	**Lower terraces:** discontinuous; up to 300 yd wide and 5–10 ft above unit 1	Coarse medium to medium-textured alluvial soils; meadow soils (Kuli); locally organic soils (Gia). Well to poorly drained	Gardens and garden regrowth; *Capillipedium* and *Ischaemum* grassland	II–IIId; I; minor Vd
3	6	**Higher terraces:** discontinuous; up to 100 yd wide, 20 ft above unit 1	Meadow soils (Mombol), meadow podzolic soils (Banz, Omahaiga); locally humic brown clay soils (Kwakanigl) and deep dark colluvial soils. Mostly poorly to imperfectly drained	Similar to unit 2. In east much *Themeda intermedia* tall grassland	$IVso_3$; minor IId; IIe
4	3	**Colluvial aprons:** hummocky gentle to moderate slopes, 5–15°; much seepage	Dark colluvial soils (Kummel, Kerebiji), meadow soils (Mombol), gleyed humic brown clay soils (Tambul); locally organic soils (Gia). Mostly imperfectly to poorly drained. Locally stony		$IVso_3$; IVe,so_3; minor IIIe; IIIe,st

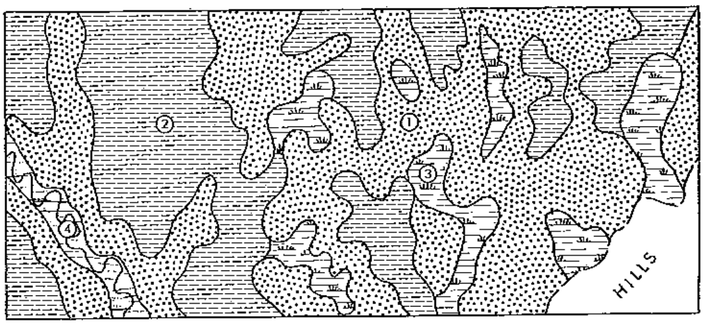
(38) Ko Land System (50 sq miles)

Poorly drained alluvial plains.

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

Physical Features.—Stable and partly aggrading alluvial plains with swampy depressions; major streams entrenched up to 20 ft; altitude 5200–6300 ft.

Population and Land Use.—5600 people using 30 sq miles; 43% moderately, 57% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	21	Alluvial plains: flat to very slightly undulating; 8–20 ft above streams; levees, terraces, and higher back-plains	Meadow soils (Kuli) and medium- to fine-textured alluvial soils; gleyed humic brown clay soils (Tambul, Winjaka) on higher levees; very locally deep dark colluvial soils. Imperfectly to poorly drained	*Capillipedium* grassland, commonly with much bracken fern; locally gardens and garden regrowth	II–IIId
2	20	Back-plain swamps: flat, slightly below unit 1	Organic soils (Gogimp, Gia), also meadow soils (Mombol). Very poorly drained to swampy	*Ischaemum* grassland and grass–sedge bog	VI–VIId
3	7	Seepage zones and distributary swamps: up to 300 yd wide; encroaching on unit 1; slopes up to 2°	Few data. Organic soils (Gia) and medium-textured alluvial soils. Swampy	*Phragmites* swamp	VIII; locally III, V, VId
4	2	Flood-plains: up to 150 yd wide; flanking meandering through-going streams	Medium-textured alluvial soils. Well to poorly drained	Stream-bank vegetation; *Phragmites* swamp	IVf; IVf,d

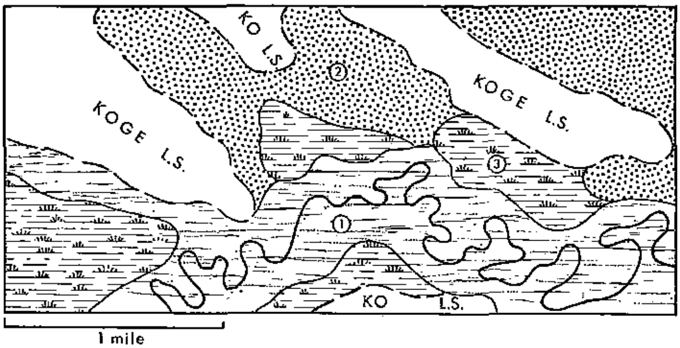
(39) Wahgi Land System (70 sq miles)

Flood-plains and flood-plain swamps.

Geology.—Recent fluviatile clay, sand, and gravel; minor peat.

Physical Features.—Aggrading low-lying flood-plains with meandering streams and oxbows; tributary plains with ill-defined stream pattern; back swamps; altitude 4700–5300 ft.

Population and Land Use.—500 people using 5 sq miles; 35% moderately, 65% lightly.



Unit	Area (sq miles)	Land Forms	Soils and Drainage Status	Vegetation	Land Class
1	29	**Flood-plains:** flat to very gently undulating; up to 600 yd wide; locally gravelly slight rises; common oxbows	Medium-textured and locally coarse medium-textured alluvial soils; locally alluvial land. Imperfectly to well drained; locally very poorly drained to swampy	*Phragmites* swamp; stream-bank vegetation	IVf; IVf,d; minor IVso$_2$; VI–VIId; VIII
2	21	**Tributary plains:** flat, with ill-defined drainage courses up to 400 yd wide	Medium- and fine-textured alluvial soils; very locally meadow soils (Mombol). Swampy	*Phragmites* swamp	VI–VIId
3	20	**Back swamps:** flat, up to 800 yd wide	Organic soils (Gumanche, less Gogimp)		VIId

PART V. CLIMATE OF THE GOROKA–MOUNT HAGEN AREA

By J. R. McAlpine*

I. Introduction

(a) Principal Climatic Features

This area has by virtue of its higher altitudinal position a climate distinctive from the tropical rain forest type (*Af*) of Köppen (1931) or wet tropical type (*AA′r*) of Thornthwaite (1931) generally prevailing in the lowlands of the oceanic and equatorial south-west Pacific. Below 5000 ft the climate very closely resembles these types but at higher elevations it approximates the moist temperate or mesothermal types of higher latitudes. Yet it differs again from these in its restricted annual range of moderately high temperatures. As Köppen (1931) classes all tropical areas above 4100 ft as *C*, this area then becomes *Cf* with a small occurrence of *Cw* at Henganofi. A similar climate in an area to the west has been described by Fitzpatrick (1965).

The climate is equable throughout the year in all its facets and is also characterized by comparatively little year-to-year variability. Monthly mean temperature varies through the year by only 4 degF, ranging at Goroka from 63 to 66°F, and decreases approximately 3 degF with every 1000-ft increase in ground elevation. Mean annual rainfall ranges from 70 in. in the east to 125 in. in the west and rainfall seasonality becomes increasingly marked in an easterly direction.

(b) Climatic Records

The lengths of rainfall records are given in Table 2. Only Goroka and Mount Hagen have been used for comparative purposes, except where otherwise stated. The standard period used for these two stations is 1952–66 inclusive. The unsatisfactory length of this period is partly compensated by the low degree of variability indicated in the area.

II. Climatic Controls

This discussion of climatic controls operating in the area is based on Brookfield and Hart (1966) and Fitzpatrick, Hart, and Brookfield (1966). It modifies their treatment only in so far as is necessary to fit the broad principles outlined to the local situation and after a consideration of upper air data available for Lae.

Throughout lowland New Guinea the major climatic controls are the seasonal latitudinal movements of two major surface air masses separated by the intertropical convergence zone (ITCZ). These consist of a perturbation belt of westerly-moving vortical circulations to the north, referred to in previous literature as the "north-

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TABLE 2

MEAN MONTHLY AND ANNUAL RAINFALL (IN.) WITH HIGHEST AND LOWEST RAINFALL ON RECORD FOR STATIONS WITH FIVE YEARS OR MORE OF FULL RECORDS

Station	Elevation* (ft)	Length of Record (yr)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Highest Annual	Lowest Annual
Aiyura	6000	24	9·19	10·13	10·53	9·66	4·84	3·63	3·98	5·18	5·26	5·91	7·54	9·43	85·28	100·96	61·60
Arona	4080	12	8·42	9·48	11·60	8·14	2·53	2·35	3·17	2·56	3·98	6·34	7·50	11·57	77·64	106·26	54·64
Baiyer River	4000	12	10·80	12·28	14·43	12·00	5·73	3·93	3·92	4·45	7·11	7·08	8·65	11·58	101·96	123·37	86·97
Goroka	5200	14	8·84	9·55	9·61	8·28	4·88	2·32	2·07	3·08	4·63	5·44	6·05	9·96	74·71	93·72	54·13
Gumine	5500	5	11·55	13·18	11·24	9·14	8·15	4·07	3·40	4·60	6·67	7·26	6·22	9·74	95·22	109·24	85·29
Henganofi	5000*	10	8·66	9·83	11·04	7·09	3·03	1·86	1·20	2·77	4·17	5·43	5·48	8·32	68·88	89·32	55·08
Kainantu	5280	11	9·29	9·99	12·06	7·96	4·59	2·91	2·16	3·89	4·27	5·75	6·98	9·74	79·59	98·23	68·14
Keglsugl†	8000	3	8·69	11·89	13·48	10·74	4·26	3·28	4·66	4·73	6·18	5·18	5·05	9·33	87·47	—	—
Toromanbuno†	7500*	3	10·96	12·56	8·87	10·56	6·19	4·35	3·43	6·06	6·04	6·92	6·54	9·90	92·38	—	—
Kerowagi	5000*	10	10·00	10·72	11·47	12·58	8·59	5·04	5·34	7·81	9·75	9·51	8·17	11·60	110·58	132·35	91·34
Kinjibi	5400*	7	10·79	10·12	12·81	11·44	5·66	3·78	3·80	6·52	7·40	6·35	7·53	13·58	99·78	120·39	81·17
Kundiawa	4900	8	9·98	9·14	11·55	9·71	5·12	4·15	2·53	4·44	6·31	6·63	6·08	8·11	83·75	104·89	68·29
Kuta	6700	7	12·51	12·69	13·84	14·17	9·42	5·31	7·56	10·40	10·11	7·84	9·68	11·81	125·34	149·59	106·19
Minj	5200	10	8·48	9·07	11·45	8·40	6·95	4·48	5·11	7·25	8·46	6·86	7·41	10·24	94·16	112·77	80·86
Mount Hagen	5500	15	10·51	10·78	11·30	10·59	7·00	5·00	5·25	7·00	9·31	8·10	8·45	9·03	102·32	131·35	83·97
Nondugl	5400	11	9·48	10·89	10·67	10·92	7·24	4·86	5·46	7·55	8·50	7·77	7·86	8·58	99·78	124·01	74·56
Togoba	5400	11	11·68	11·87	12·47	11·99	6·71	4·98	5·80	6·74	8·98	8·20	7·77	10·79	107·98	121·76	87·62
Tremearne	5400	8	13·73	14·34	13·86	11·58	7·49	5·95	5·35	7·76	9·38	10·13	10·02	12·16	121·75	151·83	108·05

* Heights as listed by Commonwealth Meteorological Bureau, except those marked with asterisk.

† Station at Keglsugl moved to Toromanbuno.

west season", and the south-east trade wind belt to the south. Upper air data from Lae indicate that over New Guinea these two belts dominate during different seasons and extend to quite different altitudes. During the perturbation belt season, from December to March, these essentially external surface masses reach an altitude sufficient to allow their upper sections to enter and affect the highlands weather pattern. Conversely, the south-east trade winds which are dominant from May to mid October generally reach insufficient height to enter or pass over the barrier. On occasion they may do so by banking up against the barrier and being forced over by updraft. However, this effect is generally confined to those ranges which lie transversely across the prevailing wind, as in the Papuan extensions of the central cordillera. When this does occur, these moist air masses in any case will become highly modified and can no longer be considered as part of the external surface circulation system but only as a moist sector in the local highland circulation. Generally, and especially in the eastern highlands, the area remains unaffected by the trade winds or their overflow during the "south-east season" but is dominated externally by dry zonal easterlies. The months of April and mid October to November form transitional periods between these two systems when the ITCZ is shifting across the area and during which either system may predominate for short periods.

The differential protection from outside surface influences causes local circulations within the highlands to be the dominant internal climatic control during the south-east season and co-dominant during the perturbation period. At this local level the highlands can be considered orographically as a series of valley basins surrounded by the much higher outer wall of the central cordillera. The major basins in this area are those of the upper Ramu, Bena–Asaro, Chimbu, Wahgi, and Baiyer Rivers. The differential heating of basin floors and slopes can be assumed to give rise in each to local circulations showing a regular diurnal alternation of katabatic and anabatic winds. These winds result in the commonly observed pattern of late morning clear basin centres and clouded slopes, giving way in the evening to clouded basin centres and clearing slopes. Later in the night clear skies commonly prevail overall, after which a situation of temperature inversion frequently occurs which results in early morning fogs over basin floors. Where rivers draining these basins form valleys which lead directly into the lowlands, air from these local highland circulations may pass down them and, conversely, lowlands air may rise up through them to enter the highlands.

With regard to rainfall distribution within such basins, Brookfield and Hart (1966) have demonstrated, by reference to the Lake Sentani basin of West Irian, that in a uniform and limited basin-type orographic situation rainfall increases with elevation and proximity to the periphery of the basin. The basins of the New Guinea highlands are neither uniform nor limited but vary in shape, size, and altitude, thus making the orographic situation within any basin complex and inter-basin comparison difficult. However, it may be assumed that this effect of increasing rainfall towards the margins of a basin will still generally prevail. No suitable sequence of rainfall stations exists in the area to demonstrate this effect reliably but it may be partly demonstrated by a rough comparison of the rainfall between stations within a basin (Fig. 6 and Table 2). Generally, those nearest the centre have lower rainfalls than those further towards the periphery.

Except within this basin situation there is no evidence of any direct relationship between altitude and rainfall. Unfortunately the altitudinal range of rainfall stations in this area is restricted and this lack of correlation between altitude and rainfall is best shown by comparing the rainfall figures in this report with those in the area to the west given by Fitzpatrick (1965).

III. General Climatic Characteristics

(a) *Rainfall*

Mean monthly and annual rainfall for stations possessing five or more years of complete records are given in Table 2. The spatial and seasonal distribution of this rainfall is illustrated by means of histograms on Figure 6. No attempt has been made to construct an isohyetal map because of the previously mentioned complexity of both the orographic situation and local circulations between and within the various basins of the area.

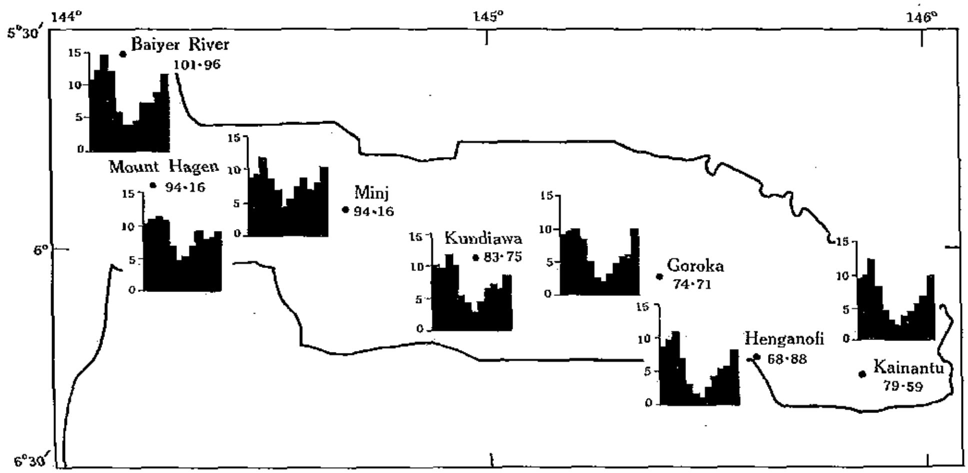

Fig. 6.—Annual distribution of rainfall (Jan.–Dec.) at 7 recording stations. Values shown with station names are the mean annual rainfall (in.) for the station.

Mean annual rainfall is least in the basin centres, 75 in. at Goroka and 102 in. at Mount Hagen, and increases towards their peripheries. Superimposed on this local pattern is an overall increase in annual rainfall in a westerly direction, a large part of this difference resulting from variations in "dry season" falls. Throughout the area June and July are the driest months and March the wettest. Rainfall seasonality is particularly marked in the east where the seasonal pattern is similar to that of Port Moresby but with higher monthly totals. To the west, seasonality decreases and begins to approach the almost complete lack of seasonality of the Southern Highlands District. This variation in seasonality may be caused by the proximity of these western areas to those ranges in Papua which lie transversely across the south-east trade winds. As a result it might be expected, by the process mentioned previously, that falls of rain may occur in this area during the "dry season" as a result of the incursions of highly modified moist south-easterly trade wind air during the dry season. It is also significant that to the east the barrier ranges to the north are narrower and lower than elsewhere in the central cordillera and hence the climate is more influenced by the markedly seasonal rainfall regime in the nearby Markham–Ramu lowland valley.

TABLE 3

AVERAGE NUMBER OF RAIN DAYS PER QUARTER WITH RAINFALL WITHIN SPECIFIED LIMITS

Amount (in.)	Jan.–Mar. (90 days)	Apr.–June (91 days)	July–Sept. (92 days)	Oct.–Dec. (92 days)
		Goroka		
0·01–0·24	37	30	29	30
0·25–0·99	26	16	10	20
1·00–1·99	7	3	1	4
2·00–3·99	< 1	< 1	< 1	1
≥ 4·00	0	0	0	0
		Mount Hagen		
0·01–0·24	31	27	36	27
0·25–0·99	29	23	22	25
1·00–1·99	9	7	4	7
2·00–3·99	1	< 1	< 1	< 1
≥ 4·00	0	0	0	0

The variability of annual rainfall, expressed by the standard deviation as a percentage of means, is between 14 and 15% at both Goroka and Mount Hagen and increases to 17% at Henganofi. This low variability is a distinguishing characteristic

TABLE 4

LENGTH OF RAINY AND RAINLESS PERIODS AND NUMBER OF DAYS WITH OR WITHOUT RAIN PER QUARTER (1952–66)

Station and Quarter	Rainy Period Average (days)	Rainy Period Longest (days)	Av. No. Rain Days	Rainless Period Average (days)	Rainless Period Longest (days)	Av. No. Rainless Days
Goroka						
Jan.–Mar.	5·8	25	71	1·7	8	20
Apr.–June	3·2	29	49	2·7	32	42
July–Sept.	2·5	22	41	3·0	15	51
Oct.–Dec.	3·7	29	55	2·4	15	36
Mount Hagen						
Jan.–Mar.	5·5	44	71	1·6	7	20
Apr.–June	3·8	34	57	2·3	22	34
July–Sept.	4·3	28	63	2·0	7	29
Oct.–Dec.	3·9	20	59	2·1	18	32

of the highlands climate. Variability is higher in the dry season than in the wet and increasing seasonality is positively correlated with increasing monthly variability. The highest and lowest annual rainfalls on record are given in Table 2.

No direct measures of rainfall intensity are available. Table 3 indicates that for Goroka and Mount Hagen, heavy rainfalls over 4 in. per day have not been recorded and that during the dry season daily falls over 2 in. are uncommon. Rainfall data for other stations show a similar pattern. This contrasts with the coastal situation where rainfall intensities are considerably higher. Table 4 indicates the rainy nature of the climate. In all the facets listed Mount Hagen is rainier than Goroka in the dry season, but not significantly different during the wet season. Mount Hagen has, on average throughout the year, somewhat heavier falls per day than Goroka.

TABLE 5

NUMBER AND LENGTH OF DRY AND WET SPELLS BY SEASONS FROM 1952 TO 1966

Duration	Goroka	Mount Hagen
Dry spells		
Dry season (Apr. 22–Oct. 22)		
1 wk	30	40
2 wk	22	13
3 wk	10	2
4 wk	6	0
≥ 5 wk	11	0
Wet season (Oct. 23–Apr. 21)		
1 wk	32	33
2 wk	12	1
3 wk	2	3
4 wk	1	0
≥ 5 wk	1	0
Wet spells		
Dry season (Apr. 22–Oct. 22)		
1–4 wk	67	42
5–8 wk	5	6
9–12 wk	2	9
13–16 wk	0	4
> 16 wk	0	1
Wet season (Oct. 23–Apr. 21)		
1–4 wk	30	15
5–8 wk	16	9
9–12 wk	3	6
13–16 wk	2	6
> 16 wk	4	5

A better indication of the frequency and duration of wet and dry spells of weather is given in Table 5. A wet spell is here defined as the number of consecutive weeks in which rainfall exceeds estimated evapotranspiration, and a dry spell as the number of consecutive weeks in which evapotranspiration exceeds rainfall. These spells have been calculated by the application of the water balance model described in Section IV. The results have been arranged in six-monthly periods to provide a

TABLE 6

TEMPERATURE CHARACTERISTICS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						Goroka (5200 ft)							
Mean maximum (°F)	78·6	78·3	78·0	77·9	78·9	76·6	76·3	77·3	77·9	78·7	79·2	78·4	78·0
Mean (°F)	68·8	68·7	68·8	68·6	68·8	66·7	66·4	67·2	67·5	68·0	68·3	68·6	68·0
Mean minimum (°F)	59·1	59·2	59·7	59·3	58·7	56·9	56·5	57·1	57·2	57·3	57·4	58·8	58·1
Highest maximum (°F)	82·3	82·6	82·7	82·4	82·7	81·0	80·9	81·6	82·2	83·7	83·7	83·1	83·7
Lowest minimum (°F)	54·9	55·5	56·1	54·8	53·2	50·3	50·1	50·7	51·3	50·2	50·6	53·3	50·2
						Mount Hagen (5500 ft)							
Mean maximum (°F)	75·6	75·6	74·8	75·1	75·9	73·7	72·4	72·9	73·9	75·0	75·8	75·2	74·6
Mean (°F)	65·8	65·8	65·5	65·8	66·0	64·0	63·4	63·8	64·3	64·7	65·3	65·5	65·0
Mean minimum (°F)	56·1	56·0	56·2	56·6	56·1	54·3	54·5	54·8	54·7	54·5	54·8	55·9	55·4
Highest maximum (°F)	81·1	79·3	78·8	78·9	79·9	78·0	76·9	78·1	78·3	79·7	79·9	78·9	81·1
Lowest minimum (°F)	51·0	51·1	51·7	52·3	50·1	46·9	48·0	48·9	47·8	46·2	48·3	51·6	46·2

comparison between wet and dry seasons. Where a spell of weather has carried through from one to the other period it has been included in that season in which the longest sector of it occurred. Table 5 indicates that dry spells tend to be more frequent and longer in Goroka than in Mount Hagen in both the wet and dry seasons, although the difference is more marked in the dry season. There is no record of a dry spell of four weeks or longer at Mount Hagen whereas dry spells of even longer duration can be expected to occur at Goroka on average once a year. The comparison of the two stations for wet spells presents a less marked contrast. Goroka has slightly more wet spells in both the wet and dry seasons but this is due to the fact that wet spells at Mount Hagen are generally more consistent and longer. An analysis of other highland rainfall stations indicates that those in the east closely approximate the Goroka wet- and dry-spell pattern while those in the west are similar to the Mount Hagen pattern. Stations in between the two are intermediate, showing a gradual transition between these two patterns rather than any sharp breaks in wet- or dry-spell frequencies and lengths.

(*b*) *Temperature*

Table 6 indicates the very restricted range of mean monthly and other temperature characteristics. At Goroka mean monthly temperature ranges from 66°F in July to 69°F in January. A comparison of these figures with data for the area to the west described by Fitzpatrick (1965) where temperature records are available for a range of altitudes, and with data (McVean 1968) for six months at Pindaunde field station (11,600 ft above sea level) on Mt. Wilhelm, indicates an overall decrease in temperature of approximately 3 degF per 1000-ft increase in altitude.

The average diurnal range of temperature at Goroka and Mount Hagen is approximately 20 degF, a figure double that of the New Guinea lowlands and considerably greater than the annual range of mean temperature in the highlands. Table 6 also lists the highest maximum and lowest minimum on record and from these it can be seen that even extreme temperatures vary only by 5–10 degF from the mean range. Ground frosts may be expected to occur very occasionally at 6000 ft, especially in cold air drainage depressions or "frost hollows". The probability of frost occurrence above this altitude increases directly with height. Ground frosts may be assumed to be reasonably common above 8500 ft above sea level and at Pindaunde they occurred on more than 50% of the days for the available record (McVean 1968). Snow falls occasionally on the summit of Mt. Wilhelm.

(*c*) *Other Climatic Characteristics*

Mean monthly relative humidity for 0900 and 1500 hours, together with estimated evaporation, is given in Table 7 for Goroka and Mount Hagen. Humidity is high throughout the year for both stations and shows little monthly variation. Early morning atmospheric conditions are mostly saturated or near saturated, frequently resulting in heavy fog in valley basins. Mean monthly dew-point temperatures range only from 1 to 3 degF above mean monthly minimum temperatures. No observational data for evaporation are available, but estimates have been made from mean monthly maximum and minimum temperature, vapour pressure, and day length (Fitzpatrick 1963).

TABLE 7
MEAN MONTHLY RELATIVE HUMIDITY AND EVAPORATION

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
					Goroka								
Relative humidity—0900 hr (%)	90	93	90	92	86	88	87	85	83	81	81	88	87
1500 hr (%)	58	60	61	60	56	58	57	55	55	54	51	58	57
Evaporation (in.)*	4·7	4·4	4·6	4·6	4·4	4·0	4·0	4·0	4·0	4·1	4·1	4·5	51·4
					Mount Hagen								
Relative humidity—0900 hr (%)	87	87	88	89	89	91	92	91	87	83	82	85	88
1500 hr (%)	67	67	71	69	66	69	68	70	67	64	63	67	67
Evaporation (in.)*	3·9	3·5	3·5	3·4	3·5	3·1	3·1	3·2	3·4	4·0	4·0	3·9	42·5

* Estimated by method of Fitzpatrick (1963).

TABLE 8

MEAN MONTHLY AND ANNUAL CLOUDINESS (SCALE 0–8) AT GOROKA AND MOUNT HAGEN, AND SUNSHINE AT AIYURA

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Goroka													
Total cloudiness—0900 hr	7	6	7	6	6	6	6	6	5	5	5	6	6
1500 hr	7	7	7	6	6	6	6	6	6	6	6	7	6
Low cloud*—0900 hr	4	4	4	5	4	4	4	4	4	3	4	4	4
1500 hr	4	4	4	4	3	4	4	4	4	4	4	4	4
Mount Hagen													
Total cloudiness—0900 hr	7	7	7	7	7	7	7	7	6	6	6	6	7
1500 hr	7	7	7	7	7	6	6	6	6	7	7	7	7
Low cloud*—0900 hr	5	5	5	5	5	6	6	6	5	4	4	4	5
1500 hr	5	5	5	5	5	5	5	5	5	4	5	5	5
Aiyura													
Total sunshine (hr)	147	130	134	139	196	155	149	150	160	175	178	138	1851

* Below 8500 ft.

Data for mean monthly cloudiness are given in Table 8 for Goroka and Mount Hagen together with sunshine figures for Aiyura. As can be seen, cloudiness varies little through the year for these two stations possessing similar central basin positions. The diurnal movements of low cloud within a basin system have been referred to earlier. Short sunshine records at Nondugl indicate approximately the same monthly range as those at Aiyura. Basin centres should experience greater sunshine duration, and basin slopes somewhat less.

IV. Plant Growth and Water Balance

The interactions between rainfall, evapotranspiration, soil water storage and run-off, and infiltration considered here are based on a water balance model similar in principle to that developed by Slatyer (1960), which uses evaporation as withdrawal

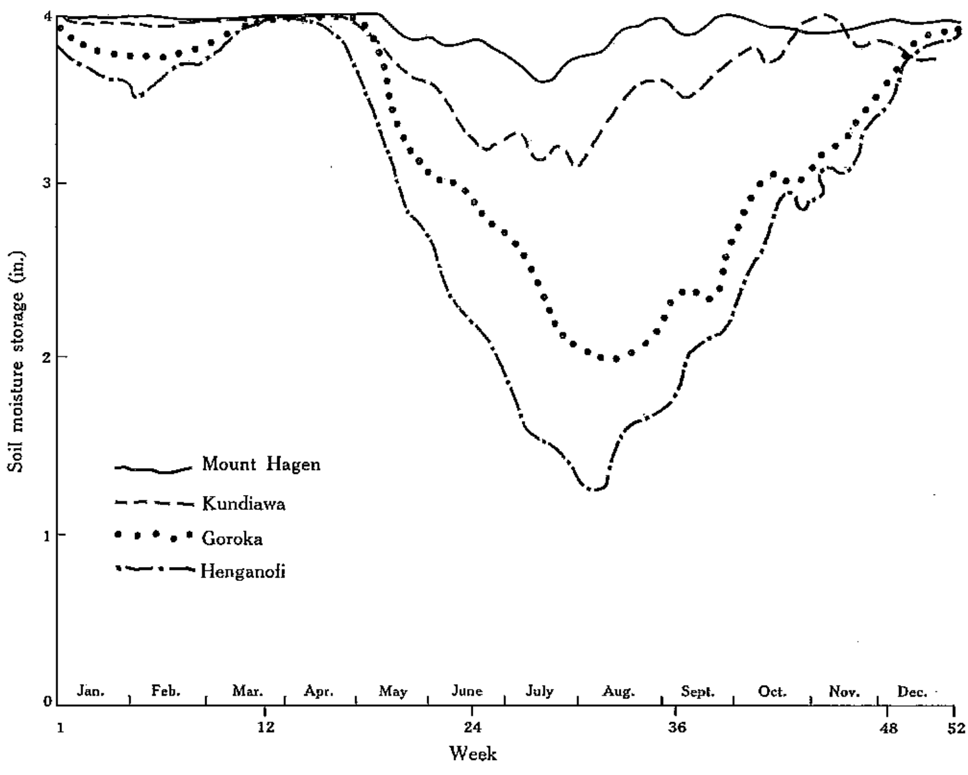

Fig. 7.—Average weekly soil moisture storage at 4 stations.

(evapotranspiration) and rainfall as input. The model is designed to indicate week-to-week changes in soil moisture levels and these have been assessed with the aid of computer processing. The assumptions in applying the model are that actual evapotranspiration (*ET*) is related to tank evaporation (*E*), estimated by Fitzpatrick's method by the relationship $ET = 0 \cdot 8E$ for those weeks with storage plus rainfall exceeding 2·50 in. and by $ET = 0 \cdot 4E$ below this level. The model may tend to underestimate evapotranspiration when the upper parts of an otherwise dry soil profile receive rains less than 2·50 in. and overestimate it during weeks without rainfall when stored soil water in the upper profiles is nearing depletion. However, these variations are of little significance in a general assessment over a number of years. Soil moisture storage capacity is assumed to be 4·00 in. and run-off is assumed to occur only when this threshold of soil moisture storage is surpassed.

The weekly changes in soil moisture level that are indicated by the application of this model have been averaged for the years of record and the results illustrated in Figure 7. This clearly indicates the effects of the increased seasonality of rainfall in the Goroka–Henganofi area compared with that in the west. However, these are only average conditions and it is the frequency with which serious soil water deficits occur which will determine the risks for plant growth and production. This is indicated in Table 9 by the number of weeks in which soil moisture reached certain

TABLE 9

NUMBER OF WEEKS IN THE DRY SEASON* IN WHICH SOIL MOISTURE STORAGE (4 IN.) WAS DEPLETED TO STATED PERCENTAGE CLASSES FOR GIVEN YEARS

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
						Henganofi					
Full storage	0	5	1	1	0	12	4	7	4	1	2
1–49% depletion	5	10	9	11	11	12	19	12	6	10	11
50–99% depletion	17	9	15	14	15	2	3	7	12	14	12
Total depletion	4	2	1	0	0	0	0	0	4	1	1
						Goroka					
Full storage	0	9	4	3	2	14	11	7	4	7	9
1–49% depletion	6	17	10	19	12	12	15	14	9	15	6
50–99% depletion	20	0	12	5	12	0	0	5	13	4	11
Total depletion	0	0	0	0	0	0	0	0	0	0	0
						Mount Hagen					
Full storage	22	22	16	23	23	21	23	18	22	11	15
1–49% depletion	4	4	10	3	3	5	3	8	4	15	11
50–99% depletion	0	0	0	0	0	0	0	0	0	0	0
Total depletion	0	0	0	0	0	0	0	0	0	0	0

* Apr. 22–Oct. 22.

depletion levels during the dry season. At Henganofi, for slightly more than half the years of record, soil moisture was depleted by more than 50% for half the dry season, and occasionally storage was completely depleted. At Goroka soil moisture is only intermittently depleted by over 50% whereas at Mount Hagen this degree of depletion has never occurred. No similar table for the wet season is given as only rarely does any soil moisture depletion occur at Goroka or Mount Hagen and this only in the mid October–November seasonal transition period. Even at Henganofi wet season depletion has been significant only in one year of record when, in the

January–March period, 1963, six consecutive weeks of depletion occurred ranging from 55 to 70%. Conversely, the results from this water balance model indicate that during the wet season, if soil drainage rates are low, soil moisture levels may remain above field capacity for considerable periods and this excessive wetness may inhibit plant growth.

TABLE 10

MEAN ANNUAL WATER SURPLUS

	Run-off and Through Drainage (in.)	Av. No. Weeks per Annum Run-off and Through Drainage Occurred
Goroka (15 yr records)		
Mean	38	24
Lowest (1963)	17	15
Highest (1960)	56	27
Kundiawa (12 yr records)		
Mean	53	35
Lowest (1965)	35	30
Highest (1962)	65	42
Mount Hagen (15 yr records)		
Mean	72	42
Lowest (1965)	48	31
Highest (1952)	94	42

A comparison of results from other rainfall stations in the area indicates that generally the Goroka water balance pattern is applicable to most stations in the basins of the east and the Mount Hagen pattern to basins in the west.

These water balance results have been further analysed to give some indication of annual water surplus through run-off and through-drainage. Table 10 gives these results as a mean, together with the highest and lowest annual occurrences on record, and again indicates the gradual increase from east to west. Ribeny and Brown (1968) have shown that the model gives good agreement with stream gauge run-off data at Aiyura, and hence the estimates given in Table 10 may be assumed to be reasonable.

V. Acknowledgments

Data preparation and tabulations have been carried out by Miss P. M. Bridson and Mrs. A. Komarowski.

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PART VI. SOILS OF THE GOROKA–MOUNT HAGEN AREA

By H. A. HAANTJENS*

I. GENERAL

(a) Soil Classification and Correlation

(i) *Classification.*—All soil profiles described in the field were afterwards grouped into 13 major soil groups which have no clearly defined categorical status but are merely groups of local convenience. The major groups were given short descriptive names, using partially the terminology of standard great soil groups as in use in Australia and the U.S.A. In addition, two major groups (lithosols and miscellaneous land types) were used to describe essentially non-soil conditions. No field observations were made in these groups. Profiles in the 13 major groups were subdivided into 37 soil families which are considerably more homogeneous classes than the major soil groups but generally too heterogeneous to be called soil series. Most families have been given locality names but those of the alluvial and colluvial soils were given short descriptive names. Each soil family (in the first instance those for which analytical data are available) was tentatively placed in the great group category of the 7th Approximation (United States Soil Conservation Service 1960). The results of this comparison are shown in Table 11.

(ii) *Correlation with Wabag–Tari Area.*—The soil families of the Wabag–Tari area to the west, which was surveyed in 1960 and 1961, were established independently (Rutherford and Haantjens 1965) from what had been done earlier in the Goroka–Mount Hagen area. A comparison indicates that many families appear to be restricted to either one of these two areas and also that many families of one area show great similarities with families of the other (Table 12). The degree of similarity varies. Where it is so great that the two families could possibly be merged into one, the names are printed in italics in the table. A few points can be made about the correlation. Mainly because of incomplete clay mineral data no distinction was made in the Goroka–Mount Hagen area between humic brown clay soils on volcanic ash and those on other soil types. Thus Ogelbeng family includes profiles of both the ash soils of Wapenamanda family and non-ash soils of Vakari family. Similarly Daulo family includes non-ash soils that were excluded from Tabunaka family. Banz family includes soils on consolidated rocks as well as on unconsolidated sediments and this largely accounts for the difference between the equivalent families Tumundan and Pumakos. Tomba and Pompameiri families are apparently less peaty and less clayey than the related Dibibi family. Bidnimin family has a better-developed topsoil and a browner upper subsoil than Kutubu family which is a typical lowland latosol. Elimbari family is much less organic than Kaijende family, which usually occurs at higher altitudes and in a wetter climate.

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TABLE 11

CLASSIFICATION, NOMENCLATURE, AND DISTRIBUTION OF SOILS OVER LAND SYSTEMS

Soil Group* and Family	Probable Equivalent Great Group in 7th Approximation	Land Systems† in which Soil Occurs
Alluvial soils		
Unclassified		12, 21, 28, 35, 37
Coarse medium-textured	Hydraquent, Haplaquent, and Hapludent, depending on drainage	29, 37, 39
Medium-textured		5, 19, 32, 34, 37, 38, 39
Fine-textured		17, 19, 28, 31, 34, 36, 38, 39
Alpine peat and humus soils		
Unclassified		10
Pinde	? Histosol order	1, 2
Tomba	Haplumbrept to Cryumbrept	1, 3, 4, 6, 14, 18, 22, 25, 27
Pompameiri	Cryumbrept	1, 3, 5, 12, 23, 26
Black earths		
Limisate	Grumaquert	15
Colluvial soils		
Unclassified		12, 27, 28, 29, 30, 35
Sandy soils	Dystrochrept	2, 5, 6, 7, 8, 9, 15, 16, 24, 27, 31
Brown soils	Dystrochrept	5, 6, 7, 8, 9, 13, 16, 19, 24, 31
Mottled soils	Dystrochrept to Ochraquept	5, 6, 7, 8, 15, 17, 24
Dark colluvial soils		
Kummel	Umbraquept	27, 33, 36, 37
Kerebiji	Umbraquept	27, 31, 34, 37
Deep colluvial soils	Haplumbrept	5, 18, 21, 22, 27, 37, 38
Gleyed humic brown clay soils		
Unclassified		12
Tambul	Umbraquept to Umbrandept	6, 7, 17, 21, 22, 24, 27, 28, 31, 35, 37, 38
Winjaka	Haplumbrept to Dystrochrept	17, 22, 24, 26, 27, 31, 35, 38
Humic brown clay soils		
Unclassified		12
Kwakanigl	Haplumbrept	5, 37
Daulo	Umbrandept to Haplumbrept	1, 3, 5, 7, 8, 9, 11, 14, 17, 18, 19, 20, 23, 24, 25, 26, 29, 31, 34
Ogelbeng	Umbrandept, Haplumbrept, some profiles Dystrochrept, Ochrandept	5, 6, 7, 8, 9, 11, 13, 14, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 31, 35

TABLE 11 (*Continued*)

Soil Group* and Family	Probable Equivalent Great Group in 7th Approximation	Land Systems† in which Soil Occurs
Humic brown and red latosols		
Wandi	Umbrustox!	8, 11, 13, 17, 19, 20, 29, 30
Singa	Umbrudox to Ochrudox	5, 7, 8, 13, 17, 18, 20, 24, 27, 28, 29, 31
Bidnimin	Umbrudox to Ochrudox	5, 7, 8, 11, 17, 18, 24, 27, 28, 29, 31
Merima	Umbrudox to Ochrudox	5, 7, 8, 20
Lateritic and gleyed latosols		
Kerowil	Umbrudox to Ochrudox	5, 7, 8, 13, 16, 17, 28, 29, 31, 34
Minj	Umbraquult	16, 17, 18, 21, 26, 27, 28, 29, 30, 32
Ombun	Mostly Plintochrult	5, 6, 7, 8, 11, 13, 16, 19, 20, 24
Gitunu	Mostly Plintumbrult	5, 7, 13, 17, 19, 24, 27, 28, 30, 32
Lithosols	Hapludent to Haplumbrept	4, 5, 7, 8, 9, 13, 15, 16
Meadow soils		
Mengendi	Argaquoll, Ochraqualf	7, 16, 19, 20
Mombol	Argaquoll, Umbraqualf	8, 13, 17, 19, 20, 27, 29, 31, 32, 33, 34, 36, 37, 38, 39
Kuli	Haplaquoll	7, 8, 13, 14, 17, 19, 28, 30, 32, 33, 34, 36, 37, 38
Kudjil	Haplaquoll	17, 22, 24, 28, 29, 30, 31, 34
Meadow podzolic soils		
Omahaiga	Plintaquult	13, 17, 27, 29, 30, 34, 36, 37
Banz	Umbraquult	7, 8, 16, 17, 20, 27, 28, 31, 32, 33, 34, 35, 36, 37
Korn	Umbraquult	27
Miscellaneous land types		
Rock outcrop	—	1, 2, 6, 8, 10, 11, 12, 15, 24, 27
Rubble land	—	1, 19
Alluvial land	—	12, 22, 27, 28, 29, 30, 32, 33, 37
Organic soils		
Unclassified		2, 29
Gumanche	Histosol order	24, 35, 39
Gogimp	Histosol order	13, 17, 21, 22, 23, 26, 27, 28, 31, 34, 35, 38, 39
Gia	Histosol order	13, 19, 23, 34, 35, 37, 38
Rendzinas		
Unclassified		15
Elimbari	Rendoll	8, 10, 11

* Soil groups are arranged in alphabetical order.

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

The fact that many soil families were observed only in the Goroka–Mount Hagen area or only in the Wabag–Tari area does not necessarily mean that they are restricted to these areas. The very broad reconnaissance surveys on which these reports are based are unlikely to cover the total variability in soils.

(b) *Soil Distribution and Formation*

The land system map, together with the land system descriptions and Table 11, presents a picture of the distribution of the soil families.

TABLE 12

SOIL FAMILIES* AND THEIR APPROXIMATE EQUIVALENTS IN THE WABAG–TARI AREA

Goroka–Mount Hagen Family	Wabag–Tari Equivalent
Medium-textured alluvial soils	*Medium-textured recent alluvial soils*
Fine-textured alluvial soils	*Fine-textured recent alluvial soils*
Pinde	*Wapu*
Tomba and Pompameiri	Dibibi
Kummel	*Muriraga*
Deep colluvial soils	*Tupisanda*
Tambul	*Klareg*
Winjaka	*Meriunda*
Daulo	Tabunaka
Ogelbeng	Wapenamanda and Vakari
Singa	*Nenja*
Bidnimin	Kutubu
Merima	*Herep*
Mengendi	*Tibiri*
Mombol	*Laiagam*
Banz	Tumundan and Pumakos
Gumanche	*Kiakau*
Gogimp	*Tirriraga*
Gia	*Mango*
Elimbari	Kaijende

*Names are printed in italics where families in the two areas are so similar that they could possibly be merged into one.

The approximate and simplified distribution of the major soil groups is presented on a small-scale map by arranging the land systems into groups of broadly similar soil contents. The reference of this map is arranged as far as possible in order of increasing soil development on consolidated rocks, and its latter half in order of decreasing soil development and increasing poor drainage on unconsolidated sediments and peats. Thus the mapping units in the middle of the legend (associations 11–16) are those with the greatest degree of soil development. The approximate areas of the major soil groups and their distribution over the soil associations of the small-scale map are summarized in Table 13. The areas listed are only intended to show the order of magnitude.

TABLE 13

APPROXIMATE AREAS OF MAJOR SOIL GROUPS AND THEIR DISTRIBUTION IN THE SOIL ASSOCIATIONS OF THE SMALL-SCALE SOIL MAP

Major Soil Group	Approx. Area (sq miles)	Distribution of Soil Group over Numbered Mapping Units				
		Dominant (> 50%)	Dominant–Subdominant	Subdominant (15–50%)	Subdominant–Minor	Minor (< 15%)
Alluvial soils	110		19	18		16, 17, 20
Alpine peat and humus soils	270	3		2, 4		11
Black earths	1					1
Colluvial soils	1140	5, 6		7, 8, 9		1, 2, 13, 16, 20
Dark colluvial soils	30					11, 16, 17, 18
Gleyed humic brown clay soils	25			20		11, 12
Humic brown clay soils	1400	11	5	3, 4, 7, 8, 12, 15	6, 10, 16	2, 9, 18, 20
Humic brown and red latosols	260			10	6, 8, 12, 16	7, 9, 11, 13, 15
Lateritic and gleyed latosols	370			9, 12, 13	6, 8	7, 11, 14, 15
Lithosols	130			1, 3		5, 6, 8
Meadow soils	200		17	14, 15, 16, 18	9, 13, 19	6, 8
Meadow podzolic soils	200	14		13, 15, 17	12, 18	6, 8, 20
Miscellaneous land types	50			1, 2	10, 18	5, 14, 16
Organic soils	75	20		19		2, 9, 11, 16, 18
Rendzinas	15			10		

As in most parts of New Guinea, and notwithstanding the wet and warm climate, strongly weathered soils (humic brown and red latosols, lateritic and gleyed latosols, meadow podzolic soils) are relatively uncommon. This generally can be ascribed to the youthfulness of the land forms. For instance the frequency of occurrence of unstable slopes in hilly and mountainous areas is reflected in the very large extent of colluvial soils which are of a regosolic nature, formed on unstable slope mantles of weathered rock. However, as a result of the rapidity with which weathering proceeds in this climate lithosols are scarce and are only present in significant amounts on the highest, coldest mountain summits and on hills in the driest part of the area south and south-east of Goroka. Climatic factors, particularly temperature, could be a factor contributing to the scarcity of strongly weathered soils, since these are virtually restricted to altitudes below 7000 ft. Also probably because of wetness, these soils are generally less red and have better-developed topsoils than their counterparts in the New Guinea lowlands.

Largest in extent are the humic brown clay soils. Occurring on stable hill and mountain slopes and well-drained plains on virtually every consolidated and unconsolidated rock type in the area except mudstone, these soils approach the concept of zonal soils in the area (Haantjens and Rutherford 1967). Their brown colours and well-developed dark humic topsoils are probably the result of the wet climate and relatively low temperatures. The accumulation of organic matter increases with increasing altitude, whilst weathering decreases. Thus a gradual transition exists towards the alpine peat and humus soils, which in New Guinea occur exclusively in this and other highland areas and in extreme instances consist of shallow peaty horizons overlying almost fresh bed-rock. The contrast in climate within the area is reflected in the soil cover by the contrast between these organic alpine soils and the black earths, which occur sporadically in the driest and relatively low part of the area near Henganofi. The black earths are formed only on rather basic volcanic rocks, but the important effect of climatic factors on their formation is suggested by the fact that the rainfall records of Henganofi display a degree of seasonality similar to that of Port Moresby, situated in the only area in New Guinea where black earths are common and where these are similarly associated with lithosols on steep hill slopes.

In terms of major soil groups, there is on the whole little evidence of strong influence of rock type on soil formation. The rendzinas on limestone are an outstanding exception to this rule, as is the absence of humic brown clay soils and humic brown and red latosols on mudstone. Soils on this slowly permeable parent material are generally gleyed and belong to the meadow soils, meadow podzolic soils, and lateritic and gleyed latosols, depending on the degree of weathering and waterlogging. The frequency with which gleyed soils occur on flat land could again be attributed to the wet climate, but slow permeability of the parent materials is probably a more important factor. This is suggested by the mudstone example above as well as by the fact that gleyed soils are particularly common on the fine-textured fan and lacustrine deposits derived mainly from sedimentary rock in the Wahgi and Asaro valleys, but are much rarer on the more permeable volcanic ash plains and fanglomerates derived largely from igneous rock.

An important difference between the soil pattern of this area and that of most lowland areas is the very small extent of alluvial soils. By far the greater portion of valley-fill sediments was laid down in late Pleistocene times, probably following the strong orogenetic movements in the Plio–Pleistocene, and possibly climatic changes connected with late Pleistocene glaciation. These older alluvia have been subjected to soil-forming processes and undifferentiated alluvial soils are now largely restricted to narrow flood-plains of incised rivers. The common occurrence both of high flood-plain terraces with, in places, dark colluvial soils and of organic soils in back swamps further suggests that sedimentation is not vigorous at the present time and the landscape as a whole is now more stable than that of most lowland areas. By far the largest area of alluvial soils and organic soils occurs in the western Wahgi valley. This is probably caused by the blocking of the original western exit of the valley by the volcanic ash deposits from Mt. Hagen (see Part III).

II. Soil Morphology

The following descriptions give brief accounts of the environmental conditions, main profile characteristics,* organic matter contents, and field pH of the soils, and an assessment of their water regime. Detailed profile descriptions of soil families and sampled profiles together with analytical data are available on request from the Division of Land Research.†

(a) *Alluvial Soils*

These soils are more than 4 ft deep, of varying texture (commonly stratified) and drainage status without pedogenetic horizon differentiation, except slight to moderate development of an A_1 horizon and gleying when poorly drained.

The alluvial soils are the predominant soils of flood-plains and low terraces along the major rivers and occur also in depressions in hilly areas and older higher depositional surfaces. They occur at altitudes between 500 and 8000 ft and support mainly gardens and garden regrowth, dry and swamp grassland, and stream-bank vegetation.

(i) *Coarse Medium-textured Soils.*—These are more or less stratified soils with loam to clay loam upper horizons and sand to sandy clay loam subsoils. The colour generally varies between dark brown and olive-brown. The soils have a low to moderate organic matter content, and a field pH of 6–6·5, generally uniform with depth. The soils are rapidly permeable and mostly well drained, occasionally imperfectly drained. Water-tables below 3 ft depth were observed in a few instances.

(ii) *Medium-textured Soils.*—These soils have a uniform texture of sandy clay loam to light clay, or consist of clay upper horizons merging into sandy loam to gravelly clay loam with depth. The colour is either dark yellow-brown to light olive-brown or, in poorly drained profiles, grey and brown mottled. The organic matter content is low to moderate. The field pH is 6–6·5 but may decrease to 5·5 in the

* The descriptions are based on the terminology set out in the soil survey manual (United States Department of Agriculture 1951). Colour names use the terminology of the Munsell soil colour chart and refer to the moist condition.

† CSIRO Aust. Div. Land Res. tech. Memo. No. 69/5 (unpublished).

subsoil. Whilst the permeability appears to be moderate, the drainage status ranges from very poorly to well drained, mainly due to variations in topographic position and water-table.

(iii) *Fine-textured Soils.*—These soils have a plastic clay to heavy clay subsoil and mostly coarser-textured (sandy clay loam to clay) upper horizons. Some subsoils are gravelly clay. The colour is mostly brown-grey to green-grey with distinct mottles, but browner layers may occur towards the surface. The organic matter content is generally low, occasionally moderate. The field pH usually increases from 6 in the topsoil to 6·5–7 in the subsoil. The soils are slowly permeable and swampy to poorly drained. Water-tables are normally found between the surface and 3 ft in depth.

(*b*) *Alpine Peat and Humus Soils*

Occurring in the high mountains above 7000 ft and up to 13,000 ft these are undifferentiated to moderately weathered soils characterized by very dark colour and strong accumulation of organic matter.

(i) *Pinde Family.*—These alpine peat soils occur between 11,000 and 13,000 ft under alpine grassland on very gentle to steep slopes.

They are shallow ($1\frac{1}{2}$–$2\frac{1}{2}$ ft) dark-coloured very wet clayey peat to peaty clay loam soils overlying hard or weathered rock or morainic sand or silt. The field pH decreases with depth from 6 to 5·5. The soils are moderately permeable and have nil to moderate run-off depending on slope. They are poorly to very poorly drained.

(ii) *Tomba Family.*—This family occurs between 7000 and 12,000 ft on igneous rocks and volcanic tuff and ash mostly on steep, but also on gentle slopes. The vegetation is forest and alpine grassland with some sword grass and shrub regrowth near the lower limit.

These are normally $1\frac{1}{2}$–$2\frac{1}{2}$ ft deep very dark grey-brown to dark red-brown friable loam to clay loam soils very rich in organic matter. They overlie more or less weathered compact volcanic ash or weathered coarse-grained rock. The field pH of the dark soil is usually 5–5·5, that of the weathered ash 6–6·5. The soils are rapidly permeable. Although they occur on steep slopes run-off is only low to moderate under forest. The soils are well to imperfectly drained.

(iii) *Pompameiri Family.*—These soils occur between 7000 and 12,000 ft on varying slopes on igneous and volcanic rocks under a vegetation of forest and, rarely, alpine grassland.

They are normally moderately deep (3–4 ft) brown very friable sandy clay loam soils with thick (10–20 in.) dark brown loam to clay loam topsoils rich in organic matter. The field pH is 6–6·5 and commonly 5–5·5 below 3 ft depth. Rapidly permeable, the soils are well drained and have low to very low run-off.

(*c*) *Black Earths*

(i) *Limisate Family.*—Developed on colluvium derived from volcanic rocks these soils occur only very locally on gentle slopes under a grassland vegetation in the driest part of the area near Bena Bena at an altitude of about 5500 ft.

The soils range in depth from shallow ($1\frac{1}{2}$ ft) to deep (>4 ft) and are very plastic cracking heavy clays, black in the upper part, dark grey in the lower part. The field pH ranges from 6·5 to 7·5. The soils are very slowly permeable, have moderate run-off, and are mostly poorly drained although they dry out in the dry season.

(d) *Colluvial Soils*

The colluvial soils are essentially regosolic soils occurring on unstable slope mantles affected by soil creep and superficial slumping. Although the soil material may be moderately weathered, little soil formation *in situ* has taken place.

(i) *Sandy Soils*.—Occurring over a wide altitudinal range (5000–11,000 ft) and consequently under greatly differing vegetation (grassland, gardens and garden regrowth, forest, alpine shrubbery), these soils are found mostly on igneous rock and locally on sandstone. They also occur on gentler slopes on gravelly colluvial deposits.

The soils are moderately deep to deep (3–$>$ 4 ft) and consist of yellow-brown stratified sandy clay loam to loamy sand, or gravelly clay loam. A dark brown topsoil moderately rich in organic matter varies in thickness from almost nil to more than 1 ft. The field pH is 6 in the topsoil, 5–6 in the subsoil. The soils are mostly rapidly permeable, have low to moderate run-off, and are well to excessively drained.

(ii) *Brown Soils*.—This family is extensive on unstable steep to very steep slopes on metamorphic and sedimentary rocks, with the exception of mudstone. Occurring between 5000 and 9000 ft it is most common in the lower part of this range. The vegetation is grassland, gardens and garden regrowth, and forest.

These are moderately deep to deep (3–$>$ 4 ft) soils overlying strongly fragmented rock. The texture varies, within the family as well as within individual profiles, from sandy clay loam to heavy clay but is mostly silty clay to clay. Varying amounts of weathered rock fragments are usually present either in bands or throughout and increasing with depth. The colour is patchy brown to brown-yellow. A dark brown topsoil, moderately rich in organic matter, varies in thickness from almost nil to 1 ft. The field pH is 5·5–6·5 in the topsoil and ranges widely from 4·5 to 6·5 in the subsoil. The soils are mostly moderately permeable and have moderate to high run-off. They are well to excessively drained.

(iii) *Mottled Soils*.—These soils occur generally in small pockets on metamorphic and sedimentary rocks, mostly on moderate slopes in re-entrants but occasionally also on salients. They are also found on dissection slopes in stratified Pleistocene deposits. Occurring between 5000 and 7000 ft, they have a vegetation of grassland (commonly of a wet type) and forest.

These are usually rather shallow ($2\frac{1}{2}$–3 ft) irregular soils in which a normally 4–10 in. thick dark firm clay topsoil, poor to moderately rich in organic matter, overlies a very firm to very plastic grey and brown mottled clay to heavy clay layer, which merges into a brown firm to plastic sandy clay subsoil with weathered rock fragments, overlying weathered rock. The field pH is 5·5–6 in the topsoil, 5–6·5 in the subsoil. The soils are slowly permeable and have high run-off. They are poorly drained.

(e) *Dark Colluvial Soils*

These soils consist of colluvial deposits found mostly in depressions, valley floors, and along the outer edges of river terraces. They are characterized by dark colours, probably because much of the soil material has been derived colluvially from topsoils on nearby slopes. Most of these soils have drainage deficiencies of varying degrees.

(i) *Kummel Family*.—This family occurs locally in depressions in very clayey fan plains and river terraces at 5000–5300 ft. The vegetation is mainly *Phragmites* swamp and *Themeda intermedia* tall grassland.

These are very dark grey brown-mottled very plastic heavy clay soils more than 4 ft deep and with 1–2 ft thick blackish friable to plastic clay loam to clay topsoils rich in organic matter. The subsoils become grey below 33–> 40 in. depth. The field pH is 5·5–6 in the topsoil and 5 (in one case 7) in the subsoil. The permeability of the dark upper part of the profile is moderate, that of the grey subsoil very low. Run-off is very low to nil and the soils are poorly to very poorly drained. A water-table is usually found above 4 ft depth and may occur very close to the surface.

(ii) *Kerebiji Family*.—Occurring locally in depressions on colluvial fans or on river terraces between 5000 and 6000 ft, this family is covered by *Phragmites* swamp and *Ischaemum* grassland. These soils have 2–> 3 ft deep irregular profiles of dark-coloured clay to sandy clay loam, rich to very rich in organic matter, overlying stony or sandy substrata. The field pH is 6–6·5. The soils are moderately permeable and have water-tables at depths between the surface and 32 in. They are swampy to moderately drained. Run-off is nil.

(iii) *Deep Colluvial Soils*.—These soils occur locally on colluvio–alluvial deposits near larger rivers and on river terraces at 4500–5500 ft under a vegetation of sword grass and shrub regrowth, grassland, and garden regrowth. These deep (4 ft and more) soils with irregular profiles may be black to very dark grey-brown to a considerable depth (> 3 ft) or much thinner topsoil may overlie a dark brown, strong brown, brown, or olive-brown and in some cases dark grey horizon which is again underlain by a dark brown to black buried topsoil. Some yellow-brown to strong brown mottles occur in some subsoils. Within the family the texture varies from loam to heavy clay and it also often varies significantly within one profile. The soils are mostly friable to very friable, but fine-textured subsoils are firm and slightly plastic. There may be layers with gravel or stones scattered through the soil. The field pH is 5·5–6·5 throughout the profile. The soils are moderately permeable, run-off is low to very low, and the soils are well to imperfectly drained.

(f) *Gleyed Humic Brown Clay Soils*

This group comprises moderately weathered soils developed in Pleistocene alluvial deposits, derived mainly from volcanic ash and igneous and metamorphic rock. They have well-developed very dark topsoils and are slightly gleyed as evidenced by pale brown to pale olive colours and some mottling directly below the topsoil or in the deeper subsoil.

(i) *Tambul Family.*—Occurring between 5000 and 7000 ft (mostly at the higher elevations) these soils are found on Pleistocene plains and fans, upper dissection slopes of these, and on some colluvial foot slopes of hills. The vegetation is mainly sword grass and shrub regrowth, also grassland, and gardens and garden regrowth.

These are deep (> 4 ft) light brown-grey to pale brown and more or less mottled friable to firm clay to sandy clay loam soils with normally 1–2 ft thick black to dark grey friable clay loam topsoils rich in organic matter. The field pH of some profiles is about 6, of others 5–5·5. The soils are moderately to slowly permeable, have low to moderate run-off, and are imperfectly to poorly drained.

(ii) *Winjaka Family.*—This family occurs on gentle to steep slopes of dissected Pleistocene alluvial deposits mainly at about 7000 ft altitude, locally lower. The vegetation is mostly sword grass and shrub regrowth.

These are deep soils (> 4 ft) in which a normally $1\frac{1}{2}$–$2\frac{1}{2}$ ft thick black to very dark brown friable loam to clay loam topsoil with a high amount of organic matter overlies a dark brownish firm to plastic clay layer, which at a depth between 25 and 45 in. merges into a pale brown to pale olive, sometimes mottled, plastic sandy clay to clay subsoil. The field pH usually ranges from 5·5 to 6·5, but may drop to 4·5 in the deeper subsoil. The soils are moderately to slowly permeable and have moderate to low run-off. They are imperfectly drained.

(*g*) *Humic Brown Clay Soils*

Humic brown clay soils are the most common soils in the area and occur over a wide range of rock and land form types. They are moderately to strongly weathered friable soils of dark brown to strong brown colour and characterized by well-developed contrasting very dark topsoils.

(i) *Kwakanigl Family.*—This family occurs only rarely, and at greatly varying altitude, on remnants of old river terraces. The vegetation is forest or gardens and garden regrowth. These are yellow-brown firm sandy clay to clay loam soils with 14–16 in. thick black to dark brown topsoils rich in organic matter and merging at depths between 30 and 40 in. into grey and brown mottled somewhat plastic clay to sandy clay. The field pH is 6–6·5. The soils are moderately permeable, have low to very low run-off, and are imperfectly drained apparently because of rather high water-tables.

(ii) *Daulo Family.*—This important family occurs mostly on igneous rocks and Pleistocene colluvium and alluvium derived thereof, and on volcanic tuff and ash. Locally it occurs also on metamorphic rocks, limestone, and coarse-textured sedimentary rocks. It is most typically and extensively developed under forest in steep mountainous country between 7000 and 10,000 ft but it occurs also below this altitude, mostly under forest or sword grass and shrub regrowth but also under garden regrowth and grassland.

These deep (4 ft or more) very friable dark brown clay loam to clay soils have a very dark brown loam to clay loam topsoil rich to very rich in organic matter but of strongly variable thickness (normally 8–20 in.). The field pH is usually 5·5–6·5 in the topsoil and 6–7 in the subsoil, often decreasing to 5–5·5 below 30–40 in. depth.

These soils have a rapid permeability and low run-off under forest even on very steep slopes. They are well drained.

(iii) *Ogelbeng Family*.—This is the most widely distributed soil family in the area and is the predominant soil type on gentle to moderately sloping Pleistocene volcanic ash deposits. It also occurs frequently on the little-dissected parts of Pleistocene alluvial fans and is a component of the soil pattern of nearly all mountainous and hilly areas where it is most common on igneous rocks and coarse-grained metamorphic and sedimentary rocks but not found at all on mudstone. Occurring mainly between 5000 and 8000 ft, but up to 9500 ft on some broader ridge crests, it is covered by a range of vegetation communities, mostly sword grass and shrub regrowth and forest but also grassland and gardens and garden regrowth.

These are deep (4 ft or more) friable yellow-brown to strong brown clay to clay loam soils with black to dark brown topsoils rich in organic matter but of very variable thickness (normally 6–15 in.). Thick topsoils are most common on gentle slopes and on steeper slopes at higher elevations. A number of profiles, particularly on lava and agglomerate, have poorly developed topsoils but a dark brown deeper subsoil. A number of other profiles have paler and slightly mottled subsoils and thick topsoils (1–2 ft) and are somewhat imperfectly drained. The field pH is usually 5–6·5 and is normally lowest in the deeper subsoil. The soils are moderately to rapidly permeable. Run-off is normally low. The soils are well drained.

(*h*) *Humic Brown and Red Latosols*

This group includes strongly to very strongly weathered clayey soils of firm consistence and with brown to reddish colours and normally with moderately to well-developed dark friable topsoils. The soils tend to have a fine blocky structure. These soils occur on a wide variety of rock types and over a wide altitudinal range but are most common at lower elevations and generally restricted to gently sloping older land surfaces and crests of ridges and spurs.

(i) *Wandi Family*.—This family occurs between 5000 and 7000 ft on limestone slopes and locally on hill crests of metamorphic and sedimentary rocks as well as on Pleistocene alluvial and colluvial fan deposits. The vegetation is mostly grassland, gardens, and garden regrowth.

These are deep (4 ft and more) dark brown firm to very firm heavy clay soils with 5–24 in. thick black to dark brown friable or firm clay topsoils rich in organic matter. The subsoils tend easily to become sticky and plastic. The field pH is mostly 6–7 throughout the profile but decreases to 5·5 in a few profiles. The soils have a moderate permeability and run-off is apparently moderate to low. They are well drained.

(ii) *Singa Family*.—Occurring between 5000 and 6500 ft this family has a wide but patchy distribution in low mountainous and hilly areas of many rock types (but excluding mudstone) and on Pleistocene colluvial and alluvial fans. It is commonly confined to gentle slopes and ridge crests. The vegetation is mostly grassland and gardens and garden regrowth, rarely forest.

These are deep (4 ft and more) firm to very firm strong brown heavy clay soils with normally 8–15 in. thick black to dark brown friable clay topsoils high in organic matter. The field pH is 6–6·5 in the topsoil and 4·5–5·5 in the subsoil but in a few cases 6–6·5 throughout the profile. The soils appear to have a moderate permeability. Run-off varies greatly with slope and vegetation, being high on grassland slopes and low on forested slopes and flatter areas. The soils are well drained.

(iii) *Bidnimin Family*.—This family occurs, always locally, on gentle to steep back slopes of limestone ridges, on undulating to rolling parts of Pleistocene alluvial and volcanic deposits (in the latter case at lower altitude on the oldest deposits far from the eruption centres), and on lower crests and basal slopes of sedimentary and metamorphic hills. The vegetation is mostly grassland, locally gardens and regrowth. The altitude is 4800–7000 ft but profiles above 6000 ft have been observed only on limestone.

These are deep (4 ft and more) firm to very firm heavy clay soils with dark friable clay topsoils up to 12 in. thick and poor to moderately rich in organic matter. The subsoils are usually brown in the upper part and always red in the lower part. The field pH is 6–6·5 in the topsoil and usually decreases to 5·5 and even 4·5 in the subsoil. The soils have a moderate permeability, mostly high run-off, and are well drained.

(iv) *Merima Family*.—This family occurs only very locally, on spur crests on intrusive and metamorphic rocks, under forest, sword grass, and shrub regrowth or grassland. It was found between 6000 and 9000 ft.

These are deep (> 4 ft) dark brown very friable clay loam soils with thin (normally 3–4 in.) very dark grey-brown topsoils and underlain at depths between 22 and 29 in. by red firm to very firm silty clay to heavy clay. The field pH of the upper two horizons is mostly 6–6·5, of the red subsoil 4·5–5·5. The soils have a rapid permeability, low to moderate run-off, and are well drained.

(*i*) *Lateritic and Gleyed Latosols*

These soils are strongly to very strongly weathered with a clay texture and mostly firm to plastic consistence. They have either layers very rich in iron–manganese concretions or strongly red, brown, light grey mottled horizons, or both. A well-developed dark friable topsoil is the rule. The soils are largely confined to the large valleys and low hills below 6000 ft.

(i) *Kerowil Family*.—This family occurs on almost flat to rolling Pleistocene alluvial deposits and on rounded low sedimentary hills. The vegetation is grassland, gardens, and garden regrowth and the altitude mostly 5000–5500 ft.

These are deep (> 4 ft) brown firm and often somewhat plastic heavy clay to clay soils with normally 8–20 in. thick black to dark brown friable clay topsoils rich in organic matter. They have a layer, usually 10–20 in. thick and usually beginning at a depth of 5–14 in. below the surface, which contains a high to very high amount of hard to firm black to brown concretions. The field pH is 6–6·5 in the topsoil and decreases gradually to 4·5–5·5 in the deeper subsoil. The soils are moderately permeable and have very low to medium run-off. The layer with concretions appears to have a disrupting effect on the growth of roots and the movement of water in the soil. Depending on the development of the concretion layer and the thickness of topsoil above it, the soils are well to excessively drained.

(ii) *Minj Family*.—This family occurs mostly on flat to gently undulating surfaces and surface remnants of Pleistocene alluvial fans and locally in flat low areas of volcanic ash deposits. The vegetation is grassland, gardens, and garden regrowth and the altitude is 4800–5300 ft.

These are deep ($>$ 4 ft) soils with a normally 10–20 in. thick black topsoil very high in organic matter overlying a normally 12–22 in. thick very light grey, red and brown mottled layer of plastic smooth heavy clay which merges very gradually into a brown firm to friable clay subsoil at a depth between 22 and 44 in. A 9–23 in. thick layer with high to very high amounts of black, brown, and red iron concretions begins in the lower part of the topsoil and continues in the upper part of the light grey plastic clay layer. The field pH is usually 6–6·5 in the topsoil and 4·5–5·5 in the brown subsoil. The permeability is slow because of the compactness of the plastic clay layer. Surface run-off is nil to very low but lateral movement of water over the plastic clay layer is probably considerable. These features, combined with the obstruction of root penetration offered by the concretionary and compact horizons, tend to make these soils poorly to very poorly drained in wet periods and somewhat excessively drained in dry periods.

(iii) *Ombun Family*.—Having a wide but patchy distribution between 5000 and 7000 ft, these soils have developed on fine-textured sedimentary rocks and are found mainly on crests and moderately steep lower slopes in hilly to low mountainous areas. The vegetation consists of grassland and locally forest.

These are usually more than 4 ft deep red, brown and grey mottled firm to plastic clay to heavy clay soils with a normally 4–16 in. thick very dark grey-brown to brown friable clay loam to clay topsoil moderately rich to poor in organic matter. The field pH is 6–6·5 in the topsoil and usually 4·5–6 in the subsoil. The soils are slowly permeable and usually have high run-off. Although imperfectly drained, they are commonly liable to rapid drying out in the dry season.

(iv) *Gitunu Family*.—Occurring mostly between 5000 and 5500 ft, these soils are found commonly but patchily on rounded ridges and rises of dissected Pleistocene alluvial deposits as well as on gentle lower slopes of sedimentary and metamorphic hills. The vegetation is grassland, locally gardens and garden regrowth.

These are deep (4 ft and more) strongly yellow-brown, red and often light grey mottled firm to plastic clay to heavy clay soils with a normally 8–20 in. thick black to dark grey-brown friable clay to clay loam topsoil high in organic matter. The soils contain high to very high amounts of red, brown, and black hard concretions, beginning at a variable depth (1–18 in.) and extending downwards to a depth which varies from 10 to 40 in. Several profiles, particularly those in the Wahgi valley, contain considerable amounts of rock gravel. The field pH is strongly variable but usually ranges from 5·5 to 6·5. The permeability appears to be moderate to slow and run-off to vary from low to high depending on slope. Although the soils are imperfectly drained, most are liable to rapid drying out during the dry season.

(*j*) *Lithosols*

These are residual soils with less than 12 in. of soil material overlying more or less weathered dense parent rock. The soils are mostly poor in organic matter, have a high run-off, and are excessively drained. Shallow black soils on limestone are excluded from this group. Lithosols are particularly common in the dry hill zone south-east of Goroka but occur scattered throughout the hilly and mountainous areas, mainly on lower spurs and foothills.

(*k*) *Meadow Soils*

Meadow soils include slightly to moderately weathered, distinctly grey to dark grey, brown-mottled plastic clay soils that are weakly acid and have well-developed dark topsoils, commonly less clayey and more friable than the subsoils. These soils are common on slumped mudstone hills and sub-Recent alluvial plains, mostly below 5500 ft.

(i) *Mengendi Family*.—This family is exclusively developed on mudstone and occurs on gentle to steep slopes under a vegetation of grassland and locally gardens and garden regrowth at an altitude of 4500–6000 ft.

These are usually shallow to moderately deep (2–3 ft) strongly grey and brown mottled plastic heavy clay soils with a normally 7–12 in. thick very dark grey-brown to grey-brown friable to firm clay to clay loam topsoil poor to moderately rich in organic matter. The soils overlie angularly fragmented weathered mudstone. The field pH is 6–6·5 in the topsoil, 5–6 in the subsoil, and variable in the weathered rock. The soils are very slowly permeable and run-off is usually high. The soils are poorly to very poorly drained, but on steeper slopes may quickly become moisture-deficient during dry spells.

(ii) *Mombol Family*.—Occurring between 5000 and 5500 ft, these soils are found on alluvial plains and terraces, in depressions and valley floors, on colluvial aprons and concave lower slopes, and on benched dissection slopes in fine-textured Pleistocene alluvial deposits. The vegetation ranges from moist grassland to *Phragmites* swamp but locally consists of gardens and garden regrowth.

These are deep (> 4 ft) grey strongly brown mottled very plastic heavy clay soils with normally 10–20 in. thick black to very dark grey friable to firm and plastic clay topsoils high to very high in organic matter. The field pH is 6–6·5 throughout the profile, mostly 6 in the topsoil and mostly 6·5 in the subsoil. The soils are slowly permeable and run-off is nil to low. Water-tables ranging in depth from very close to the surface to 3 ft below are commonly found. The soils are mostly poorly to very poorly drained, locally swampy.

(iii) *Kuli Family*.—These are common soils on river terraces, approximately 10 ft above river level, but also occur widespread on colluvially disturbed dissection slopes of Pleistocene alluvial deposits. The vegetation is grassland (commonly *Ischaemum*) and locally gardens and garden regrowth. The altitude is 5000–5500 ft.

These are more than 4 ft deep light grey to dark grey or green-grey strongly brown mottled firm to plastic clay to sandy clay soils with normally 12–23 in. thick black to very dark grey often brown mottled friable to firm clay loam to clay topsoils rich in organic matter. The subsoil can also be gravelly clay or sandy clay loam. The field pH is usually 5·5–6 in the topsoil and 6–6·5 in the subsoil. The soils are moderately permeable. Run-off is very low to nil. The soils are poorly to very poorly drained. Water-tables between 2 and 3 ft depth are occasionally found.

(iv) *Kudjil Family*.—These soils occur locally on colluvially disturbed dissection slopes and colluvial foot slopes in Pleistocene alluvial deposits and, rarely, on river terraces.

These are more than 4 ft deep moderately brown and grey mottled firm to very firm clay to heavy clay soils with a normally 6–15 in. thick black to very dark grey-brown topsoil rich in organic matter. The field pH is 6 in the topsoil and usually 5–6 in the subsoil. The soils are slowly permeable and have low run-off. They are moderately to poorly drained.

(*l*) *Meadow Podzolic Soils*

This group includes strongly weathered light grey and mostly prominently brown to red mottled plastic clay soils with well-developed coarser-textured friable very dark topsoils. Iron–manganese concretions can be present in large amounts. Although the subsoils are mostly acid to strongly acid, profiles with a weakly acid reaction throughout are also common. These soils are restricted to altitudes below 5500 ft where they occur on sub-Recent to Pleistocene fine-textured alluvial, colluvial, and volcanic ash surfaces and locally on mudstone ridge crests.

(i) *Omahaiga Family*.—This family occurs widely between 5000 and 5500 ft on older river terraces, in depressions, and on remnants of Pleistocene fan surfaces, as well as on gentle foot slopes of sedimentary hills and dissected old alluvial deposits. The vegetation is gardens and garden regrowth and various types of grassland.

These soils are more than 4 ft deep and consist of light grey plastic clay to heavy clay with brown to red mottles. They normally have a 10–20 in. thick very dark topsoil of friable clay loam to clay rich in organic matter. Black and brown concretions are plentiful, mostly concentrated in a 7–20 in. thick subsurface horizon. The field pH is 6–6·5 throughout or decreases to 4·5–5·5 in the subsoil. The soils appear to be moderately to slowly permeable, have low to very low run-off, and are poorly drained. Water-tables above 3 ft depth were occasionally observed.

(ii) *Banz Family*.—Occurring between 5000 and 5500 ft, these soils are common on older alluvial plains and river terraces and are also found on colluvial slopes associated with sedimentary ridges and dissected Pleistocene deposits and, rarely, on mudstone ridge crests. The vegetation is grassland, commonly of a wet type.

These are deep (> 4 ft) light grey but strongly brown mottled very plastic heavy clay soils with black to dark grey friable to plastic clay topsoils (normally 9–22 in. thick) rich to very rich in organic matter. The field pH is usually 6 in the topsoil and varies from 5 to 6·5 in the subsoil. The soils are slowly permeable and run-off is low to nil. The soils are poorly to very poorly drained. Water-tables above 3 ft depth are not uncommon.

(iii) *Korn Family*.—These soils have developed on alluvial plains derived from volcanic ash. They occur at about 5300 ft and have a vegetation of grassland with local sword grass and shrub regrowth.

These are more than 4 ft deep very light grey variably brown to red mottled heavy clay soils with 20–34 in. thick dark very friable clay loam topsoils very rich in organic matter. A thin browner clay horizon may be present between topsoil and subsoil.

The field pH decreases from 6 in the topsoil to 4–4·5 in the deeper subsoil. The soils have moderate permeability and very low run-off. They are imperfectly drained.

(*m*) *Miscellaneous Land Types*

This group refers to surface materials that cannot be properly classified as soils, due to lack of weathering or instability of the land surface.

(i) *Rock Outcrop*.—This consists of areas of outcropping hard bed-rock and is virtually confined to alpine mountains, limestone ridges, and lavas.

(ii) *Rubble Land*.—This is land of which more than 90% of the surface is covered by boulders, stones, and gravel. Its occurrence is confined to the summit area of Mt. Wilhelm and to rare large landslides in mudstone areas.

(iii) *Alluvial Land*.—This consists of mostly sandy or gravelly very recent alluvial deposits in the river flood-plains. It is normally vegetated but is strongly liable to flooding and subject to changes caused by shifting of the river channels.

(*n*) *Organic Soils*

This is a group of swamp soils ranging from almost raw peat to well-decomposed peaty clay of varying depth. Occurring over a rather wide range of altitude, these soils support typical swamp vegetation communities.

(i) *Gumanche Family*.—This family occurs in *Phragmites* swamps with locally open water at an altitude of 5000 to 7000 ft.

These soils consist of dark brown open-textured poorly decomposed peat apparently mainly derived from *Phragmites*. This may be more than 4 ft thick or merge at about 2 ft depth into mixtures of soft clay, roots, and organic residue, or into black clayey peat to peaty clay. Soft clay layers can also be found within the raw peat. The soils are rapidly to moderately permeable. Run-off is nil. They are swampy with water-tables permanently at or above the surface.

(ii) *Gogimp Family*.—This family occurs in swamps, usually with a vegetation of sedges and wet grasses but locally with *Phragmites*, at an altitude of 5000–9000 ft.

These are black to very dark brown well-decomposed close-textured peat to peaty clay soils underlain at depths of 3–>7 ft by green-grey to grey-brown sandy clay loam to heavy clay. The field pH ranges from 5 to 6·5. The deep-lying peat will locally become extremely acid (pH 2·5) upon drying. The soils are moderately permeable but locally contain slowly permeable clay layers. Run-off is nil. The soils are swampy and have a water-table between 1½ ft and the surface. Where drained the topsoils gradually lose their peat characteristics and become very friable highly organic soils.

(iii) *Gia Family*.—This family occurs, often in association with the Gogimp family, in wide swamps and locally on swampy flood-plains, low terraces, and colluvial seepage hollows. The vegetation consists of sedges, wet grasses, or *Phragmites*. It occurs at altitudes from 5000 to 9000 ft.

These soils consist of normally $1\frac{1}{2}$–3 ft thick black friable to plastic and sticky peaty clay loam overlying different kinds of alluvial subsoils, usually grey to grey-brown in colour and ranging in texture from sandy loam to heavy clay. The field pH is 5·5–6 in the peaty layers and 6–6·5 in the alluvial subsoil. The soils are moderately permeable and run-off is nil. In many profiles a water-table is found between the surface and 36 in. depth. The drainage status is usually poor to very poor. When drained the peat begins to lose its typical characteristics and becomes a very friable highly organic soil.

(*o*) *Rendzinas*

(i) *Elimbari Family*.—Occurring between 6000 and 9000 ft, these soils are restricted to massive limestone, where they are found on gentle to very steep slopes, commonly in association with much rock outcrop. The vegetation is forest and gardens and garden regrowth.

These are very shallow (< 1 ft) soils of black very friable and granular clay sharply overlying and tonguing into hard limestone. The soils are rapidly permeable, have little or no run-off, and are well to excessively drained.

III. Soil Analytical Data

Ranges in the values of some chemical properties are given in Table 14 for those soil families of which samples were collected.

(*a*) *Granulometric Composition*

No data for granulometric composition are included in Table 14 because in many cases dispersion difficulties led to completely anomalous results. Some soils, clearly clays in field texture, yielded only very little clay (as little as 1%) but up to 90% fine and coarse silt (2–20 μ and 20–50 μ) in the granulometric analysis after oven-drying. The difficulties were greatest in Pompameiri family (alpine peat and humus soils), all gleyed humic brown clay soils and humic brown clay soils, Singa and Merima families (humic brown and red latosols), and Kerowil family (lateritic and gleyed latosols). All of these are predominantly brown soils. Results were less anomalous in Bidnimin family (humic brown and red latosols), Ombun family (lateritic and gleyed latosols), Mengendi family (meadow soils), and Omahaiga and Korn families (meadow podzolic soils). Discrepancies varied from very small to very large in Minj family (lateritic and gleyed latosols), Kuli family (meadow soils), and Gogimp family (organic soils). On the other hand, apparently normal results were obtained for the alluvial soils, for Pinde family (alpine peat and humus soils), black earths, brown colluvial soils, Mombol family (meadow soils), and Banz family (meadow podzolic

TABLE 14

RANGES OF SOME CHEMICAL PROPERTIES OF SOIL FAMILIES

Analyses by Royal Tropical Institute, Amsterdam. Topsoil range 0–16 in., subsoil 12–30 in., deeper subsoil below 30–40 in.

Soil	No. of Obs.	pH 1:5	Base Satn. (%)	C.E.C. (m-equiv. %)	Exch. K (m-equiv. %)	P_2O_5 HCl (p.p.m.)	P_2O_5 Truog (p.p.m.)	Total N (%)	Organic C (%)
Alluvial soils combined									
Topsoil	2	4·8–6·2	56–69	23–25	0·5–1·0	N.d.	24–60	0·2–0·3	2·7
Subsoil	2	5·2–6·6	59–84	14–24	0·2–0·3	N.d.	30–54	0·1	1·0–1·4
Alpine peat and humus soils									
Pinde family									
Topsoil	1	5·8	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	12·6
Subsoil	1	5·2	6	64	1·1	N.d.	12	0·5	21·0
Pompameiri family									
Topsoil	2	5·0	17–28	41–46	0·4–0·7	N.d.	4–8	0·8–0·9	10·0–13·1
Subsoil	1	5·2	11	31	0·1	1500	4	0·3	4·2
Deeper subsoil	1	5·6	46	11	0·2	2100	N.d.	N.d.	0·2
Black earths									
Limisate family									
Topsoil	1	6·4	98	50	0·5	N.d.	20	0·3	3·6
Subsoil	1	7·2	100	55	0·1	100	8	0·02	0·3
Deeper subsoil	1	7·4	N.d.	N.d.	N.d.	300	N.d.	N.d.	N.d.
Colluvial soils									
Brown soils									
Topsoil	1	5·0	36	72	0·4	N.d.	14	0·6	7·8
Subsoil	1	5·4	19	20	0·6	1100	0	N.d.	N.d.
Gleyed humic brown clay soils									
Tambul family									
Topsoil	4	4·8–5·6	2–15	42–71	0·7–1·0	N.d.	2–14	0·4–0·9	5·4–12·0
Subsoil	4	4·6–5·4	5–13	19–25	0·3–0·4	N.d.	12–14	N.d.	0·8–1·8
Winjaka family									
Topsoil	1	5·2	6	42	1·9	N.d.	0	0·6	5·5
Subsoil	1	4·8	N.d.	N.d.	N.d.	N.d.	4	N.d.	N.d.

Humic brown clay soils									
Daulo family									
Topsoil	5	5·2–6·0	5–29	39–58	0·3–2·1	N.d.	0–20	0·6–1·3	7·2–17·4
Subsoil	3	5·4–6·0	6–13	35–36	0·1	800	0	N.d.	2·8–4·7
Deeper subsoil	1	4·4	11	22	0·2	900	N.d.	N.d.	0·3
Ogelbeng family									
Topsoil	9	4·6–6·0	3–40	29–54	0·3–0·6	N.d.	0–10	0·4–1·0	4·4–14·8
Subsoil	8	4·6–5·4	7–17	18–35	0·1–0·5	600–700	4–18	0·1–0·3	0·8–5·0
Deeper subsoil	6	4·4–6·0	2–13	19–49	0·3–0·5	1000–1900	N.d.	N.d.	0·5–3·6
Humic brown and red latosols									
Singa family									
Topsoil	1	6·6	62	24	0·9	N.d.	12	0·4	3·6
Subsoil	1	6·0	32	19	0·4	N.d.	2	N.d.	0·6
Bidnimin family									
Topsoil	2	5·2–6·4	43–60	24–27	0·1–0·7	N.d.	0–18	0·2–0·3	3·3
Subsoil	2	4·6–6·8	30–100	17–21	0·1–0·4	700–1600	0	N.d.	0·4–1·1
Merima family									
Topsoil	1	4·8	7	44	0·4	N.d.	N.d.	0·9	10·9
Subsoil	1	5·8	6	23	0·1	1100	0	0·3	2·7
Deeper subsoil	1	4·8	21	11	0·1	1200	N.d.	N.d.	0·1
Lateritic and gleyed latosols									
Kerowil family									
Topsoil	2	6·0–6·2	45	31	0·2	N.d.	0–6	0·3	3·8–5·3
Subsoil	2	6·4	31	23	0·1	2900	0–2	0·1	1·0–1·2
Deeper subsoil	2	6·2–6·4	37	21	0·1	6500	N.d.	N.d.	0·3
Minj family									
Topsoil	2	5·2–6·0	45	31	0·6	3900	8–20	0·3–0·4	4·1–5·1
Subsoil	3	5·0–6·2	36	20	0·2	1800	2–12	0·1	0·4–1·4
Deeper subsoil	2	4·8–6·0	25	20	0·1	1200	0–16	N.d.	0·1
Ombun family									
Topsoil	1	5·0	49	25	0·5	N.d.	10	0·3	3·4
Subsoil	1	5·4	47	19	0·5	500	12	0·02	0·4
Deeper subsoil	1	4·4	29	35	0·2	600	8	N.d.	N.d.

TABLE 14 (*Continued*)

Soil	No. of Obs.	pH 1:5	Base Satn. (%)	C.E.C. (m-equiv. %)	Exch. K (m-equiv. %)	P_2O_5 HCl (p.p.m.)	P_2O_5 Truog (p.p.m.)	Total N (%)	Organic C (%)
Lateritic and gleyed latosols (*continued*)									
Gitunu family									
Topsoil	1	6·0	37	20	0·4	N.d.	2	0·3	4·3
Subsoil	1	6·2	45	8	0·2	N.d.	8	N.d.	0·4
Meadow soils									
Mengendi family									
Topsoil	1	5·2	73	23	0·5	N.d.	14	0·2	2·2
Subsoil	2	4·6–5·2	76	22	0·3	400–1200	4	N.d.	0·6
Mombol family									
Topsoil	2	5·2–5·4	44	34	0·3	N.d.	8–54	0·4–0·5	4·5–5·9
Subsoil	2	4·8–6·4	44–72	16–25	0·3	N.d.	2–48	N.d.	0·3–0·4
Kuli family									
Topsoil	3	4·8–6·4	38–85	22–35	0·4–0·5	N.d.	8–28	0·2–0·4	2·7–6·0
Subsoil	3	4·8–6·8	49–100	10–13	0·2	900	0–14	0·1	0·4–0·6
Meadow podzolic soils									
Omahaiga family									
Topsoil	3	4·4–6·2	37–42	24	0·4	N.d.	12–28	0·2–0·6	2·5–6·3
Subsoil	4	5·2–6·8	N.d.	N.d.	N.d.	N.d.	2–14	0·05	0·04
Banz family									
Topsoil	2	5·0–5·2	39–69	26–29	0·4–0·5	N.d.	8–34	0·4–0·6	3·8–6·9
Subsoil	2	5·0–5·2	53–88	24–27	0·5–0·7	1100	10–14	N.d.	0·4
Korn family									
Topsoil	1	5·4	7	46	0·3	N.d.	8	0·3	5·7
Subsoil	1	5·4	40	18	0·3	600	50	N.d.	0·2
Organic soils									
Gogimp family									
Topsoil	2	5·4–5·6	32	19	0·5	N.d.	24	0·5–1·0	11–19
Mineral subsoil	1	5·6	N.d.	N.d.	N.d.	N.d.	N.d.	0·1	4·0
Deeper subsoil	2	2·4–5·6	6	28	0·8	N.d.	0	0·6	13·7–22·2

soils). The cause of the difficulties must be sought in irreversible aggregation of clay upon oven-drying, but it is not clear why certain samples react differently from others, sometimes within the same profile.

Sand fractions (50–2000 μ) are generally small: 28% of the samples has $< 1\%$ sand, 42% has 1–4·9%, 10% has 5–9·9%, 15% has 10–19·9%, and 5% has 20–37% sand. In half of this last category the sand consists mainly of iron concretions. Nearly all soils are rich in silt and several soils that were assessed as heavy clays in the field appear to have only 40–60% clay but 30–50% silt. In most cases textural differences between major groups and families are not great, and the marked variation in consistence appears to be mostly related to differences in gleying, microstructure, and organic matter content.

(b) *pH, Base Saturation, and Cation Exchange Capacity*

(i) *pH.*—The data show that except for the black earths there is no consistent relationship between pH and soil family. In general, pH appears to be related mostly to climatic factors, decreasing westwards and with increasing altitude, increasing towards the valley bottoms and particularly in the drier eastern half of the region, notably in the Bena Bena area where rainfall is lowest. Higher pH was also observed in the western part of the area in soils derived from calcareous rocks.

(ii) *Base Saturation.*—As expected, there is a general correlation between pH and base saturation, but with quite a few exceptions in individual samples. Base saturation is lowest in the alpine peat and humus soils, gleyed humic brown clay soils, humic brown clay soils, and organic soils, and highest in the black earths, alluvial soils, and meadow soils, although in the last it is only fractionally higher (as is pH) than in the meadow podzolic soils. Base saturation is strongly variable in the humic brown and red latosols. It is commonly unexpectedly high (as is pH) in these and in the lateritic and gleyed latosols considering the advanced state of weathering. This is probably due to the fact that the flatter stable land surfaces, on which these soils mostly occur, are most common in the lower, drier parts of the area, particularly in the east.

(iii) *Cation Exchange Capacity.*—Cation exchange capacity is generally high to moderately high, which is caused partly by high organic matter contents but in the case of black earths by 2 : 1 lattice clays. The high figures confirm that the low clay contents obtained during granulometric analysis are indeed unreal. In view of the apparent influence of organic matter on the C.E.C., the figures for the organic soils are unexpectedly low. The lowest C.E.C. values occur in the humic brown and red latosols, but they are still higher than is normal for this kind of soil. The highest values for C.E.C., in the humic brown clay soils, are in soils developed on volcanic ash and probably due to amorphous clay minerals. Poor crystallinity of clay minerals may well be a general factor causing the rather high C.E.C. values throughout.

(c) *Potash, Phosphorus, Organic Matter, and Nitrogen*

(i) *Potash.*—Contents of exchangeable K are generally satisfactory, the highest values occurring in the alluvial soils, alpine peat soils (Pinde family), gleyed humic brown clay soils, and some humic brown clay soils (Daulo family). The potash content appears to be correlated with parent rock rather than with soil type, the highest values having been recorded in soils developed in Mt. Giluwe volcanic ash.

(ii) *Phosphorus*.—In no instance are contents of "total" phosphorus very low, and in some cases they are very high. However, the generally low to very low amounts of "available" phosphorus suggest that deficiency of this nutrient is widespread. The only soils that appear not to be deficient are the alluvial soils and the Mombol family of the meadow soils. In view of the great differences between "total" and "available" phosphorus, fixation of this element appears to be particularly strong in many of the alpine humus soils, humic brown clay soils, humic brown and red latosols, and lateritic and gleyed latosols. In some profiles "available" phosphorus is lower in the topsoil than in the subsoil, indicating strong fixation to organic matter. Again there appears to be a regional difference in phosphorus content, since consistently higher values for "available" phosphorus are found in the Wahgi valley between Korn and Minj, as compared with the remainder of the area.

(iii) *Organic Matter and Nitrogen*.—Topsoil organic matter contents ($1 \cdot 7 \times \%$ organic carbon) are mostly high and tend to increase with increasing rainfall, from east to west and from low to high. Some high-altitude humic brown clay soils have such high amounts of organic matter that they come within the range of peaty soils. In the alpine humus soils, humic brown clay soils, and the Merima family of the humic brown and red latosols the organic matter content decreases only gradually with depth in the profiles. In the other soils, particularly those that have gleyed subsoils, there is a sudden decrease below the topsoil. The organic matter contents of the organic soils are much lower than expected.

In two-thirds of the samples of mineral soils the nitrogen content follows the organic matter content fairly closely (C : N ratios between 10 and 15), but in some cases of both topsoils and subsoils it is either relatively high (C : N ratio of $6 \cdot 7$–$9 \cdot 7$) or relatively low (C : N ratio between 15 and 20). Peaty layers of alpine peat soils and organic soils have C : N ratios between 22 and 42. Nowhere in the area are the soils seriously deficient in nitrogen, although its availability may be low where the C : N ratio is very high (mineralization) or very low (fixation).

(*d*) *Clay Minerals*

X-ray data* of many of the residual mineral soil families suggest that their clays are dominated by varying proportions of poorly crystalline kaolin and metahalloysite, and commonly some goethite. Kaolin is rather consistently dominant only in the humic brown and red latosols whilst metahalloysite tends to be dominant in the meadow soils. In the alpine humus soils, gleyed humic and humic brown clay soils, lateritic and gleyed latosols, and meadow podzolic soils there is either codominance of kaolin and metahalloysite or kaolin is dominant. One profile of the humic brown clay soils was dominated by gibbsite with some vermiculite, whilst illite was present in another one. The only soil family with a radically different clay mineralogy is Limisate (black earths) with illite and montmorillonite codominant. It seems reasonable to

* Analyses carried out by Royal Tropical Institute, Amsterdam.

expect from later work (Rutherford and Haantjens 1965; Haantjens and Rutherford 1967) that allophane will be characteristic for humic brown clay soils derived from volcanic ash, and probably also for alpine humus soils, although this is not revealed in the available X-ray data.

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PART VII. VEGETATION OF THE GOROKA–MOUNT HAGEN AREA

By R. G. Robbins*

I. General

(a) Classification and Distribution of Vegetation Communities

The classification and naming of the vegetation communities in the Goroka–Mount Hagen area follows closely that employed for the adjoining Wabag–Tari area (Robbins and Pullen 1965), although there are differences in the communities present. A minor alteration is that lower montane grassland has been named montane grassland in this report. The classification is presented in Table 15 together with a list of the numbers of the land systems in which each community was observed.

No vegetation map was prepared but a reasonable picture of the distribution of the most important communities may be obtained from the map of forest resources and land use intensity.

(b) Ecological Controls

The principal controls in the distribution of the vegetation are climate (Robbins 1963), drainage, and human interference. These cannot always be clearly separated from one another.

In view of the generally high rainfall and uniform temperatures it may be assumed that forest constituted the original natural vegetation over almost the whole of the area, although no rain forest in the true sense may have been present in the driest part of the area near Henganofi. This forest shows a clear altitudinal zonation (Robbins 1958) governed by decreasing temperature and increasing cloudiness, but not necessarily increasing rainfall, and expressed in marked structural and floristic changes (Fig. 8). Below 3000 ft occurs lowland rain forest which in the area is found only on the lower north-eastern slopes of the Bismarck Range and which is not considered as an integral part of the vegetation pattern of this highland area. A broad zone of lower montane rain forest occurs between 3000 and 9000 ft. This forest is both structurally and floristically less complex than the lowland rain forest. In general this forest is still mixed (Plate 7) and, in places, rich in conifers (Plate 3, Fig. 2) but two simpler types are also found: the oak forest (*Castanopsis*, *Lithocarpus*) occurring between 3000 and 7500 ft, and the beech forest (*Nothofagus*, Plate 8) occurring between 7000 and 9000 ft.

From between 9000 to 10,000 and up to 12,000 ft there is montane rain forest which is markedly different in aspect from the lower montane rain forest. The altitudinal variations are probably caused by local variations in exposure to cloud and wind, in temperature gradients, and in edaphic conditions. At still higher altitudes

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TABLE 15

CLASSIFICATION, NOMENCLATURE, AND DISTRIBUTION OF VEGETATION COMMUNITIES IN LAND SYSTEMS

Vegetation Community	Land Systems (by Number) in which Community is Mentioned
Forest and scrub	
Lowland rain forest	
Lowland hill forest	5
Lower montane rain forest	
Oak forest	7, 14, 18
Beech forest	6, 7, 8, 10, 11, 13, 14, 24
Mixed forest	4, 5, 6, 8, 9, 14, 18, 23, 24, 25
Montane rain forest	1, 2, 3, 4
Subalpine woody communities	
Subalpine forest	1
Subalpine scrub	1, 2, 23
Remnant woody communities	
Remnant and secondary forest	5, 9, 12, 16, 20, 27, 28, 29, 30, 31, 32, 33, 35, 36
Stream-bank vegetation	7, 12, 16, 17, 18, 20, 22, 27, 28, 29, 30, 32, 33, 34, 35, 36, 37, 38, 39
Swamp vegetation	
Swamp grassland	
Phragmites swamp	5, 13, 17, 19, 20, 21, 22, 24, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39
Leersia swamp	21, 22, 35
Herbaceous bog communities	
Alpine peat bog	1, 2, 23
Grass–sedge bog	27, 34, 35
Sedge bog	21, 22, 26, 27, 35
Dry grassland	
Natural grassland	
Alpine grassland	1, 2
Montane grassland	23
Induced grassland	
Capillipedium grassland	7, 8, 9, 11, 13, 15, 16, 17, 18, 19, 20, 21, 24, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38
Themeda grassland	5, 7, 13, 15, 16, 17, 19, 24, 26, 29, 33
Ischaemum grassland	7, 8, 13, 15, 16, 17, 19, 20, 21, 24, 27, 28, 29, 30, 32, 33, 34, 36, 37, 38
Themeda intermedia tall grassland	29, 36, 37
Secondary vegetation	
Sword grass and shrub regrowth	5, 6, 8, 9, 11, 12, 14, 18, 22, 24, 25, 26, 27, 28, 29, 30, 31, 35
Gardens and garden regrowth	5, 6, 7, 8, 9, 11, 14, 17, 18, 19, 20, 22, 24, 27, 28, 29, 31, 32, 34, 35, 36, 37, 38

montane forest merges into subalpine forest and scrub (Plate 9) which is usually confined to the most sheltered positions.

One of the few environments that is not likely ever to have had a forest vegetation comprises the mountain summits above 12,000 ft (Hoogland 1958). These areas above the tree line are covered with alpine tussock grassland (Plate 3, Fig. 1), merging

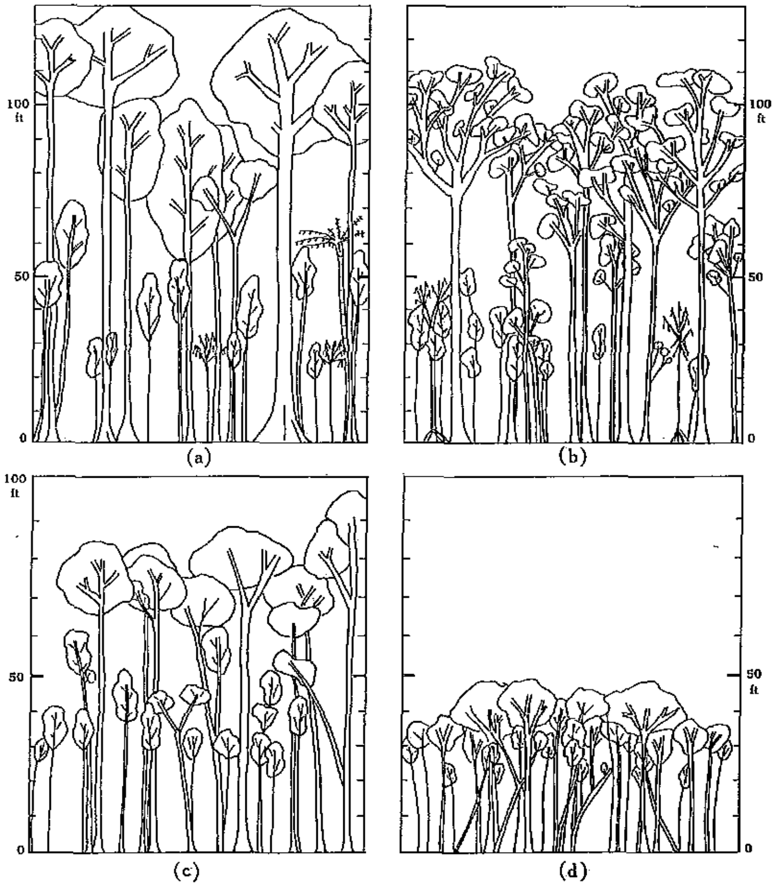

Fig. 8.—Profile diagrams of rain forest types: (*a*) lowland rain forest below 3000 ft above sea level, with three tree layers; (*b*) tall beech forest at 8000 ft, with two tree layers; (*c*) mixed lower montane rain forest at 8000 ft, with two tree layers; (*d*) single-tree-layered montane rain forest at 9500 ft.

into herb fields and bare rock at 14,000 ft (Plate 4, Fig. 1). Naturally treeless areas also occur in a few broad valleys at about 9000 ft, where montane grassland may owe its existence primarily to the influx of cold air into the valleys. Both montane and alpine grassland, however, appear to have been modified by man-made fires.

The effect of man on the vegetation has been considerable throughout the lower parts of the area (Robbins 1960, 1961). In many places the forest edge has been pushed back to about 8000 ft (Plate 1, Fig. 1), the limit of productive sweet-potato growing, the main subsistence crop in the area. This has led in particular to large-scale destruction of the oak forest zone of which only small remnants are left (Plate 10, Fig. 1). In contrast to the New Guinea lowlands where shifting cultivation generally results in extensive areas of woody garden regrowth and secondary forest, agricultural occupation in the Goroka–Mount Hagen area has caused the formation of extensive grassland but little secondary forest. This can be attributed partly to the more intensive methods of land clearing and cultivation (Plate 10, Fig. 2) and partly to the much slower natural regeneration of forest in the colder climate. On well-drained land tall *Miscanthus* sword grass and shrub regrowth (Plate 6, Fig. 1) occur as successional secondary communities, but in many places these have been converted to stabilized disclimax short grassland of the *Capillipedium* and *Themeda* types (Plate 11, Fig. 1) as a result of continued cultivation and burning. Besides the intensity and duration of such human interference, climatic and edaphic factors have a large influence on the rate of change from tall to short grassland. Thus short grasslands are particularly common in the drier eastern part of the area (Plate 5, Fig. 1), in the lower warmer parts of the Baiyer River and Nebelyer River plains, and in areas of steep hill slopes and shallow or physically poor soils. *Themeda* grassland in particular appears to be indicative of physiologically dry sites.

In contrast to the general destructive influence of man on the forest vegetation is the increasing custom of planting *Casuarina* trees on fallow land (Plate 2, Fig. 1), particularly in the Chimbu–Chuave area. Thus areas of short grassland are gradually acquiring a more wooded appearance.

Since poorly drained land is very largely restricted to the lower valleys where the vegetation is strongly influenced by man, it is not easy to separate these two controls on the vegetation. *Ischaemum* grassland is almost certainly an induced community confined to wet poorly drained sites. It probably never went through the intermediate stage of tall sword grass and shrub regrowth. Similarly, some grass–sedge bog and sedge bog may be of a secondary nature, since it is common to find tree trunks in the soil and remnant bog forests were found in the adjoining Wabag–Tari area (Robbins and Pullen 1965). On some of this land, forest destruction could have been caused by cultivation but in other instances the forests may simply have been used for fuel and timber.

Whilst the sedge swamp communities are found on stable sites with stagnant water (Plate 6, Fig. 1) mostly fed by seepage water of probably low nutrient status, *Phragmites* swamp occurs mainly on less stable land with flood-plain characteristics (Plate 6, Fig. 2) and fed by less stagnant and probably richer river water. In view of this, it seems likely that *Phragmites* swamp is largely a rather seral natural community. Another natural swamp community is subalpine to alpine peat bog found in depressions above 11,000 ft.

Field observations have provided relatively little evidence for lithological or land form control over the vegetation, apart from the indirect influence of land form on drainage conditions. Limestone country appears to be generally associated with beech forest, although the reverse does not hold. Sword grass and shrub regrowth appear to be a particularly stable community on volcanic ash deposits and well-drained fan deposits. Over-steepened mountain slopes (>40°) are commonly characterized by more irregular and scrubby types of forest, undoubtedly due to the instability of such slopes. Similar vegetation occurs on landslide scars.

II. Description of Vegetation Communities

(a) *Lowland Rain Forest*

(i) *Lowland Hill Forest.*—Occurring only on the lower slopes of the Bismarck Range along the Ramu River, this forest is not a part of the highland vegetation pattern and has not been investigated in the field during this survey. It is a tall three-layered rain forest of mixed composition (Fig. 8(*a*)). A more detailed description is given in the Gogol–Upper Ramu area* where it has been named *Intsia bijuga–Pometia pinnata–Celtis* association. It is associated with lowland garden regrowth and secondary forest.

(b) *Lower Montane Rain Forest*

(i) *Oak Forest.*—Confined to altitudes below 7500 ft, only small areas of this forest type remain, as a result of widespread forest clearing for land cultivation.

Oak forest is a two-tree-layered forest with a canopy layer of large spreading crowns at 80–90 ft and an under-storey layer of trees reaching between 30 and 50 ft. Oak species, particularly *Castanopsis acuminatissima* and *Lithocarpus*, dominate the canopy while species of *Cryptocarya*, *Elaeocarpus*, *Garcinia*, *Gordonia*, *Nothofagus*, and *Syzygium* may also contribute.

Trees commonly found in the second layer are *Spiraeopsis* spp., various species of *Ficus*, Myrtaceae generally and many Araliaceae, *Diospyros*, *Helicia*, *Litsea*, and *Myristica*. Also present here are *Euodia*, *Gardenia*, *Medinilla*, *Saurauja*, *Timonius*, the screw-pine *Pandanus*, and abundant climbing bamboo.

Among the many small undergrowth shrubs may be found *Ardisia*, *Dichroa febrifuga*, *Eurya*, *Geniostoma*, *Prunus*, and *Rapanea*. *Symplocos* is a common shrub together with several species of *Piper*.

The ground layer includes small herbaceous plants with mosses, liverworts, ferns, and seedlings. Recorded here are *Alpinia*, several Araceae, *Begonia* spp., *Freycinetia*, and small Palmae.

(ii) *Beech Forest.*—This forest, occurring between 7500 and 9000 ft, is common in the eastern and southern parts of the area but rare in the northern part. *Nothofagus*, of which several species are present, occurs either in pure stands in which 75% or more of the canopy consists of beech trees or as an important component in an otherwise mixed forest. Rather pure stands are common on ridge crests and occur as isolated pockets on slopes.

Beech forest is a two-tree-layered forest (Fig. 8(*b*)) with a closed canopy of spreading crowns 90–100 ft high and including the following trees: *Alphitonia incana*, *Bubbia*, *Castanopsis*, *Cryptocarya*, *Elaeocarpus* spp., *Lithocarpus*, *Nothofagus* spp., several *Podocarpus* spp., *Quintinia*, *Spiraeopsis*, *Weinmannia* and other Cunoniaceae, and *Zanthoxylum*.

The lower stratum at 30–50 ft may be richer in species but is not very dense in cover. Some of the small trees here are *Alstonia*, *Drimys*, *Euodia*, many species of *Ficus*, *Mischocarpus*, *Neuburgia*, *Nothofagus*, *Psychotria*, *Pullea*, *Rapanea* and other

* Lands of the Gogol–Upper Ramu area, New Guinea. CSIRO Aust. Div. Land Res. Reg. Surv. divl Rep. 57/2 (unpublished).

Myrsinaceae, *Schefflera*, *Sloanea*, several *Syzygium* species, *Timonius*, and *Weinmannia*. Very common members are *Helicia microcarpa*, *Medinilla*, *Pittosporum pullifolium*, *Polyosma*, *Sphenostemon papuanum*, and *Symplocos*.

Epiphytes, which are frequent, include many climbing and perching pteridophytes, the small liane *Freycinetia*, scrambling Gesneriaceae such as *Cyrtandra*, and many small orchids.

An undergrowth of small woody shrubs such as *Piper* spp. and tree ferns may be present, while tall *Pandanus* and an abundance of climbing bamboo are very characteristic features.

A ground layer includes the ferns *Blechnum* and *Hymenophyllum*, the herbs *Elatostema* and *Pilea*, together with orchids, lycopods, mosses, and seedlings.

(iii) *Mixed Forest*.—Occurring widely throughout the mountainous parts of the area, this forest is particularly extensive in the Bismarck Range. This is a forest with two tree layers (Fig. 8(*c*)), frequently with coniferous emergents and with a dense tall shrub layer. On unstable very steep slopes and along broken limestone cliffs a stunted aspect of the forest occurs composed mainly of lower-strata trees and hardy shrubs.

Upper storey trees forming the canopy at 80–100 ft are *Aistopetalum*, *Opocunonia*, *Schizomeria*, and *Spiraeopsis*, all belonging to the Cunoniaceae and very frequent in occurrence. *Elaeocarpus* species include *E. sarcanthus*, *E. schlechterianus*, *E. sphaericus*, and *E. trichophyllus*. The genus *Cryptocarya* in the Lauraceae is well represented as are *Ficus* and *Syzygium* by their numerous respective species. Other broad-leaf tree genera are *Albizia*, *Alphitonia*, *Astronia*, *Elmerrillia*, *Fagraea*, *Galbulimima*, *Garcinia*, *Guioa*, *Ilex*, *Perottetia*, *Planchonella*, *Prunus*, *Sterculia*, and *Zanthoxylum*.

Gymnosperms are commonly represented by the following species: *Dacrydium elatum*, *D. falciforme*, *Papuacedrus papuanus*, *Phyllocladus hypophyllus*, *Podocarpus amarus*, *P. imbricatus*, *P. ledermannii*, *P. neriifolius*, *P. pilgeri*, and *P. rumphii*. Podocarps are generally present and locally common. *Phyllocladus*, while present throughout, is not a common tree. *Dacrydium falciforme* occurs as a small tree throughout the mixed forest but *Dacrydium elatum* is rare. *Papuacedrus papuanus* dominated a small area on the lower southern slopes of Mt. Hagen.

In the second tree stratum with limits between 40 to 60 ft are to be found all of the Cunoniaceae, *Elaeocarpus dolichostylus* and *E. polydactylus*, *Ficus* spp., *Gillbeea*, *Pullea*, *Spiraeopsis*, *Syzygium* spp., and *Weinmannia*, and a host of small trees such as *Ardisia*, *Carpodetus arboreus*, *Casearia pachyphylla*, *Castanopsis acuminatissima*, *Cedrela*, *Daphniphyllum gracile*, *Dillenia montana* and *D. schlechteri*, *Diospyros*, *Discocalyx*, *Eurya*, *Euodia*, *Gordonia papuana*, *Helicia microcarpa*, *Laportea*, *Litsea*, *Macaranga*, *Myristica*, *Neuburgia*, *Pittosporum pullifolium*, *Quintinia*, *Rapanea*, Sapotaceae, *Saurauja*, *Schuurmansia henningsii*, *Sericolea*, *Sloanea*, *Sphenostemon papuanum*, *Ternstroemia*, *Timonius*, and *Zanthoxylum*.

Tall shrubs are *Aglaia*, *Alstonia*, *Ascarina*, *Bubbia*, *Casearia angiense*, *Chloranthus*, *Decaspermum*, *Dichroa febrifuga*, *Geniostoma*, *Harmsiopanax aculeatum*, *Mearnsia cordata*, *Olearia*, *Rhododendron*, and *Xanthomyrtus*. *Pandanus* spp., tree ferns, *Cyathea contaminans*, *Dicksonia*, and a tall *Marattia* as well as climbing bamboo contribute to the luxuriance. Palms may be locally present.

Very frequent smaller shrubs are the Rubiaceae—*Amaracarpus, Gardenia, Mussaenda*, and *Psychotria*—while Melastomataceae have *Beccarianthus, Medinilla*, and *Poikilogyne*. Small *Prunus* spp., *Eurya* such as *E. meizophylla*, and *Symplocos*, the ubiquitous forest shrub in the highlands, are present; also *Acronychia, Euodia, Perottetia moluccana, Phaleria, Pittosporum*, and *Rhamnus javanicus*.

A rich ground flora includes *Begonia* spp., some Araceae, the sedges *Carex, Schoenus*, and *Scleria*, and the dwarf *Pittosporum sinuatum*. Three or four species of *Pilea* and *Elatostema* are particularly abundant. *Alpinia* is a common member of the Zingiberaceae with the two Rubiaceous herbs *Argostemma bryophilum* and *Ophiorrhiza*.

Several *Cyrtandra* and *Piper* spp. may be small shrubs or semi-climbers. Creeping herbs are *Nertera granadensis* and *Pratia*. The Liliaceous *Dianella* is frequent, while among the ground ferns are found *Adiantum, Asplenium, Athyrium cordifolium, Blechnum, Diplazium cordifolium, Hymenophyllum* spp., and *Leptopteris alpina*. Lycopods and a *Selaginella* also occur with an abundance of mosses and liverworts.

No large lianes are found but among small climbers and scramblers may be *Alyxia lamii*, several Bignoniaceae, *Celastrus, Clematis, Freycinetia* (two species), *Geitonoplesium cymosum*, Gesneriaceae such as *Dichrotrichum, Hoya*, a number of Monimiaceae, *Parsonsia lata, Rubus, Secamone, Smilax*, and *Strongylodon*.

Epiphytes are *Amyema* and many other Loranthaceae, *Pittosporum ramiflorum*, Santalaceae, *Schefflera*, a *Solanum* sp., and Vitaceae. Many orchids find representation here: *Appendicula, Bulbophyllum, Calanthe, Ceratostylis, Coelogyne, Dendrobium, Epiblastus, Glomera, Liparis, Octarrhenia*, and others. Ferns too are abundant, mostly as epiphytes including many Davalliaceae such as *Scyphularia*, and also *Aglaomorpha novoguineensis, Antrophyum, Belvisia, Cyclosorus superbus, Loxogramme vittariiforme, Microsorium neoguineensis, Nephrolepsis, Vittaria, Xiphopteris secunda*, and many species of *Asplenium* and *Hymenophyllum*.

(*c*) *Montane Rain Forest*

Occurring between 9000 and 11,000 ft, montane rain forest mostly has an abrupt boundary with the lower montane forest below. Reflecting the general misty conditions, mosses and liverworts are common to abundant in this forest type which is most extensive in the Kubor Range.

A single-tree-layered forest (Fig. 8(*d*)), montane rain forest is often dominated in this canopy layer by species of Myrtaceae and Podocarpaceae. The canopy is compact, 35–40 ft high, and made up of closely growing trees with commonly crooked trunks 6–9 in. in diameter, The branches and forest floor are festooned with a mass of bryophytes (both mosses and liverworts). Tree ferns are abundant here while filmy ferns of the Hymenophyllaceae grow on fallen logs and tree trunks. Leaf size is generally small and leaves coriaceous and dark green.

Broad-leaf trees belonging to the montane rain forest are *Decaspermum, Syzygium* spp., *Xanthomyrtus*, all of the Myrtaceae, with *Carpodetus major, Daphniphyllum gracile, Drimys, Elaeocarpus azaleifolius, Eurya, Prunus* and Rutaceae, *Quintinia, Rapanea* and other Myrsinaceae, *Schefflera*, and *Schuurmansia henningsii*. Gymnosperms are *Papuacedrus papuanus, Phyllocladus hypophyllus, Podocarpus brassii, P. compactus*, and *P. pilgeri*.

Among a few small shrubs may be *Amaracarpus, Coprosma, Piper, Pittosporum, Polyosma, Rhododendron* spp., *Symplocos*, and *Vaccinium*. Orchids, ferns, and bryophytes make up the ground flora which in more open glades may include *Acaena anserinifolia, Alpinia, Elatostema, Libertia pulchella, Uncinia*, and many ferns.

(*d*) *Subalpine Woody Communities*

(i) *Subalpine Forest.*—Occurring above the mist level, this forest finds but limited expression on the mountains of the Goroka–Mount Hagen area. Small patches are present above 11,000 ft on Mt. Wilhelm. Here it adjoins the alpine grassland. Subalpine forest contains species from both the montane rain forest and the subalpine scrub.

The structure of the forest is a dense canopy of tall shrubs 25–30 ft high over which stands a scattered emergent layer of coniferous trees (*Podocarpus compactus*), individuals of which may reach 50 ft in height. This is the "high mountain forest" of Lane-Poole (1925), McAdam (1951), and Womersley and McAdam (1957).

(ii) *Subalpine Scrub.*—This community occurs above the subalpine forest at altitudes about 12,000 ft above sea level and may extend as tongues and outliers into the tussock grassland. It is present on sharp crests of the Kubor Range and as an upper woody community on main mountain peaks throughout, particularly Mt. Wilhelm.

Subalpine scrub is a dense growth of shrubs and small trees up to 20 ft high. Among the many *Rhododendron* species are *R. beyerinkianum, R. hooglandii, R. keysseri, R. womersleyi*, and *R. yelliotii*. *Vaccinium* spp. are also very common. Other shrubs include *Decaspermum, Dimorphanthera parvifolia, Drimys montis-wilhelmi, D. brassii, Eurya brassii, E. pullenii, Olearia spectabilis, Pittosporum pullifolium, Polyosma, Quintinia, Rapanea, Schefflera, Sericolea, Styphelia, Symplocos, Xanthomyrtus*, members of the Rubiaceae such as *Amaracarpus, Coprosma*, and *Psychotria*, and Rutaceae. Tree ferns may also be present as are small individuals of *Papuacedrus papuanus, Podocarpus brassii*, and *P. compactus*.

Epiphytes include Loranthaceae such as *Dactyliophora* and species of the orchid genera *Bulbophyllum, Dendrobium*, and *Phreatia*. Ferns include *Grammitis locellata, Hymenophyllum foersteri*, and Polypodiaceae. Mosses and liverworts abound throughout. The ground flora includes *Belvisia, Blechnum archboldii, Polystichum*, and herbs such as *Acaena anserinifolia, Libertia pulchella, Lycopodium macgregorii, Oxalis magellanica, Rubus, Trachymene saniculifolia, Trigonotis abata*, and *T. haackei*.

Since it is agreed that the term "alpine" should be reserved for vegetation communities at least above the natural tree line and perhaps even above the "tall shrub line", this community has been erroneously named "alpine shrubbery" in Robbins (1958) and Robbins and Pullen (1965). Brass (1964) has pointed to the close affiliation of his subalpine forest and scrub, considering the latter as an aspect of the subalpine forest. Wade (1968) goes further and recognizes merely a lower and an upper subalpine forest association reaching to 12,800 ft on Mt. Wilhelm. He points out that the trees, *Podocarpus compactus* and *Rapanea vaccinioides*, continue as emergents to the limit of the "scrub" and that many of the so-called shrubs are really tree species but here reduced to a shrub form, the status thus remaining a "shrub-dominated forest".

(*e*) *Remnant Woody Communities*

(i) *Remnant and Secondary Forest.*—In this community are grouped the many small groves of trees that still persist as remnants in the more dissected country. They are more frequent in the western districts. On the whole, their affinities are with the lower oak zone of the lower montane rain forest.

Trees and shrubs frequently occurring in this community are *Aglaia*, *Ardisia*, *Castanopsis acuminatissima*, *Decaspermum neurophyllum*, *Eurya*, *Euodia*, *Ficus*, *Gardenia*, *Lithocarpus*, *Litsea*, *Maesa*, *Myristica*, *Octamyrtus pleiopetalus*, *Syzygium*, *Timonius*, and *Trimenia papuana*.

Parasitic Loranthaceae are common, including *Amyema*, *Amylotheca*, and *Dendrophthoe* as well as the epiphyte *Antrophyum*, while climbers and scramblers present are *Alyxia*, *Melothria*, *Muehlenbeckia monticola*, *Poikilogyne*, and *Scaevola*.

(ii) *Stream-bank Vegetation.*—This is a community of small trees, shrubs, and tall cane grasses fringing streams and watercourses in areas where the original forest cover has been destroyed.

Commonly occurring stream-side shrubs and trees are *Acalypha*, *Breynia*, a number of small *Ficus*, *Maclura cochinchinensis*, *Piper*, *Saurauja* spp., *Schefflera*, *Syzygium*, and *Wendlandia paniculata*. *Casuarina*, particularly *C. papuana*, frequently lines the banks of the larger rivers while from the Chimbu area eastwards *Araucaria cunninghamii* is found as a tall tree, scattered along river gorges or aggregated into small remnant groves (Plate 11, Fig. 2).

Grasses include *Coix lacryma-jobi*, *Echinochloa*, *Panicum*, *Pennisetum macrostachyum*, *Phragmites karka*, *Saccharum spontaneum*, *Setaria palmifolia*, and, in the eastern highlands, *Polytoca*.

(*f*) *Swamp Grassland*

(i) Phragmites *Swamp.*—This community occurs widely on poorly drained to swampy flood-plains and locally in very wet seepage areas. *Phragmites* forms a generally pure cover, 10–20 ft high. In places associated plants are found in and bordering the swamps: *Ischaemum digitatum*, *Leersia hexandra*, *Polygonum*, *Saccharum spontaneum*, Convolvulaceae, and Cyperaceae. Occasionally small trees such as *Ficus* and *Syzygium* are seen marking watercourses traversing the swamp.

(ii) Leersia *Swamp.*—Occurring only in small depressions in the western part of the area, this swamp community is dominated by the grass *Leersia hexandra*. The community is 1–3 ft high and includes *Isachne*, *Ischaemum*, with *Typha angustifolia*, ferns (*Blechnum*), and sedges such as *Gahnia*.

(*g*) *Herbaceous Bog Communities*

(i) *Alpine Peat Bog* (including subalpine bog).—This community is found in swampy valleys above 10,000 ft. It consists of a mixture of low bog herbs, sedges, and grasses.

Small herbs are *Astellia papuana, Drosera peltata, Gentiana piundensis, Epilobium keysseri, Haloragis microphylla, Oreomyrrhis papuana, Potentilla foersteriana, Ranunculus basilobatus, Trachymene tripartita,* and *Viola arcuata.* Among the sedges are tussocks of *Carpha alpina,* with *Scirpus crassiusculus* and *S. mucronatus, Carex capillacea, C. echinata,* and *C. gaudichaudiana.*

The grasses include *Agrostis reinwardtii, Monostachya oreoboloides, Anthoxanthum angustum, Brachypodium sylvaticum,* and *Festuca crispatopilosa.* The fern *Gleichenia vulcanica* often dominates locally while the mosses *Campylopium* and the golden-brown *Bruetelia* are common.

Wade (1968) recognized nine different "mire" communities on Mt. Wilhelm. These he divided into bogs with stagnant water and fens which are wetter and show some water movement. The fens are invariably Cyperaceae or sedge communities while the bogs are composed of grasses, ferns, and hummocks of the Liliaceous *Astelia papuana.* All are considered subalpine with the exception of one *Astelia* association which is a true alpine bog.

(ii) *Grass–Sedge Bog.*—Occurring in semi-swampy depressions and plains to 8000 ft this community consists of a distinct association of grasses and sedges, interspersed with herbs and locally dwarf shrubs. The community is 2–4 ft tall.

Characteristic grasses are *Dimeria dipteros, Isachne arfakensis,* and a *Paspalum* species. The sedges are many and commonly quantitatively dominant. Together with various swamp herbs they are generally those enumerated in the sedge bog community described below. The scattered shrubs, 2–3 ft high, include *Haloragis, Hypericum, Melastoma,* and *Styphelia.*

(iii) *Sedge Bog.*—Sedge bog occurs on swampy depressions and plains with stagnant very high water-tables at altitudes of 6000 ft and more.

Of the many different sedges, some forming tussocks up to 2 ft high, *Machaerina rubiginosa* (syn. *Cladium glomeratum*) is the most frequent and commonly forms pure stands. Others are *Carex, Cyperus globosus, C. unioloides, Eleocharis congesta, Fimbristylis, Lipocarpha chinensis, Schoenus curvulus,* and *Scirpus mucronatus.* Associated bog herbs include *Dichrocephala bicolor, Dysophylla verticillata, Eriocaulon, Gunnera macrophylla, Ludwigia, Nymphoides, Polygonum, Ranunculus, Salvia, Sparganium simplex, Utricularia, Viola,* and *Xyris.*

(h) Natural Grasslands

(i) *Alpine Grassland* (including subalpine grassland).—By definition the term alpine should be applied here only to climatic climax grasslands found above the natural tree limit. In the past Brass (1941, 1964), Robbins (1958), Robbins and Pullen (1965), and Hoogland (1958) have all loosely referred to the summit grasslands lying generally above the forested slopes of the New Guinea mountains as alpine grasslands. It has been recognized that these may well include certain downward extensions below the forest edge due to such factors as cold air drainage and biotic interference, particularly fires.

Wade (1968) has recently completed a detailed study of the grasslands of Mt. Wilhelm and has defined the alpine zone as that above 13,400 ft or above the tall

(1 metre) woody shrub limits. He found tussock grasslands as low as 10,700 ft, well below the forest limits at 12,800. Although superficially similar to primary alpine grassland of the upper altitudes, Wade points out that these grasslands are neither growing under alpine conditions nor composed of completely alpine species. They belong to a subalpine formation. He further considered that all but one of the subalpine grasslands on Mt. Wilhelm were secondary—the result of destruction of the original subalpine forest.

There is little doubt that much of the summit grasslands of New Guinea represent modified communities and that many rate only a subalpine status. There seems much to recommend the view that these subalpine grasslands constitute those in which scattered shrubs up to 2 or 3 ft in height were still present and to reserve the term alpine for grasslands of tuft or tussock grasses in which the shrubs were dwarfed to 8 in. or less. This is also the zone of the alpine heaths and tundras (Walker 1968).

The "summit grasslands", then, may consist of both secondary and primary subalpine to alpine grasslands and other mountain communities but are basically climatic climaxes above 12,800 ft above sea level. The grassland community is characterized by tussock grasses forming clumps 1 ft in diameter and some 2 to 3 ft high. In between grow smaller tuft grasses, cushion plant, mountain herbs, ferns, and matted lichens and mosses. The floristic composition of the dominants may vary from location to location, such changes expressing differences in altitude and drainage.

Common tussock grasses are *Deschampsia klossi*, *Danthonia archboldii*, *Hierochloe redolens*, and *Poa nivicola*. Smaller tuft grasses are *Agrostis reinwardtii*, *Anthoxanthum angustum*, *Danthonia vestita*, *D. penicillata*, *Deyeuxia brassii*, *Dichelachne novoguineensis*, and *Festuca papuana*.

Herbs include *Astelia papuana*, *Centrolepis philippinensis*, *Epilobium keysseri*, *Euphrasia rectifolia*, *Gentiana*, *Lactuca laevigata*, *Hydrocotyle sibthorpioides*, *Myosotis saruwagedica*, *Oreomyrrhis andicola*, *Ranunculus basilobatus*, and *Potentilla papuana* while Compositae are well represented by *Anaphalis mariae*, *A. lorentzii*, *Gnaphalium japonicum*, *Keysseria trachyphylla*, and *Tetramolopium alinae*. Among the ground ferns are *Gleichenia bolanica*, *Belvisia*, *Grammitis*, *Papuapteris* with several *Lycopodium* species, and a few sedges.

Scattered throughout the tussocks, and often locally abundant to make a scrub-tussock, are many small shrubs which may reach a height of 3 ft. These are *Coprosma divergens*, *Leucopogon suaveolens*, *Gaultheria mundula*, *Detzneria tubata*, *Drimys brassii*, *Hebe albiflora*, *Eurya brassi* var. *erecta*, *Hypericum macgregorii*, *Drapetes ericoides*, and several *Rhododendron* and *Vaccinium* spp.

Groups of small cycad-like tree ferns (*Cyathea atrox*) are characteristic of the tussock grasslands in many localities and may represent prolonged seral stages following destruction of the original subalpine woody vegetation.

At altitudes around 14,000 ft both short and tussock grassland without large shrubs are still present. Sites, however, become exposed to a more rigorous climate and the soils more rocky and shallow. Lichens and mosses play an increasing role in the vegetation. *Papuapteris linearis* dominates a fern meadow and alpine heaths, composed of low woody plants now compacted and dwarfed to a few inches, together with small sedges such as *Carex*, *Carpha*, and *Oreobolus*, are matted with the grey mountain moss *Rhacomitrium lanuginosum*. Sparse open communities of herbs, mosses, and lichens can be described as tundra. Here are found *Poa callosa, Lactuca, Ranunculus, Potentilla, Cerastium keysseri, Ischnea elachoglossa,* and *Geranium,* while the alpine moss *Andreaea* is common.

(ii) *Montane Grassland*.—This grassland occurs in open valleys at 9000–10,000 ft on the divide between the Asaro and Chimbu–Wahgi valleys and appears to be the result of frost-pocket conditions due to cold air drainage, although the community has also been affected by hunting fires.

Diagnostic here are the grasses *Arundinella furya* and *Imperata exaltata*. Others are *Agrostis reinwardtii* and *Anthoxanthum angustatum* together with the alpine grasses *Danthonia archboldii, D. vestita, Dichelachne novoguineensis,* and *Festuca papuana*.

The cover is commonly sparse. Small herbs and dwarf shrubs are characteristic, including *Gaultheria mundula, Haloragis, Hypericum macgregorii, Lycopodium, Potentilla, Rhododendron, Styphelia suaveolens,* and the fern *Gleichenia*. Tall tree ferns are common in places.

(*i*) *Induced Grasslands*

(i) Capillipedium *Grassland*.—This is by far the most extensive grassland community, occurring on hill slopes and plains under conditions ranging from moderately dry to moderately wet. Many combinations of the characteristic species occur and marked variations are commonly evident over short distances.

The community typically has a 2–3 ft high canopy of trailing and erect grasses such as *Capillipedium parviflorum, Apluda mutica, Themeda australis,* and *Sorghum nitidum,* through which small tussocks of *Arundinella setosa* and *Ophiuros exaltatus* are scattered emergents. Less frequent species are *Arthraxon hispidus, Hyparrhenia, Ischaemum digitatum, Sacciolepis indica,* and *Setaria*. *Imperata cylindrica* may be dominant locally, while among sedges, species of *Cyperus* and *Fimbrystylis* together with bracken ferns *Cyclosorus* and *Pteridium* may be frequent.

The following forbs may form ground cover associated with the grasses: *Borreria, Cassia mimosoides, Desmodium heterocarpum, D. sequax, Euphorbia serrulata, Exacum tetragonum, Ipomoea, Phyllanthus, Polygala chinensis, P. japonica, P. paniculata, P. persicariifolia, Sida, Smithia sensitiva, Urena lobata, Wahlenbergia gracilis,* and *Pueraria thunbergiana* (a long trailing vine). In the eastern highlands particularly are *Helichrysum bracteatum, Indigophora trifoliata,* and *I. hirsuta*.

Small woody herbs and shrubs are frequent. Some of the more commonly occurring species are *Crotalaria laburnifolia, C. mucronata,* and the small woody melastome *Osbeckia chinensis*. Also to be included here are *Pipturis, Pouzolzia, Triumfetta,* and occasional *Hypericum mutilum, Rhododendron macgregoriae,* and *Styphelia suaveolens*.

Small moist to wet situations show an increase in certain herbs such as *Astilbe rivularis, Centella asiatica, Dysophila verticillata, Epilobium, Equisetum debile, Floscopa scandens, Haloragis, Hydrocotyle, Juncus, Limnophila, Lindernia, Ludwigia, Mazus pumilus, Oenanthe javanica, Polygonum, Viola,* and sedges.

(ii) Themeda *Grassland*.—This is typically a community of drier sites, i.e. steep hill slopes and crests, shallow soils.

Grasses of the community are *Themeda australis*, *Arundinella setosa*, *Imperata cylindrica*, *Ophiuros exaltatus*, and, from the Chimbu area eastwards, *Eulalia leptostachys*. Many of the grassland forbs already listed in the previous community are present.

Themeda is strongly dominant on the steep hills in the western part of the area, whilst *Arundinella* is generally codominant on the gentler topography and deeper soils in the east. Small patches where *Imperata* reaches codominance generally reflect recent strong interference by man.

(iii) Ischaemum *Grassland*.—Typical for wet sites in depressions, valley floors, and at the base of colluvial slopes, this community is strongly dominated by *Ischaemum polystachyum* forming a dense cover of trailing and 3–4 ft suberect stems. Minor associated grasses are *Isachne*, *Leersia hexandra*, *Paspalum* spp., and *Sacciolepis indica*. Many of the moisture-loving herbs and sedges listed above for *Capillipedium* grassland can be present.

(iv) Themeda intermedia *Tall Grassland*.—This community is restricted to moist river terraces in the Goroka–Bena Bena area. It is dominated by 5–6 ft high tussocks of *Themeda intermedia* growing in close association with *Imperata cylindrica*. The community probably represents an induced grassland that has not yet been greatly affected by fire, and in this respect would have a status similar to that of sword grass and shrub regrowth, described below.

(*j*) *Sword Grass and Shrub Regrowth*

This community appears after initial forest clearing and is regarded as successional vegetation, which without further interference would return to forest. The succession becomes arrested by continuing mild human interference, mainly land cultivation. Continued strong interference, particularly burning, will deflect the succession towards short grassland vegetation, a process that will proceed fastest under poor environmental conditions, i.e. lower rainfall, steep slopes, shallow or physically poor soils. Hence many different phases of sword grass succession can be seen, ranging from sword grass with many forest-affiliated shrubs, through pure stands of sword grass or stands with typical grassland shrubs, to mixtures of sword grass and short grassland. The community occurs extensively in the area, particularly on the volcanic slopes and plains in the west.

The community is dominated by *Miscanthus floridulus*, a tall cane grass with sharp finely serrated leaves and typically forming a dense cover 10 ft or more high. Common regrowth shrubs found in association with the *Miscanthus* are *Acalypha*, *Antidesma*, *Breynia*, *Buddleia asiatica*, *Callicarpa*, *Dodonaea viscosa*, small *Ficus* spp., *Glochidion*, *Grevillea papuana*, *Medinilla*, *Pittosporum ferrugineum*, *P. ramiflorum*, *Rhododendron multinervium*, many species of *Saurauja*, *Schefflera*, *Schuurmansia henningsii*, *Solanum*, *Syzygium* and other Myrtaceae, *Wendlandia paniculata*, and tree ferns.

Some small trees are *Alphitonia incana*, *Althoffia pleiostigma*, *Commersonia bartramia*, *Macaranga*, *Omalanthus*, and *Pipturus argenteus*. More advanced regrowth leads to the appearance of such trees as *Carpodetus arboreus*, *C. major*, *Castanopsis acuminatissima*, *Cinnamomum*, *Dichroa febrifuga*, *Elaeocarpus*, *Eurya oxysepala*, *Sloanea*, *Spiraeopsis*, and *Pandanus*. Epiphytes include *Myrmecodia*, orchids, and ferns.

(*k*) *Gardens and Garden Regrowth*

In this community are placed all stages in the native garden cycle from current cropping to short-term fallow periods when typical garden weeds and regrowth grasses appear. Also included is herbaceous regrowth vegetation found on any disturbed ground in the inhabited areas.

Common grasses characteristic of roadside and abandoned garden plots are *Agrostis avenacea*, *Arthraxon hispidus*, *Chloris virgata*, *Digitaria violescens*, *Echinochloa crus-galli*, *Echinopogon ovatus*, *Eragrostis*, *Imperata cylindrica*, *Setaria*, and *Sporobolus*.

Garden weeds, mostly annuals, include *Alternanthera sessilis*, *Bidens pilosa*, *Blumea hieraciifolia*, *Crassocephalum crepidioides*, *Erigeron sumatrensis*, and *Sigesbeckia orientalis*.

Species of Boraginaceae and Euphorbiaceae occur with *Borreria*, *Buchnera tomentosa*, *Desmodium scalpe*, *Galium*, *Lindernia*, *Polygonum*, *Portulaca*, *Swertia*, and *Veronica*, together with ferns and sedges.

In addition to these naturally occurring weeds and regrowth plants, the community includes several planted species other than normal garden crops. Many small trees and shrubs are planted around huts and gardens for ornamental purposes, to mark boundaries, and to provide useful products. Most conspicuous are plantings of *Pandanus* with edible fruits, clumps of tall bamboo, and particularly groves of *Casuarina* trees. These groves, planted primarily for fuel supply, also appear to be beneficial for the garden fallow period, possibly by improving the potash and nitrogen status of the soils and by reducing the influx of grasses, which constitute a weed problem in gardening activities. *Casuarina* planting is on the increase particularly in the Chimbu, Kundiawa, and Chuave areas and is gradually changing the vegetation aspect of some large former grassland areas here.

III. Acknowledgments

The species lists for the plant communities described are based on over 3000 plant specimens lodged in the Herbarium Australiense, CSIRO, Canberra. The great majority of these were collected in the area during 1956 and 1957, as well as later in the Wabag–Tari area, by Dr. R. D. Hoogland, plant taxonomist, and Mr. R. Pullen, botanical collector, who also undertook the task of the identification of these specimens. The author also acknowledges the collaboration received from Mr. J. C. Saunders, forest botanist in the survey team.

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PART VIII. FOREST RESOURCES OF THE GOROKA–MOUNT HAGEN AREA

By J. C. SAUNDERS*

I. INTRODUCTION

The aim of this Part and its associated map is to describe the forest resources of the area, indicating the location and extent of forests and assigning estimated stocking rates to each forest type. The land has also been classified into access categories.

The wide altitudinal range in the area may be subdivided into four zones: lowland, below 3000 ft; lower montane, 3000–9000 ft; montane, 9000–12,000 ft; and alpine, above 12,000 ft. No forest occurs in the alpine zone. Within the lower three zones forested land covers 38 % of the area.

The present-day distribution of forest types is due primarily to two factors, climate and man. Climatic controls, affecting forest structure and floristics, are discussed further in Part VII. The anthropogenic influence, however, is far the greater. The montane zone is virtually undisturbed because of an unsatisfactory growth environment for crops. The two lower zones, considered to be once almost entirely forested, have been extensively cleared for indigenous agriculture. Clearing has been confined mainly to the valley bottoms and lower slopes of major valley systems, but where the population is or has been dense the forest has been cleared to higher altitudes and on rugged terrain. Consequently most of the remaining forest occurs on steep and rugged terrain and in the less populated areas of the Kubor and Bismarck Ranges. This is clearly shown in Table 16.

TABLE 16

LAND SYSTEMS AND AREAS WITHIN ACCESS CATEGORIES

Access Category	Area (sq miles)	Land Systems
I	225	Tari, Banz, Kinjibi, Makuntus
Is	192	Aiyura, Tambul, Kaugel, Ko, Wahgi
Ia	88	Nunga, Goroka, Minj
Ias	20	Ogu
II	480	Oga, Limisate, Abiera, Teiga, Kumun, Womei, Winjaka, Omahaiga
IIa	2957	Bismarck, Ambum, Koge, Pira, Doma, Elimbari, Lai, Yonki, Nemarep, Korambogl, Kwongi, Okapa, Birap, Moruma
III	303	Wilhelm, Kubor, Giluwe, Ialibu

Sawmills throughout the area, many of them small, are operated by government, private enterprise, and missions. Output from these mills is used locally.

Government reafforestation schemes had commenced, particularly in the Goroka area.

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II. Survey Methods

During preliminary air-photo interpretation the forests of the area were divided into types with distinct photo patterns. Sample plots, each 200×25 ft, were located in the different types except in the montane and lowland zones. The montane zone was considered to be non-commercial and the lowland zone had been sampled on a 2-acre plot sampling system during the survey of the Gogol–Upper Ramu area.* Each plot was clear-felled and measurements of total height, length and character of bole, and girth (outside bark) at breast height were taken of all trees over 15 ft in height. Where the species was unknown or doubtful, herbarium specimens together with a wood sample were collected and have since been lodged in the Herbarium Australiense, Canberra. In most cases, duplicate specimens have been sent to the Herbarium of the Department of Forests, Lae.

These plots formed the basis for the description of each forest type. However, in view of the small plot area and the variability within each forest type, data from other botanists in the survey team were included to give a more accurate description of each type. For comparison, the forest types were subsequently modified to conform with those of the adjacent Wabag–Tari area.† From the quantitative data stocking rates were estimated for each forest type, taking into consideration the representative value of each plot to the forest type.‡ These figures are a very approximate indication of timber volume and must be used with caution. Volume figures quoted were based on a form factor of 0·5 and no allowance was made for internal defect.

The map of forest types is at a scale of 1 : 300,000 and, with the exception of montane forest, includes only forests containing at least 3000 super ft per ac of standing timber from trees over 5 ft in girth.

III. Access Categories

The land systems have been divided into three major categories (I, II, and III) on the basis of dominant slope. Lower-case letters (a,s) modify some of the major categories, giving a total of seven categories.

Category I includes all land systems where the proportion of slopes less than 10° is dominant over or codominant with the proportion of slopes greater than 10°.

Category II includes all land systems where the proportion of slopes less than 30° is dominant over or codominant with the proportion of slopes greater than 30°.

Category III includes those land systems where the dominant slope is greater than 30°.

In categories I and II, where 15% or more of the slopes exceeds 10° and 30° respectively, the letter "a" follows the category symbol.

Similarly, where 15% or more of the land is swampy or subject to prolonged flooding the category symbol is followed by the letter "s".

* Lands of the Gogol–Upper Ramu area, New Guinea. CSIRO Aust. Div. Land Res. divl Rep. 57/2, 131–5 (unpublished).

† Saunders, J. C. (1965).—Forest resources of the Wabag–Tari area. CSIRO Aust. Land Res. Ser. No. 15, 116–24.

‡ Only trees over 5 ft in girth were included in assessing stocking rates.

The grouping of land systems into access categories, together with the area of each category, is shown in Table 16. Access categories closely approximate the ruggedness and maximum relief grouping shown on a small-scale map. The general distribution of access categories can be seen by consulting this map and Table 17 which shows the relationship between the two groupings.

TABLE 17

RUGGEDNESS AND MAXIMUM RELIEF GROUPINGS WITH ACCESS CATEGORY EQUIVALENTS

Ruggedness and Maximum Relief Grouping	Access Category
Very rugged	III
Rugged	IIa
Moderately rugged	II, rarely IIa
Slightly rugged	Ia, rarely II or Ias
Very slightly rugged	I, rarely Is
Non-rugged	Is, rarely I

The categories give an indication of accessibility within the area. In categories Is and III, access is difficult or even impossible because of swampy conditions in the former and very steep slopes in the latter. Category I land is readily accessible and this is generally true also for categories Ia and Ias except in their steepest parts and for the latter in its wetter parts. Categories II and IIa may present moderate difficulty only, except for the latter in its steepest parts. Existing access roads within the area are shown on the land system map.

As stated, the access categories are based on the slope characteristics of the land system as a whole. In any detailed investigation of accessibility, the land unit descriptions in the tabulated land system must be consulted. Anomalies do occur, for example, in Oga land system access category II. This land system is inaccessible due to its surrounding cliffs.

IV. Classification and Description of Forest Types

The area has been subdivided into "forest" and "other areas". For the purposes of this report, a forest is defined as containing at least 3000 super ft per ac of standing timber from trees over 5 ft in girth at breast height (or above buttresses). Stands of timber excluded by this definition have thus been included in "other areas". Montane forest is the only exception to this because of its value as a watershed protection forest. As stated in Section I, the forests of the area fall into three broad altitudinal zones: lowland, lower montane, and montane. Because of the gradual transition from one zone to another, the altitudinal limits selected are only approximate and floristic elements of one zone often penetrate deeply into another.

Within each zone the forest has been classified into types based on characteristics observable on aerial photographs, namely species dominance in the canopy and

TABLE 18

AREAS OF FOREST TYPES WITHIN LAND SYSTEMS (SQ MILES)

Land System	Access Category	Hill Forest	Irregular Hill Forest	Mixed Forest	Degraded Mixed Forest	Mixed–Beech Forest	Beech Forest	Beech–Mixed Forest	Stunted Beech–Mixed Forest	Montane Forest	Total Forest Area	Other Areas	Total Area
Wilhelm	III									29	29	36	65
Giluwe	III									2	2	6	8
Kubor	III				97					48	145	20	165
Ialibu	III			28	3	2		1		18	52	13	65
Bismarck	IIa	12	65	368	296	209	36	91		8	1085	665	1750
Ambum	IIa			20	33	16	1	35	1		106	94	200
Koge	IIa			2	16	27	3	4			52	438	490
Pira	IIa			2	4	8		1			15	95	110
Oga	*II*				3						3	0	3
Elimbari	IIa			1	8	4		3	7		23	12	35
Yonki	IIa			13	2	4					19	86	105
Nemarep	IIa			14		11		2			27	23	50
Teiga	II			1	3			3			7	133	140
Kwongi	IIa			20	10	1		4			35	10	45
Okapa	IIa				5	8		1			14	36	50
Birap	IIa			1							1	4	5
Other land *systems*	IIa–Is										0	979	979
Total area		12	65	470	480	290	40	145	8	105	1615	2650	4265

emergent layers, density, height, and other canopy characteristics. Table 18 shows the areal extent of each forest type in each land system.

(*a*) *Lowland Zone*

Lowland forest covers an area of approximately 77 sq miles and occurs on the northern slopes of the Bismarck Range along the Ramu valley. It is generally a tall forest 100–120 ft high with emergents rising to 150 ft. Occasional patches of scattered *Araucaria* occur above 2000 ft altitude.

Two forest types have been recognized in this zone: hill forest, which is more or less undisturbed, and irregular hill forest, which has a lower overall stocking rate and often includes disturbed forest.

(i) *Hill Forest* (12 sq miles).—A tall forest, 100–120 ft high with emergents to 150 ft, it has a closed canopy and mixed floristic composition. The very common species present are *Pometia pinnata*, *Intsia bijuga*, and *Celtis* spp. Boles are generally straight and clear with the exception of some *Pometia pinnata*, *Pterocarpus indicus*, and *Vitex cofassus* and range from 15 to 80 ft, but mainly from 40 to 75 ft. Girths range from 5 to 9 ft.

The estimated stocking rate for the type is 10,000 super ft per ac.

In addition to those mentioned above, the following trees were recorded: *Chrysophyllum lanceolatum*, *Cryptocarya*, *Diospyros*, *Elaeocarpus comatus*, *Ficus* spp., *Hernandia papuana*, *Microcos argentata*, *Neonauclea*, *Neuburgia corynocarpa*, *Parinari*, *Pterocymbium beccarii*, and *Sloanea*.

(ii) *Irregular Hill Forest* (65 sq miles).—This forest is in most respects similar to the previous type. It differs, however, in having a more irregular canopy layer and a greater proportion of secondary species. The stocking rate is approximately 3000 super ft per ac.

(*b*) *Lower Montane Zone*

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

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

Beech is found in the lower montane zone mainly above 7500 ft and may occur as a pure stand on ridge crests only, with mixed forest on the side slopes and in gullies, or it may cover all three sites.

Coniferous forest is found mainly above 8500 ft in areas where low temperatures and frost appear to inhibit the growth of broad-leaf species. The canopy is relatively open and is composed of typical conical crowns. Because of the small areas involved this community has also been included in the mixed forest.

In addition to floristics, density and/or height have been used as criteria to subdivide the forest into types and permit allocation of reasonably uniform estimated stocking rates.

(i) *Mixed Forest* (470 sq miles).—The mixed forest is the most extensive type in the area. It is distributed throughout the area above 3000 ft altitude but is concentrated mainly above 7000 ft. Below this level extensive areas of mixed forest have been and still are cleared for indigenous agriculture.

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

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

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

The following is a list of tree genera recorded in the mixed forest: *Ackama, Alphitonia, Alstonia, Araucaria* (L), *Ascarina* (H), *Astronia, Calophyllum, Casearia, Castanopsis* (L), *Cinnamomum, Claoxylon* (H), *Cryptocarya, Dacrydium* (H), *Dryadodaphne, Elaeocarpus, Elmerrillia* (L), *Euodia* (H), *Ficus* (L), *Galbulinima, Garcinia* (L), *Gordonia, Halfordia* (H), *Ilex* (H), *Lithocarpus* (L), *Litsea, Mallotus, Mischocarpus, Neonauclea* (L), *Neuburgia, Nothofagus* (H), *Opocunonia, Papuacedrus* (H), *Phyllocladus* (H), *Planchonella, Platea, Podocarpus, Prunus* (H), *Quintinia* (H), *Schizomeria, Sloanea, Sterculia* (L), *Syzygium, Timonius* (H), *Weinmannia* (H), *Xanthomyrtus* (H), and *Zanthoxylum* (H).

(ii) *Degraded Mixed Forest* (480 sq miles).—This type of forest is scattered throughout the area in the lower montane zone, associated with centres of population and indigenous agriculture at lower altitudes or at higher altitudes with poor site quality, particularly in Kubor and Bismarck land systems.

The forest is 60–100 ft high with an open canopy, less dense than the mixed forest type. Species composition is similar to the mixed forest. Girths are mainly 5–6 ft and the estimated stocking rate is 3000 super ft per ac.

(iii) *Mixed-Beech Forest* (290 sq miles).—The mixed–beech forest type is found throughout the lower montane zone.

It consists of a mixed forest covering more than 50% of the area occupied by the forest, the remaining area occupied by beech in pure stand. The beech forest is confined to ridge tops and the mixed forest to the side slopes and gullies. Thus the greater the ridge density, the greater is the proportion of beech forest. Each of the two components of this complex is similar to its counterpart described separately, the beech forest being commonly 20 ft higher than adjacent mixed forests.

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

(iv) *Beech Forest* (40 sq miles).—Stands of beech forest are scattered through the lower montane zone.

Beech forest consists of a pure, or almost pure, stand of *Nothofagus*, 90–100 ft high, exhibiting a pattern of compact, rounded, and more or less distinct crowns. Girths generally fall into the 5–9 ft range and the estimated stocking rate is 11,000 super ft per ac from 11 trees per ac.

Several species of *Nothofagus* are present in the area and may occur in monospecific stands or as combinations of species, the smallest leaf species occurring at higher altitudes.

Beech forest occurs mainly on the northern slopes of the Kubor Range

(v) *Beech–Mixed Forest* (145 sq miles).—This type is another complex forest found throughout the lower montane zone. In this type the beech forest covers more than 50% of the area, the remainder being covered by mixed forest. As with the mixed–beech forest, each component is similar to its counterpart already described.

Assuming a ratio of 75% beech to 25% mixed forest, the estimated stocking rate would be 10,500 super ft per ac from 11 trees per ac.

This forest occurs throughout the area but mainly in the western half.

(vi) *Stunted Beech–Mixed Forest* (8 sq miles).—This type is restricted to karst topography within the lower montane zone. The main occurrence is on the steep and rugged limestone topography of Mt. Elimbari.

The forest is 60–80 ft high with pure stands of beech on the ridges and mixed forest on slopes and gullies. Species composition is similar to the beech–mixed forest described above. The estimated stocking rate of this type is approximately 3000 super ft per ac from 11 trees per ac.

(*c*) *Montane Zone*

Montane forest covers an area of 105 sq miles and is restricted to elevations above 9000 ft. Only one type has been recognized. The main occurrences are on the Kubor Range, on Mt. Hagen, and on Mt. Ialibu. The canopy is dense and fine-textured in pattern and is generally 30–40 ft high. Emergent conifers, *Papuacedrus* and *Phyllocladus*, may be present. The trees are of small girth and twisted bole form. At the upper boundary, where the forest borders on alpine grassland, there is an alpine shrubbery or thicket up to 15 ft high. This has been included with montane forest as a mapping unit.

Although montane forest is of no commercial interest, it has a valuable function as a protection forest. The forest is above the altitudinal limit for indigenous agriculture and is therefore rarely cleared.

PART IX. POPULATION AND LAND USE IN THE GOROKA–MOUNT HAGEN AREA

By J. R. McAlpine*

I. Introduction

Over a distance of about 200 miles, the highlands of the Territory of Papua and New Guinea possess a number of major SE.–NW.-trending valleys, 2–15 miles wide. Together these contain nearly half the total population of the mainland of the Territory. Settlements occur mainly between 4500 and 7000 ft altitude, but use is also made of the associated mountain slopes to an altitude of 8500 ft. The more heavily populated eastern sections of these highlands are dealt with here. Land use in the adjoining western area has previously been mapped by McAlpine (1965).

Compared with other areas of New Guinea, a considerable amount of information is available on land use and ethnography. For land use, the reader is particularly referred to Brookfield and Brown's (1963) study of the Chimbu, to Howlett (1962) for the Asaro–Bena River area, to Bulmer (1960) for the Baiyer River area, to Salisbury (1962, 1964) for the Siane, and Hughes (1966) for the Sina Sina area. The last two authors are of further interest in that they particularly deal with land use changes resulting from economic development. The references and bibliographies in each of these works are generally exhaustive and are not repeated here. Information on ethnography and linguistics may be obtained from a recently published bibliography on New Guinea ethnography (Anon. 1968). Much of this material includes discussions of varying length dealing with land use practices.

Present subsistence land use is discussed here with emphasis on its relation to the physical environment as described in Part IV. As such, it has been designed partly to complement two papers by Brookfield (1962, 1964) which deal with aspects of land use and population in the highland areas of the whole New Guinea mainland. The first deals with the ecology of highland settlement and the environmental relationships described here add detail to Brookfield's broader treatment. His second paper, with its emphasis on comparative local studies, gives detail to both his ecological paper and this intermediate-level discussion.

The relationships derived between population, land use, and environment in this Part should not be considered in a deterministic sense; their causality is undetermined. Further, as will be seen below, the nature of the data and methods employed give only right order measures of the relationships presented at the scale employed and hence are not necessarily accurate in detail at a specific point.

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II. Population

(a) *Statistics*

Indigenous population data have been obtained from the quasi-annual censuses of those villages and groups of each administrative district which are present in the area surveyed. McArthur (1955) has dealt with the inconsistencies and qualified the reliability of these censuses, but the village population totals given are considered sufficiently reliable for the purposes of this Part. The indigenous* population is recorded as 354,000 (1962–63), the non-indigenous† as 4118 (1966).

For the districts as a whole, 41% of the population are children under 16. The percentage of males is 51 amongst children, 53 amongst adults.†

Population totals at the census division level for the period 1960–65 indicate an annual increase between 0·5 and 1·2%, a figure significantly lower than the 2–3% per annum commonly found in many lowland and island areas of New Guinea.

The indigenous population is engaged chiefly in subsistence cultivation together with some cash cropping, mainly of coffee. The area has been a major source of recruited labour for coastal plantations and other employment. About 8000 persons were absent for this reason during 1963–64. By contrast 11,000 indigenous persons were employed in the area, of which 3000 came from outside.‡

The non-indigenous population is engaged mainly in government, plantation, mission, and urban-based commercial activities. The major towns (see Part II) contain 44% of this population and the indigenous urban population is 10,276, or 3% of the total indigenous population.†

Overall crude population density is 80 persons per sq mile, which rises to 190 on land used for cultivation. Local population densities on tribal lands rise to over 500 persons per sq mile. No population distribution map has been made, for reasons indicated below, but the distribution can be broadly inferred from the land use intensity map.

(b) *Settlement Patterns*

Broadly, the settlement pattern is dispersed to the west of the Chimbu area, but nucleated to the east. Within the Chimbu area the pattern is transitional. For the west, Reay (1959) states "the characteristic form of settlement is the homestead type found everywhere in the Western Highlands of New Guinea . . . dwellings are scattered among gardens—mostly in loose clusters of two to six, but with isolated dwellings dispersed between. They are so dispersed that it is hard to see from their relative density which ones form the settlement of a distinct community". Major centres of communal focus in this area are the casuarina-ringed, level, grassed, ceremonial grounds which are a distinct feature in the landscape. For periods during the pig festivals, long low huts may be built around the ceremonial grounds but normally they are not

* Source: 1962–63 quasi-annual census of villages listed in the "Village Directory, 1960", Department of Native Affairs, Port Moresby.

† Source: Territory of New Guinea Report for 1956–66, Commonwealth of Australia.

‡ Source: Labour Information Bulletin No. 2, March 1965, Department of Labour, Territory of Papua and New Guinea.

associated with housing. In the east the nucleated pattern consists of large linearly aligned villages or strings of hamlets in the Asaro valley with smaller villages more common in the Bena–Kainantu area.

However, over and above the broad western disperse–eastern nucleated trend, air-photo interpretation reveals that, in fact, nuclear and disperse settlement patterns occur together throughout the area and that it is only the proportion of each that varies. It further reveals that nucleated patterns are generally associated with small areas of very intensive and areally compact land use. This type of use occurs only on fairly level or gently sloping areas which are little dissected (e.g. better-drained flood-plains and undissected portions of alluvial fans). Villages within this pattern are either in the midst of these compact gardened areas or very closely associated with them.

By contrast, disperse settlement patterns are usually a feature of more rugged topography. It might be surmised that in this type of environment the proportion of cultivable land is smaller, which in itself may directly obviate strong nucleation. In any case, it will certainly affect the walking time from village to garden, thus making nucleation less intensive.

Brown and Brookfield (1968) have dealt at some length with settlement patterns in the heavily populated Chimbu area and the reader is referred to this paper. Air-photo interpretation indicates that their findings could be broadly extrapolated over much larger areas of disperse or slightly nucleated settlement types.

(*c*) *Method of Assessing Population according to Environment*

Two different techniques were used in relating population data to land systems and thus to environment. For the Chimbu and Eastern Highlands districts, group or village population totals from census and village directory data were related to an existing village location map, and subsequently transferred to the land system map. Although lack of control of the village map made this transfer liable to error, the results are sufficiently accurate for the purposes of this report. No such group or village location map was available for the Western Highlands district, and population data were compiled from patrol reports and limited field checking. Moreover, as a result of the disperse settlement pattern, few precise village locations can be noted on the air photos to serve as a bench-mark for a group population total. Thus the population data are unavoidably less reliable for the western part of the area, but still sufficiently accurate to give figures of the right order of magnitude. The results of these procedures are presented in the land system descriptions in Part IV.

III. Past Land Use

A seminar held at the Australian National University, Canberra, in 1967 reviewed current knowledge and hypothesis concerning the prehistory, particularly in regard to past land use practices, of the New Guinea highlands. A review of this seminar, containing a full bibliography, has been published by Brookfield and White (1968).

The area appears to have been peopled mainly from the east with later migrations from the west. An earlier hypothesis (Watson 1965*a*, 1965*b*) of a rapid population growth and change in land use following the introduction of sweet potato about the fifteenth century appears to be rebutted by evidence from different fields, of which the most important is the discovery in the Wahgi valley of extensive drainage ditches buried below recent peaty deposits (Golson *et al.* 1967). These were carbon dated at 2300±120 years B.P. and they indicate the presence of a labour and land-intensive agricultural system well before the fifteenth century. Evidence of earlier occupation of these highlands by man is given by Bulmer (1964) and Bulmer and Bulmer (1964). Occupation is dated back to at least 10,000 years B.P., and stone tools and bones have been found near Chuave indicating that hunting and gathering may have been the main way of life.

Direct European contact with the area commenced in the 1930s (see Part II). The immediate pre-contact culture was neolithic and its land use practices have been described by Leahy and Crain (1937) and Howlett (1962). Although the actual settlement pattern may have differed somewhat from that of the present, partly because of the exigencies of warfare, the type of subsistence cultivation employed has not greatly changed.

IV. Present Land Use for Subsistence Cultivation

Since the conclusion of World War II and the cessation of local warfare following pacification, particularly since the mid 1950s, the rate of change has increased. The establishment of non-indigenously owned coffee plantations and the rapid development of cash cropping by the indigenous people has altered the land use pattern, of which the most easily observed features are the presence of cash crops and the density of casuarina plantings within the subsistence sectors. Nevertheless, the greater proportion of present land use is still devoted to subsistence agriculture.

(*a*) *Crops and Diet*

The dominant subsistence crop is sweet potato (*Ipomoea batatas*). Other common crops are taro (*Colocasia antiquarium*), yam (*Dioscorea* sp.), banana (*Musa* spp.), cassava (*Manihot* sp.), sugar-cane (*Saccharum officinarum*), papaw (*Carica papaya*), wing beans (*Psophocarpus tetragonolobus*), edible pit-pit (*Saccharum edule*), and peanuts (*Arachis hypogaea*). Many other minor crops are grown including crops introduced by Europeans (e.g. potato, tomato, cucumber).

Meat protein is provided mainly by pigs, poultry, and some hunting. Pig meat tends to be consumed irregularly at festivals rather than as part of the daily diet. The overall diet in energy terms is discussed by Hipsley and Kirk (1965).

(*b*) *Cultivation Systems and Patterns*

The system of cultivation employed cannot be classed as shifting cultivation but generally varies from a long fallow cultivation in the least densely occupied areas to the intensive almost permanent short-fallow cultivation found with dense populations. The general limitations of these terms are discussed by Brookfield and Brown (1963).

Even this generalization, depending on population distribution, does not hold true in all areas. Short-fallow cultivation also occurs in some areas of relatively low population density (e.g. the lower slopes of Mt. Hagen), where the tendency is to concentrate gardens in agglomerations leaving the land in between untouched. The author has noted that between 1955, when the air photos were taken, and 1967 the garden complexes in this area have not shifted to any large extent.

The literature indicates that the length of the cultivation and fallow cycle differs greatly throughout the area and is related to land pressure, environment, and cultivation techniques. Garden cultivation methods, on the other hand, do not appear to vary greatly in intensity, except perhaps for some increase in intensity in areas of highest land pressure. Differences between individual cultivators appear to be as great as those between different areas. Most gardens are enclosed by cordyline, casuarina, cane grass, or wood fences. The chief purpose of these fences is to demarcate boundaries between gardens and to keep out marauding pigs. When gardens are abandoned, pigs enter and the fences not used for firewood are allowed to deteriorate. This fencing results in a distinctive air-photo pattern which greatly facilitates land use mapping. Detailed descriptions of land use practices are found in the references cited earlier.

Most cultivation takes place on sloping land and in the Chimbu area gardened slopes may reach over 40°. Because of the dissection of most slopes the cultivation pattern on them is relatively disperse. Where long less dissected slopes occur, the cultivation pattern tends to consist of separate isolated agglomerations of gardens as referred to earlier. Most gardens on sloping land are drained by a rectangular lattice of shallow trenches which may or may not connect directly to a small watercourse downslope.

Where cultivation occurs on more level areas, fenced groups of gardens may form a pattern of more or less continuous, very intensive land use, especially along the better-drained flood-plains on the upper reaches of rivers. These cultivated areas may extend over 2 or 3 sq miles. The drainage of these gardens is connected to watercourses by deep trenches which, in the upper Wahgi valley, run for a considerable distance.

On the slopes of Mt. Hagen root crops are grown in composted mounds in a similar fashion to that described for the Wabag area by McAlpine (1965). Elsewhere, although preparation is equally intensive, composting does not form part of the method and fertility is maintained by longer fallowing, and increasingly by the planting of casuarina trees. These are also a major source of fuel in many areas.

Cultivation extends to 8000 ft and in some areas of high land pressure even higher, the line of demarcation between forest and cultivation being sharp and distinct. Above 8000 ft the risk of frost damage and the increase in time for crop maturation tend to make sweet potato cultivation unprofitable.

The literature cited earlier indicates that the area of current garden per head of population ranges from 0·2 to 0·6 ac per head with a median of 0·3.

(c) *Mapping of Present Land Use*

Areas of land use shown in the land use–physical environment analysis below and on the map of present land use have been compiled from air-photo interpretation of subsistence cultivation and regrowth patterns together with reference to the literature cited earlier. The photos were taken in 1955–56. The scale and locally the quality of the air photos preclude mapping of actual present cultivation, and necessitate arbitrary grouping at varying intensities of patterns of regrowth in conjunction with observable cultivation.

These groupings have been classed on the basis of two criteria. The first is by the percentage of land actually used within an area. This is defined by eliminating all unused areas as indicated by the presence of primary vegetation and non-anthropogenous secondary successions. The remaining areas consist of gardens and garden regrowth, seral stages in the progression, or regression of other anthropogenic secondary communities and other man-made features of the landscape (e.g. roads, villages, etc.).

TABLE 19

LAND USE INTENSITY

Class	Area (sq miles)	Mapping Criteria
Intense	250	More than 75 % is anthropogenous vegetation, of which more than 20 % is in cultivation
Moderate	1180	More than 50 % is anthropogenous vegetation, of which 5–20 % is in cultivation
Light	400	Less than 50 % is anthropogenous vegetation, of which less than 5 % is in cultivation
Induced stabilized disclimax short grassland	330	Less than 0·1 % is in cultivation

It is necessary to introduce one major modification to this dichotomous anthropogenous–non-anthropogenous classification. The stabilized disclimax short grasslands which occur in the area are considered to be anthropogenic in status but are related to past rather than present land use practices. Where occurrences of these are small and found in conjunction with currently used land, they have been included in the percentage of the area unused in the land mapped as used in the same manner as primary vegetation and non-anthropogenous secondary communities. These occurrences are mostly in the low land use intensity class (see below). Where larger occurrences are found, they have been mapped out separately as a category indicating areas of past use. Nevertheless, a recent field trip indicates that at least in the Chimbu area use is being made again of these grasslands for subsistence and cash crop cultivation. For a fuller description of the anthropogenous status of these grasslands see Part VII.

As this first-order land use criterion defined above gives only a broad measure of area used and does not indicate actual intensity of use (e.g. an area could be 100 % anthropogenous vegetation and yet be unused at present), a second-order mapping criterion has been established to indicate present land use intensity. This is based on the percentage of the area of anthropogenous vegetation which is in present use for

TABLE 20

POPULATION AND LAND USE WITHIN LAND SYSTEMS

(Arranged in order of % use)

Land System	Area (sq miles)	Population			Land Use			
		Total	Density per Sq Mile		Intensity and Area Used on Land System (sq miles)			% Use of Land System
			Crude	On Land Used	Intense	Moderate	Light	
Goroka	50	14,500	290	290	23·1	21·5	5·4	100
Winjaka	5	0*	0*	0*	0·0	4·4	0·6	100
Kumun	85	24,900	293	298	45·8	35·8	2·0	98
Doma	25	2000	80	88	2·0	20·7	0·0	91
Moruma	55	12,000	218	243	9·8	24·8	14·8	90
Omahaiga	55	15,000	273	310	7·0	32·5	8·9	88
Tambul	6	1500	250	288	0·0	2·6	2·6	87
Okapa	50	7200	144	171	1·8	36·4	3·8	84
Womei	45	11,200	249	304	22·9	11·8	2·2	82
Minj	13	2500	192	234	0·0	6·6	4·1	82
Aiyura	16	4200	263	321	0·0	8·0	5·1	82
Teiga	140	26,300	188	238	22·9	72·5	15·0	79
Koge	490	57,500	117	153	20·8	291·8	63·6	77
Kaugel	50	12,500	250	329	0·4	29·3	8·3	76
Ogu	20	1400	70	97	0·0	6·4	8·0	72
Lai	17	0*	0*	0*	0·6	7·9	3·7	72
Elimbari	35	3000	86	121	12·5	7·8	4·4	71

Pira	110	33,300	303	425	44·8	31·5	2·1	71
Tari	120	14,500	121	176	9·8	46·2	26·4	69
Korombogl	20	2400	120	185	0·0	4·2	8·8	65
Ko	50	5600	112	187	0·0	12·9	17·0	60
Nunga	25	2500	100	167	0·5	6·3	8·2	60
Birap	5	500	100	167	0·0	0·0	3·0	60
Banz	30	3600	120	212	1·8	10·5	4·7	57
Abiera	130	11,300	87	164	0·0	35·9	33·1	53
Yonki	105	7400	70	136	0·0	43·5	11·0	52
Ambum	200	17,300	87	171	5·2	81·3	14·4	50
Kinjibi	40	1700	43	104	0·0	5·1	11·2	41
Limisate	17	200	12	32	0·0	2·2	4·0	36
Nemarep	50	1000	20	58	0·0	8·1	9·1	34
Makuntus	35	900	26	110	0·2	2·0	6·0	23
Bismarck	1750	56,000	32	154	19·5	263·3	81·8	21
Wahgi	70	500	7	98	0·0	1·8	3·3	7
Ialibu	65	0*	0*	0*	0·0	0·7	0·0	1
Kwongi	45	0	0	0	0·0	0·0	0·0	0
Kubor	165	0	0	0	0·0	0·0	0·0	0
Giluwe	8	0	0	0	0·0	0·0	0·0	0
Wilhelm	65	0	0	0	0·0	0·0	0·0	0
Oga	3	0	0	0	0·0	0·0	0·0	0
Total	4265	354,400	83	194	251·4	1176·3	396·6	43

* Used by people on surrounding land systems.

subsistence cultivation. Present use is defined as including all stages between initial clearing and that part of the garden regrowth cycle which, on the air photos used, can no longer be distinguished from the induced grasslands or from the sword grass and shrub regrowth communities described in Part VII. Present use includes all clearing, recent fallow, productive gardens, and from 1 to approximately 5 years of garden regrowth following abandonment of the garden.

Three land use intensity classes and one of past use have been established. These are shown in Table 19.

It must be emphasized that virtually no field measurements have been made to support the interpretation.

In addition to these intensity mapping categories, areas of currently producing gardens that are discernible and of sufficient size to map have been indicated, to give a rough approximation of the localization of actual use within each intensity class. However, as the degree of "discernibility" depends on whether gardens are aggregated into large clusters or disperse, and on photo quality, relative comparison of one area with another in this respect is not valid. It is for this reason that it has been omitted from the intensity classification.

On the northern fall of the Bismarck Range (Bismarck land system), 55 sq miles of what appears to be shifting cultivation at very light intensity in tall secondary forest has been mapped. As there is not even any qualitative ground observation of this type of land use it is excluded from this discussion but its areal extent is indicated on the map.

Of the total area surveyed, 1800 sq miles (43%) has been mapped as land used. The detailed figures in total and by land systems are given in Table 20. The table is arranged in order of unweighted percentage use.

(*d*) *Land Use and Physical Environment*

Whilst the data of Table 20, and those on the tabular land systems in Part IV, provide a fairly detailed breakdown of population and land use distribution in relation to the physical environment of the land systems, it is also of interest to draw attention to marked regional differences in land use, associated with particular spatial associations of land systems called suites. Whilst such regional differences are likely to be partly culturally and historically determined, they also appear to reflect differences in evaluation of the same kind of environment, resulting from its being associated with different other environments in different localities.

Each suite consists firstly of a core group of land systems which are generally alike and particular to that suite alone. Hence these core land systems serve to distinguish a suite from every other suite. Secondly, each suite also contains some land systems that are common to other suites. Usually these last are either compound land systems of mountains peripheral to the core land systems or alluvial land systems of terraces and flood-plains which are found to run through most suites.

Figure 9 shows the location and name of each suite of land systems, whilst Figures 10–14 present schematic diagrams of five suites illustrating the land system associations and relating terrain to land use intensity and population data. It should be noted that the land use intensity and population data refer to the actual area encompassed by the illustrated suite, and will therefore differ from the data given for the whole land system, particularly for those land systems of widespread distribution. It is not possible to give the total area for the compound land systems on the periphery of the suite where their outer boundaries are indefinite. Because of the schematic nature of the diagrams, it is useful to compare them with the relevant parts of the land system and land use maps. For simplicity, only major land systems are shown. Minor land systems and any small outlying occurrences of the suite are ignored.

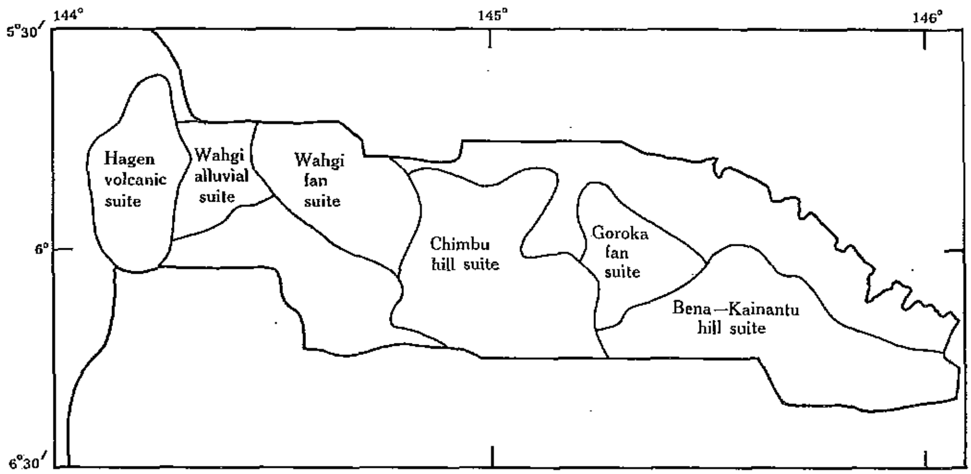
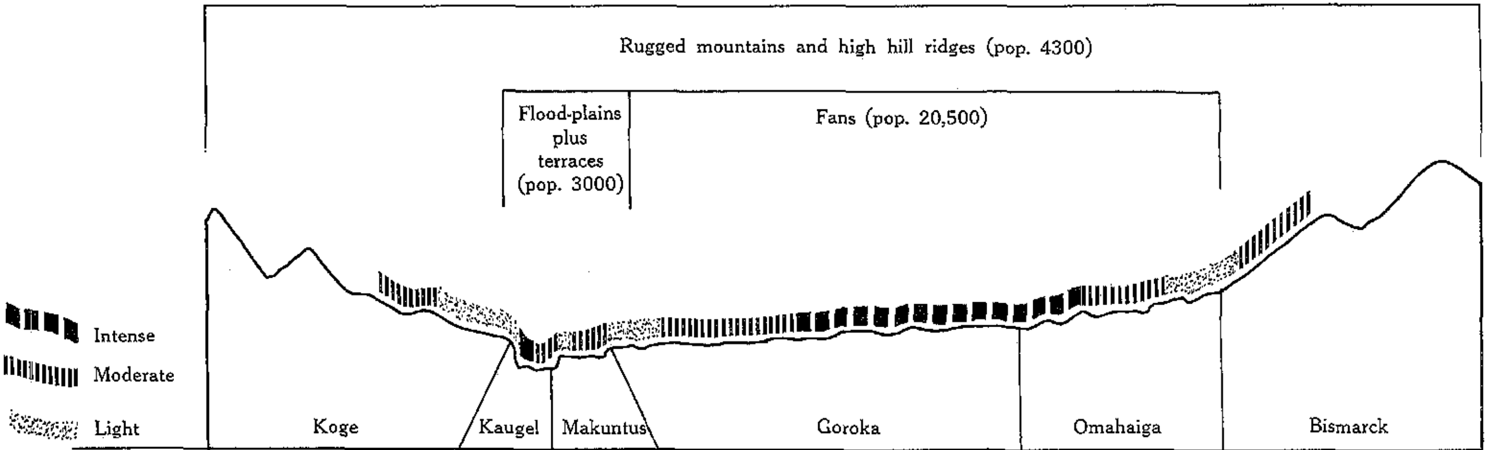


Fig. 9.—Regional physical environments (land system suites).

(i) *Goroka Fan Suite* (Fig. 10).—This suite is mainly associated with the Asaro valley and surrounding mountains, but a further smaller occurrence of it occurs on the Bena River. This small occurrence, not included in the figure, has a population of 6000 and a fan area of 15 sq miles; use is also made of the surrounding mountains but the extent of this use is not known. The suite consists mainly of fans and surrounding mountains, with by far the greatest proportion of land use occurring on the fans. The land use intensity on the fans is also high; however, the most intensive use occurs on the small Asaro flood-plain (Kaugel land system) where population density on used land is given as 375 persons per sq mile but rises locally to over 500 per sq mile.

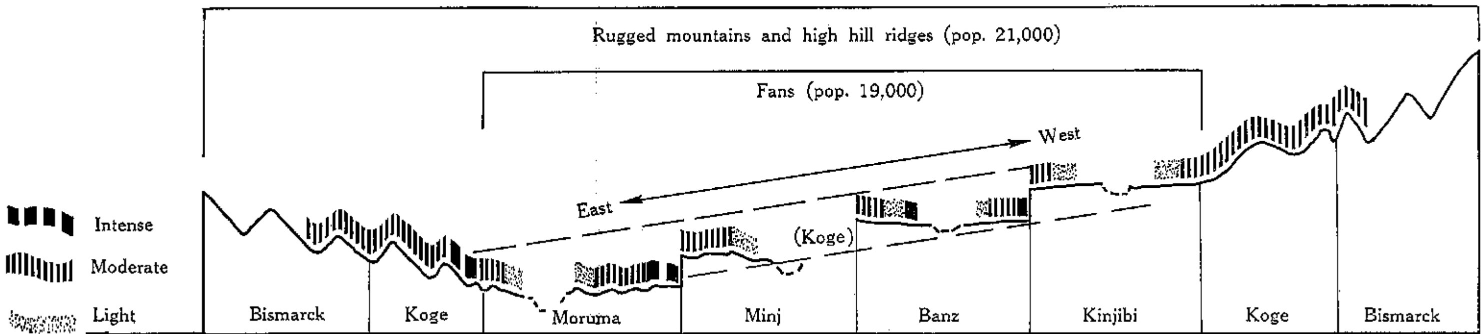
(ii) *Minj Fan Suite* (Fig. 11).—Another suite of fans surrounded by mountains is located in the Wahgi valley between Kerowagi and Kinjibi. Unlike the Goroka suite, approximately half the land use occurs on the peripheral mountains and high hill ridges, and the fans are much less intensively used. The small alluvial land systems (Kaugel, Makuntus) are virtually unused. On the different fan land systems the amount and intensity of land use, as well as the population density, increase from west to east in association with increasing dissection and ruggedness.

(iii) *Bena–Kainantu Hill Suite* (Fig. 12).—The main southern portion of this suite consists of a recurring sequence of high and low hill ridges with alluvial valleys,



	Koge	Kaugel	Makuntus	Goroka	Omahaiga	Bismarck
Land form	Rugged low mountains and high hill ridges	Flood-plains	River terraces	*Slightly rugged, dissected*	Moderately rugged, variably dissected	Rugged high mountains
Population	1300	3000	0	11,300	9200	3000
Area (sq miles)	Very large	8	3	45	40	Very large
Used area (sq miles)	12	8	3	45	40	50
Population density on used area (per sq mile)	108	375	0	250	230	60

Fig. 10.—Physical environment in relation to land use intensity and population distribution in the Goroka fan suite.



	Bismarck	Koge	Moruma	Minj	Banz	Kinjibi	Koge	Bismarck
Land form	Rugged high mountains	Rugged low mountains and high hill ridges	Moderately rugged, strongly dissected	Slightly rugged, little dissected	Slightly dissected, nearly level	Nearly level	See across	
Population	5000	16,000	12,000	1500	3600	1700		
Area (sq miles)	Very large	110	55	12	30	40		
Used area (sq miles)	50	100	50	10	17	16		
Population density on used area (per sq mile)	100	160	240	150	210	105		

Fig. 11.—Physical environment in relation to land use intensity and population distribution in the Minj fan suite.

backed by peripheral mountains. In the north the gentler hill topography is absent, leaving only narrow strips of alluvium surrounded by mountains. Both aspects of the suite are illustrated in Figure 12. Occurrences of fans in this region (e.g. Bena River) are outliers of the Goroka fan suite.

In the southern part of the suite, population density on used land is highest on the alluvial basin plains (Aiyura land system). Locally, areas of flood-plains (Kaugel land system) have population densities varying greatly from the average of 110 persons per sq mile. Near Kainantu densities on flood-plains rise to 400, yet near Arona the flood-plains are unused. In the north, the high population density on used land on the alluvial terraces is possibly below the 440 indicated, since the degree to which these people use the nearby mountains is unknown. Generally, over one-third of the population in this suite live on the rugged mountains whilst the remainder use the less rugged hill ridges and alluvial tracts.

(iv) *Chimbu Hill Suite* (Fig. 13).—Physically this suite is generally similar to that of the Bena–Kainantu suite except that alluvial land systems are virtually absent. The population and land use distribution are, however, in marked contrast. Over twice as many people use the rugged mountains compared with those using the less rugged hill areas. The land use intensity data on the figures indicate that this difference may arise partly because the hill areas approach maximum population density in the sense used by Brookfield and Brown (1963).

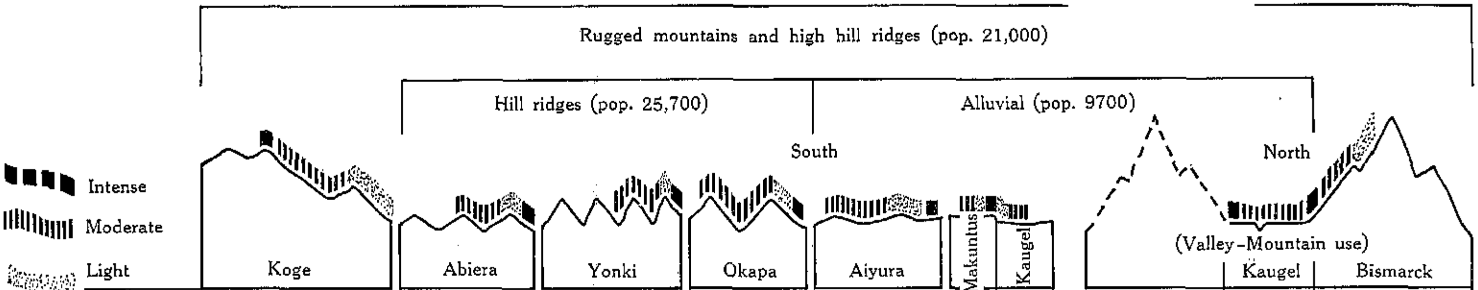
(v) *Hagen Volcanic Suite* (Fig. 14).—This suite of land systems lies on the low watershed separating the south-flowing Nebelyer, the north-flowing Baiyer, and the east-flowing Wahgi Rivers. It is distinguished from the other hill and fan suites by its less rugged land forms. These consist largely of undulating and little-dissected alluvial, ash, and volcanic plains. The major difference, however, lies in the ubiquity of old volcanic ash surface deposits.

Variations of this suite are found in the Baiyer River plain and on the lower Kaugel valley. Within the suite, population densities on used land vary from 100 to 250 per sq mile with less than one-third of the population using the peripheral mountains. Although the plains of Tari land system are moderately used within the area illustrated, large parts of this land system are virtually unused in the Baiyer River plain.

(vi) *Wahgi Alluvial Suite.*—Between the Minj fan and Hagen volcanic suites lies a large unpopulated area of poorly drained alluvium and peat at the head of the Wahgi River. The plains of the southern Wahgi tributaries, the Kaip, Kormun, and Kuli Rivers, are better drained and have a population of 8000 persons using 19 sq miles of flood-plain alluvium (Ko and Kaugel land systems) at moderate intensity and 20 sq miles of peripheral mountains (Ambum and Bismarck land systems) at low to moderate intensity. No figure is presented for this small suite.

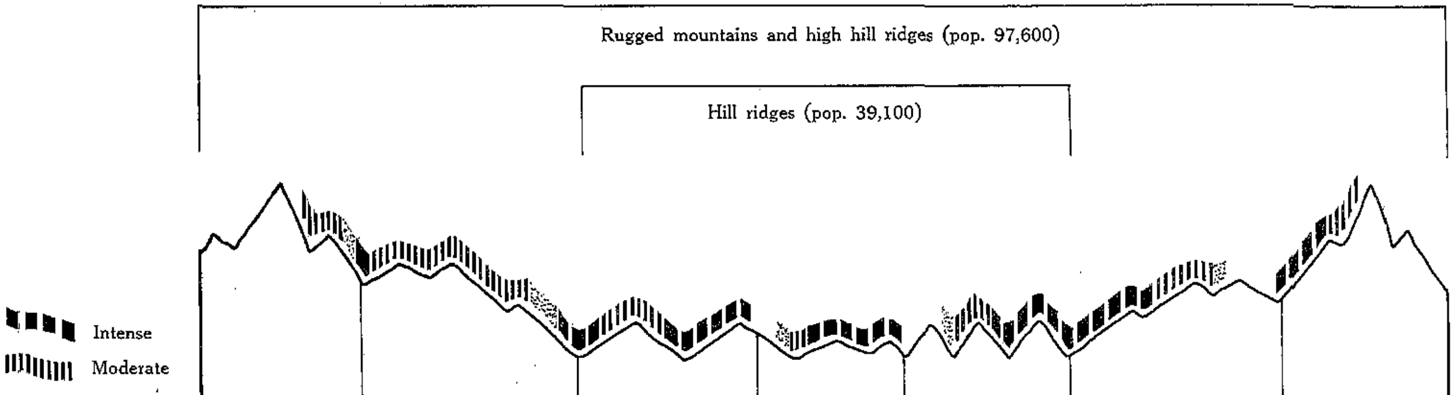
(*e*) *Land Use in Relation to Land Use Potential*

Field experience generally suggests that the land types recognized in this report are similar to those recognized by indigenous subsistence cultivators. The agricultural assessment of the land use capability of these types presented in Part X is, however,



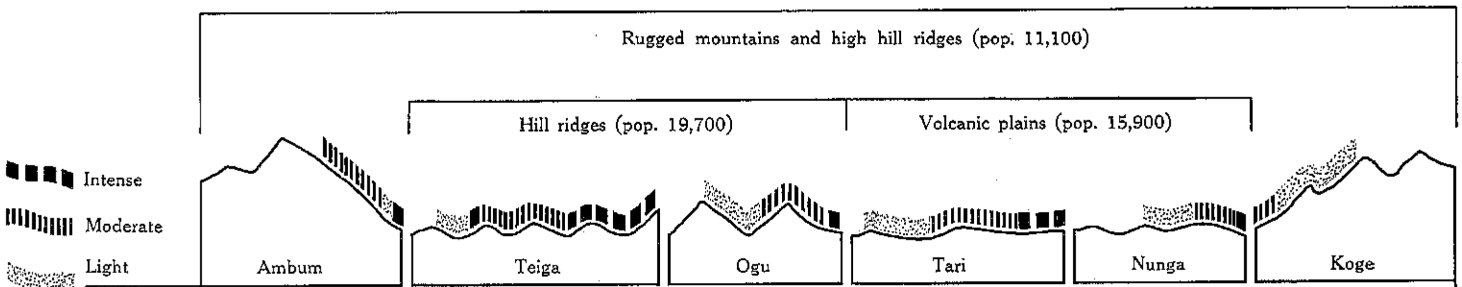
	Koge	Abiera	Yonki	Okapa	Aiyura	Makuntus	Kaugel	Kaugel	Bismarck
Land form	Rugged low mountains and high hill ridges	Moderately rugged low hill ridges	Rugged high hill ridges	Moderately rugged high hill ridges	Basin plain	Terrace	Flood-plain	Flood-plain	Rugged high mountains
Population	3400	11,300	7200	7200	4200	500	1000	4000	18,600
Area (sq miles)	Very large	130	105	50	16	6	11	9	Very large
Used area (sq miles)	30	70	55	42	13	5	9	9	180
Population density on used area (per sq mile)	110	160	130	170	320	100	110	440	100

Fig. 12.—Physical environment in relation to land use intensity and population distribution in the Bena–Kainantu hill suite.



	Bismarck	Koge	Kumun	Womei	Elimbari	Pira	Bismarck
Land form	Rugged high mountains	Rugged low mountains and *high hill ridges*	Moderately rugged high hill ridges	Slightly rugged low hill ridges	Rugged low *mountain ridges*	Rugged low mountains and hill ridges	Rugged high *mountains*
Population	5800	39,400	24,900	11,200	3000	33,300	19,100
Area (sq miles)	Very large	170	85	39	35	110	Very large
Used area (sq miles)	45	170	83	32	25	78	84
Population density on used area (per sq mile)	130	230	300	350	120	430	230
Remarks	Refers to use in area					Most use on hill ridges	Refers to use in Chimbu, Watabung, Kerowagi area

Fig. 13.—Physical environment in relation to land use intensity and population distribution in the Chimbu hill suite.



	Ambum	Teiga	Ogu	Tari	Nunga	Koge
Land form	Rugged low mountains	Moderately rugged low hill ridges	Slightly rugged high hill ridges	Little-dissected volcanic plain	Slightly rugged volcanic plain	Rugged low mountains and high hill ridges
Population	8500	18,300	1400	13,400	2500	2600
Area (sq miles)	Very large	75	20	70	25	Very large
Used area (sq miles)	58	72	14	66	15	28
Population density on used area (per sq mile)	145	250	100	200	160	95

Fig. 14.—Physical environment in relation to land use intensity and population distribution in the Hagen volcanic suite.

based on quite different criteria from those used for subsistence agriculture. For instance, the cultivation of steep slopes up to 30° with considerable dissection is not a limiting factor at the subsistence level, whereas in the classification in Part X this constitutes a major limitation.

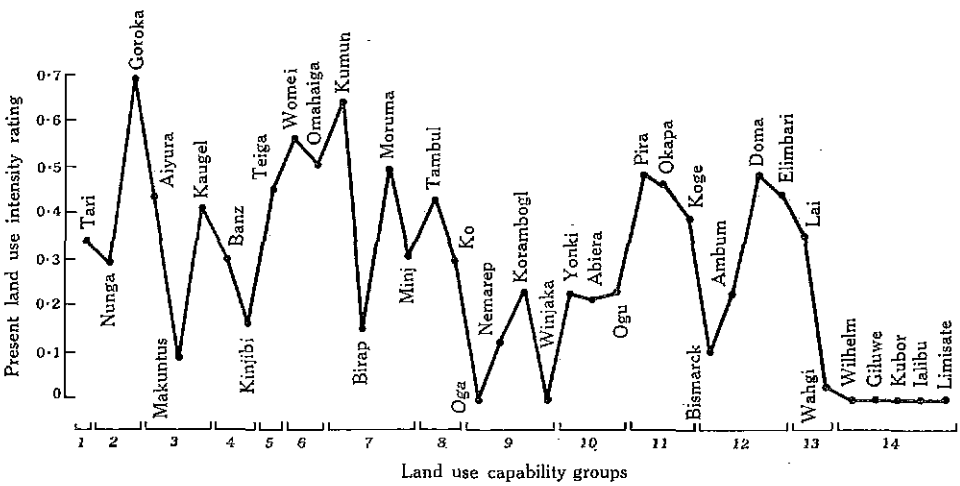


Fig. 15.—Present land use of land systems compared with their land use capability.

The comparison of present and potential land use made here serves solely to indicate the degree to which land of certain capability is already being used for subsistence cultivation. Land systems have been arranged into 14 capability classes in Part X and these were related to a weighted land use intensity rating of each land system derived from Table 20. Land systems were ranked by present use and potential use and compared by using Spearman's rank correlation coefficient. The correlation was $r = 0 \cdot 53$, indicating little relation between the two. The individual variations are shown in Figure 15. Since land use intensity is never uniform over the whole area of a land system, it is necessary to make a direct comparison between the land use and land use capability maps to assess the frequency with which certain land use intensity classes correspond with areas of a certain land use capability.

By contrast, agricultural production by non-indigenous persons (see below) occurs almost wholly on those areas classified in the highest capability classes in Part X.

V. Present Land Use for Commercial Production

Cash cropping and livestock production occur under two different systems of production. They are organized by indigenous people on a small-lot basis generally in areal conjunction with subsistence cultivation, whereas production controlled by non-indigenous lessees takes place on a plantation-economy basis. The two forms are discussed separately here, partly because production statistics, particularly of areas planted, are more reliable for the non-indigenous than for the indigenous sector. Short general accounts of particular rural industries and their agronomy are given by Barrie (1956) and Anon. (1961) for coffee; by Hill (1965), Quinlan (1968), and Schindler (1959) for pyrethrum; and by Grant-Cook (1966) for tea.

(*a*) *Production by Indigenous Persons*

Cash cropping by the indigenous population is based chiefly on highland coffee production (*Coffea arabica*). Other cash crops are pyrethrum (*Pyrethrum* (*Chrysanthemum*) *cinerariifolium*), passion-fruit (*Passiflora* sp.), and tea (*Thea sinensis* L.). The last is a recent introduction and the estimated acreage in 1967 was 1500. Money income is also gained from the sale of surplus subsistence crops, European vegetables, and firewood.

Approximate areas and production of the main cash crops are given in Table 21.

TABLE 21

APPROXIMATE PRODUCTION OF MAIN CASH CROPS*

Crop	Area (ac)	Production (tons)	Value ($)
Coffee	30,000 (33–50% immature trees)	5789	4,300,000
Pyrethrum	1000	160	N.a.
Passion-fruit (pulp and juice)	N.a.	540	175,000
Tea	1500	See text	

* Source: Rural Industries Production Bulletin No. 8, Bureau of Statistics, Territory of Papua and New Guinea, 1967.

Cash cropping takes place in the same general area as subsistence cultivation and for annual crops in direct conjunction with it. Small coffee plots are nearly all close to the road network, and a considerable amount of coffee processing is centralized at large factories. Passion-fruit is grown in areas within easy access of the pulping factory at Goroka. While coffee is grown in areas below 6500 ft, pyrethrum production occurs only above this height. The major area for pyrethrum cropping is along the upper Chimbu River where 70% of the crop is produced. Yields of coffee are of the order of 8–10 cwt per ac and of pyrethrum 3 cwt per ac. The recovery of pulp and juice from passion-fruit is approximately one-third by weight.

An indication of the rate of expansion of cash cropping can be seen from the percentage of immature coffee trees indicated in Table 21. Actual coffee production commenced only in the mid 1950s.*

Livestock projects, commenced recently, are aimed at enriching the subsistence diet and providing a further source of cash income. These projects carry approximately 1600 head. The recent introduction of intensive village piggeries has a similar aim.

* Since the time of writing, expansion of coffee planting has been discouraged owing to international market quota restrictions.

(*b*) *Production by Non-indigenous Persons**

Most of the 208 non-indigenously leased rural holdings occurring in the highland districts are located in the area surveyed. These holdings are concentrated in the Western and Eastern Highlands Districts; the Chimbu District, with its considerably higher population densities, has only minimal alienated land. Of these holdings, 158 are used for coffee production on a plantation system. The total holdings cover 60,000 ac (i.e. $< 2\%$ of area surveyed and $< 5\%$ of land used) of which 10,500 are under coffee and 5000 under other crops, mainly sweet potato grown for plantation labour and local sale. A further 6000 ac are under established pastures (i.e. non-native grasses) and another 8500 ac are listed as cleared. The balance of 30,000 ac consists of unused land, natural pastures, and the area set aside for large-scale tea development.

Coffee production from these plantations for 1965–66 was 3463 tons valued at $2,800,000. An indication of the expansion rate is given by the fact that of the 10,500 ac under coffee trees 3200 ac were immature, and of this latter acreage 33% represented the area of new plantings for the year ended March 1966. Like production by indigenous persons, actual production commenced chiefly in the mid 1950s, although a few small pioneering plantations were producing in the early 1950s. Average coffee yields per productive acre are 8·57 cwt in the Western Highlands and 10·32 cwt in the Eastern Highlands. The highest commercial yields have been up to $1\frac{1}{2}$ tons per ac.

By far the greater part of this coffee production occurs on the alluvial fans around Goroka (Goroka fan suite) and in the Wahgi valley (Minj fan suite). A minor amount is produced on the Hagen volcanic suite.

The most recent expansion of land use has been the development of the large flood-plains of the upper Wahgi River (Ko and Wahgi land systems) and the lower section of the fans of Kinjibi land system for tea estates. Total land alienated for this purpose is approximately 16,000 ac. In 1967–68, large-scale production had not yet commenced but 4800 ac had been planted.

On the pasture acreages given above, 5600 head of cattle are carried together with small numbers of pigs, sheep, goats, and horses. The two largest livestock establishments at the time of the survey were in the area at Baiyer River and Arona and were controlled by the Administration. Baiyer River station in the west lies on Tari land system and Arona in the east is on Abiera land system.

Indigenous employment on these rural holdings is approximately 8000 and non-indigenous 200.

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* Source: Rural Industries Production Bulletin No. 8, Bureau of Statistics, Territory of Papua and New Guinea, 1967.

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PART X. AGRICULTURAL POTENTIAL OF THE GOROKA–MOUNT HAGEN AREA

By H. A. HAANTJENS*

I. SYSTEM OF LAND USE CAPABILITY CLASSIFICATION

(a) General Considerations

In Part IV the land use capability of the land units has been expressed in terms of land use capability classes and subclasses, based on the land classification system of the United States Soil Conservation Service (Klingebiel and Montgomery 1961). The system has been adapted to suit the conditions of the survey and the New Guinea environment (Haantjens 1963). All land is grouped into eight classes (I–VIII) which indicate the level of suitability of the land for different types of agricultural production. The classes are subdivided into a number of subclasses, denoted by letter symbols, indicating the nature of the limiting factors which have caused the land to be placed in a particular land use capability class. The classification thus expresses the physical features of the land in general agricultural terms.

Several points should be kept in mind when considering the land classes and subclasses described in Section III.

The classification system is *not* a productivity rating in a narrow sense. It does *not* aim at making productivity predictions for specific crops. Class I land may well be capable of lower yields (especially for specific crops) than class II, III, or even class VII land, but special agronomic measures and precautions that have to be taken to reach or maintain productivity in these classes are not necessary on class I land. Or, the choice of crops or forms of agricultural production may be limited in the higher land classes, but not in class I except by climatic conditions. Such special measures and crop limitations will add to the cost and risks in farm management.

The system is based on modern western agricultural methods. It does not apply to systems of shifting cultivation or to peasant farming systems. Any major changes in modern western farming methods might render this classification invalid to some degree, and it would have to be reviewed in the light of such new technological development.

The system only assesses possibilities for land improvement that are within the reach of the individual modern farmer or small group of farmers. No consideration is given in this classification to more remote possibilities of land improvement that could be effectuated only in large-scale reclamation projects carried out or subsidized by government or large organizations. Such possibilities are briefly discussed in Section II.

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During field work there was little opportunity for correlating the classification with existing modern western land use in the area, since this was limited to scattered and generally recently established coffee plantations and a few cattle stations. Although the experience gained in these forms of agriculture has been incorporated as much as possible, the classification nevertheless remains largely tentative in character, the more so as it is also based on only a limited amount of field observations. This means it is possible that land will have to be transferred from one class to another as a result of additional research and experience. However, it is unlikely that the subclass letter symbols will need to be changed as there is little doubt about the nature of the limiting factors in the assessment in this report.

(b) *Climatic Limitations*

Climatic limitations for agricultural production have not been incorporated directly in the land use capability classification, although the water balance data discussed in Part V, Section IV, have indirectly influenced the so_2 subclasses of droughty soils. Climatic factors, particularly temperature and cloudiness, as related to altitude are known to be of great significance for particular crops. Thus, the productivity of arabica coffee decreases rapidly between 6000 and 7000 ft. Most indigenous subsistence crops do not produce well above 8000 ft. Normal rice varieties will not give good yields even on the valley floors at 5000 ft. On the other hand, certain vegetable crops and pyrethrum thrive between 6000 and 9000 ft. The degree to which such limitations apply can be assessed from the land system descriptions in Part IV and from the small-scale map of capability for agricultural land use.

(c) *Plant Nutrient Deficiencies*

No attempt has been made to incorporate plant nutrient deficiencies as limiting factors in the land use capability classes and subclasses. The reader is referred to Part VI, Section III, for data on soil analyses.

Southern (1966) states that soil analytical data have been of limited use in assessing fertilizer requirements of arabica coffee. Available phosphorus, determined by the sodium bicarbonate method (which is different from the method used to obtain the values in Table 14), correlates well with the vigour of young coffee. High exchangeable potash is never associated with potash deficiencies, but low potash values do not necessarily indicate such a deficiency. Abnormal C : N ratios sometimes indicate lack of nitrogen mineralization and thus nitrogen deficiency.

In discussing plant nutrient deficiencies in arabica coffee as revealed by foliar analysis and response to fertilizer, Southern (1966) and Hart (1966) note that nitrogen deficiencies are rare and occur mostly in the Eastern Highlands. Response to phosphate fertilizer is rare in mature coffee. Potash is commonly the most deficient element. Because of antagonism, magnesium deficiencies commonly follow potash fertilizer applications. Sulphur deficiency appears to be widespread, and there appears to be antagonism between sulphur and nitrogen uptake by coffee. Zinc deficiency and to a lesser extent iron deficiency are common, whilst boron deficiency is suspected in some cases. It is clear that coffee nutrition is a complex subject. That fertilizer applications can be highly successful, however, is shown by Carne and Charles

(1966), who mention mean annual yield increases of up to 1000 lb/ac processed coffee over a 6-yr period, 3000 lb constituting a good yield for this crop.

No data on fertilizer response have been published for other crops. It can be expected that responses often will be obtained and that phosphate fertilizers will be of greater value for annual arable crops than for perennial crops such as coffee. On the whole, nutrient deficiencies are probably least in the alluvial and organic soils and greatest in the lateritic and gleyed latosols.

II. Regional Land Use Capability

(a) General

The small-scale map of agricultural land use capability was prepared by grouping the land systems into 14 groups according to similarities in their level of suitability for arable crops (regular cultivation for essentially annual crops), tree crops (perennial plantation crops), and improved pastures. The level of suitability of each land system was calculated by a weighted summation* of the percentages of land in different land use capability classes. Table 22 summarizes this information by listing the total

Table 22

APPROXIMATE AREAS* (SQ MILES) OF LAND OF DIFFERENT LEVELS OF SUITABILITY FOR ARABLE CROPS, TREE CROPS, AND IMPROVED PASTURES

	Land Use Capability†			
	High	Moderate	Low	Very Low
Arable crops	120	245 (170)	455 (55)	345 (90)
Tree crops	335	360	2430 (125)	90 (90)
Improved pastures	605 (170)	370 (55)	2140 (90)	320

* The areas in each column are *not* mutually exclusive.

† The land use capability of that part of an area which is indicated in brackets can be raised one or two levels, including very high capability, by land reclamation (mainly drainage improvement).

areas at different levels of suitability for these three main types of agricultural land use. The table shows the relative scarcity of arable land in this generally densely populated area. Since the arable land is also equally suitable for tree crops or improved pastures, further development of the area will involve important policy decisions concerning the relative merits of adequate local food production and commercial agricultural activities in the form of perennial cash crop plantations and grazing. The figures in Table 22 indicate that whilst there is in principle much room for expansion of tree crops, their areal potential is greatly exceeded by the capability of the land for pastoral industries. Climatic conditions appear to be more favourable for cattle than in any other part of Papua and New Guinea. Finally, the figures in brackets in Table 22 show that significant increases in the agricultural

* Haantjens, H. A. (1969).—Agricultural land classification for New Guinea land resources surveys. CSIRO Aust. Div. Land Res. tech. Memo. 69/4 (unpublished).

productivity of the area can be derived from land reclamation by drainage improvement. This is confirmed by small-scale reclamation projects already completed or in progress (A. C. Hartley, personal communication).

(b) *Land Use Capability Groups*

The 14 land use capability groups shown on the small-scale map are briefly described below. They are arranged in order of decreasing capability, firstly for arable crops and secondly for tree crops.

Land Use Capability Group 1.—Comprising the slightly dissected volcanic plains of Tari land system, erosion hazards are slight and restrict only the capability for arable crops. Physically poor soils restrict the capability in parts of the area, particularly for tree crops. Small areas are poorly drained or too steep. Overall this group has the greatest capability for improved pastures, but development could well be based on all three kinds of land use, each adjusted to local slope and soil conditions.

Land Use Capability Group 2.—Comprising the rolling volcanic surfaces of Nunga land system and the dissected fans of Goroka land system, this group has only a moderate capability for arable crops, largely as a result of erosion hazards, but a high capability for tree crops and improved pastures. Local physical soil deficiencies are as much a limitation as erosion hazards for tree crops in Goroka land system, whilst the capability of Nunga land system is lowered by the presence of some very poorly drained land. Mixed development is recommended for this group, with tree crops preferably on steeper land with deep soils, arable cropping on good level land, and pastures on the poorer level and sloping land.

Land Use Capability Group 3.—Poor drainage commonly associated with slowly permeable soils is the main limitation reducing the capability for arable crops and tree crops to moderate, although it can still be rated high for improved pastures. The group comprises the alluvial basins of Aiyura land system and the terraces and flood-plains of Makuntus and Kaugel land systems. Flooding is a contributory hazard in Kaugel land system. Drainage improvement would considerably increase the capability of this group for all forms of land use. This would involve interception of run-on, gravitational and locally pump drainage of low-lying areas with soils that are likely to give a good response, and trench and tile drainage of the slowly permeable higher-lying soils, which will probably respond less. Since flood control would be very difficult, drainage of flood-plain land would not be practical.

Land Use Capability Group 4.—Land use capability on the fan plains of Banz and Kinjibi land systems is limited to moderate for arable crops, low for tree crops, and high for improved pastures, mainly by poor drainage commonly associated with slowly permeable soils. It is therefore similar to and only slightly lower than that of group 3. Drainage improvement appears to be most effective in Kinjibi land system because soils appear to be generally more permeable. Gravitational drainage by ditches, combined with interception of seepage water at the head of the plains, appears generally possible. Many soils in Banz land system will probably respond less well, although results on existing coffee plantations appear to be better than was expected.

If effective, such land improvement would greatly increase the capability for tree crops and arable crops. Less intensive drainage by cambering and shallow grassed drainage lines is commonly adequate for improved pastures, raising the capability of this group to very high for pastoral use.

Land Use Capability Group 5.—This group of hilly volcanic ash land of Teiga land system has generally such erosion hazards that only small areas could be regularly cultivated, thus reducing the overall capability for arable crops to low. Other limitations are, however, very minor, so that the suitability for tree crops and improved pastures has been assessed as high, there being very little land with excessive erosion hazards for these forms of land use.

Land Use Capability Group 6.—Combining the irregular low mudstone hills of Womei land system with the commonly steep and dissected colluvial fans of Omahaiga land system, this group has a low capability for arable crops as a result of locally variable but commonly great erosion hazards and the irregularity of the terrain. Only small pockets of land could be safely cultivated. Surface stoniness is an additional limitation for cultivation in small areas of Womei land system. The soils in this group are commonly less suitable for tree crops than those of group 5 because of poor drainage, slow permeability, and locally shallowness. Hence the capability for tree crops is assessed as only moderate. In places there could be landslide hazards, which would be harmful for tree crop plantations in particular. Since these limitations probably would have little effect on pasture growth, the capability for improved pastures appears to be high. Local variations in land use capability are great in Omahaiga land system, less in Womei land system, where most land is moderately good to moderately poor. Generally this land appears to be most suitable for small mixed farms with the emphasis on pasture development.

Land Use Capability Group 7.—Most of the land in this group is hilly: sedimentary rocks in Kumun land system, volcanic ash and lava in Birap land system, and strongly dissected fan deposits in Moruma and part of Minj land systems. Since only rather small areas have sufficiently low erosion hazards to allow regular cultivation, and in this case commonly have poorly drained or droughty soils, this group has only a low capability for arable crops. The capability for tree crops and improved pastures is moderate, in large parts of the area mainly as a result of poor physical soil conditions and in other parts (particularly in Birap land system) because of very steep slopes and associated erosion hazards. Since the largest part of Birap land system is above 6000 ft altitude, there is an additional climatic limitation, particularly in the choice of tree crops. There is only little land in this group which has no capability at all.

Land Use Capability Group 8.—These mostly poorly drained to swampy plains of Tambul and Ko land systems have a low capability for arable crops and tree crops, and a moderate capability for improved pastures. Parts with rather minor limitations contrast with other parts that are very poor or virtually useless in their present conditions. Drainage improvement by land reclamation appears generally feasible by gravitational discharge of excess water through deep drainage channels, but pumping may be locally necessary. The soils are expected to respond well to such measures, although shrinkage may be a problem in some organic soils of Tambul land system. Reclamation would increase the capability for arable crops and tree crops to moderate or high, for improved pastures to high or very high. Tambul land system occurs above 6000 ft altitude, and has additional climatic limitations, particularly in the choice of tree crops. The percentage of totally unusable land is low.

Land Use Capability Group 9.—This is a rather heterogeneous group of small limestone plateaux (Oga land system), strongly dissected volcanic slopes (Nemarep land system), sedimentary hill ridges (Korambogl land system), and strongly dissected valley fill (Winjaka land system). The capability is very low for arable crops, and moderate for tree crops and improved pastures, but the nature of the limiting factors differs, although erosion hazards on steep slopes are always important. Rockiness is an additional limitation in Oga land system, poor drainage in Winjaka land system, and slowly permeable or shallow droughty soils in Korambogl land system. The greatest contrast in land capability is in Nemarep land system where about 20% of good land is offset by an equally large area of wholly unusable steep land. Except for Korambogl land system, most land in this group is above 6000 ft altitude and thus subject to climatic limitations affecting particularly the choice of tree crops. On the whole, therefore, this land is probably best used for grazing or forestry purposes, with minor arable and tree crops on the best land.

Land Use Capability Group 10.—This hilly land on igneous and sedimentary rock (Yonki land system), strongly dissected old alluvium (Abiera land system), and volcanic agglomerate (Ogu land system) has a very low capability for arable crops, a low capability for tree crops, and a moderate capability for improved pastures. Apart from small pockets near or in valley bottoms, which are commonly poorly drained, the land is too steep for regular cultivation. The suitability for tree crops is reduced by the commonly slowly permeable or droughty concretionary soils in Yonki and Abiera land systems and by very poor drainage in a large part of Ogu land system. Since these limitations are less serious for pasture growth, the land of this group would on the whole be most suitable for grazing purposes. Reafforestation could also be attractive, since this land is situated in the centre of large areas with little or no timber and has no access problems. The percentage of totally unusable land is low.

Land Use Capability Group 11.—This high hilly to low mountainous country, mainly on sedimentary rocks in Koge, Pira, and Okapa land systems, has so little land suitable for regular cultivation that its capability for arable crops is rated as nil. There is a large proportion which is also almost too steep for tree crops and improved pastures, but the percentage of totally unusable land is small. In many places, but particularly in Pira and Okapa land systems, slowly permeable or shallow droughty soils are additional limitations for tree crops. Hence the overall capability for improved pastures and the capability for tree crops have been assessed as moderate in Koge land system, low in Pira and Okapa land systems. The high altitude of the greater part of Koge and Pira land systems introduces a climatic limitation, particularly in the choice of tree crops. Development of this land could probably best be based on reafforestation combined with cattle-grazing and minor tree crop plantations. Any land use should be aimed at conservation, since much of this group is part of the major catchment areas in the region.

Land Use Capability Group 12.—This very large group of rugged low and high mountains on various rock types (Bismarck, Ambum, and Doma land systems), including limestone (Elimbari land system), and on the isolated steep hilly uplands of Kwongi land system has no overall capability for arable crops (although small pockets of cultivable land exist in some valleys) and a low capability for tree crops and improved pastures. The group includes a varying but generally rather high percentage of wholly unusable land. Very steep slopes and consequent erosion hazards are the main limitations, reinforced in places by shallow soils and rockiness of the land (Elimbari land system). With the exception of Doma land system the greater part of the land in this group is above 6000 ft (a small proportion exceeding 9000 ft in altitude), so that climatic limitations exist, particularly with regard to the choice of tree crops. A significant proportion of Bismarck land system along the Ramu River is between 1000 and 4000 ft, where the climate is rather unsuitable for both typical lowland and typical highland tree crops. Since this group constitutes the major catchment areas of the region, it is probably best left largely under protective forest, or reafforested in the east where large areas are now under grassland. Some agricultural development may be necessary in certain populated valleys such as the Chimbu. This would be best based largely on a grazing industry, with very minor cultivation and some tree crop plantations in the valleys and on the lower slopes.

Because of its scenic features and, for the greater part, isolation from human interference, this land use capability group is of importance in the development of a tourist industry and for the preservation of wildlife.

Land Use Capability Group 13.—This is a heterogeneous group, combining the rugged river gorges of Lai land system and the flood-plain swamps of Wahgi land system. Whilst some river terraces and flood-plains could be used for arable cropping and/or tree crops, their total area is so small that the overall capability for arable crops is nil to very low, and for tree crops very low. Limitations would be somewhat smaller for improved pastures, and since other very poorly drained land in Wahgi land system also has limited scope for pasture improvement the capability for improved pastures is judged to be low. Reclamation of the swamps of Wahgi land system would require costly drainage and flood-control works and an efficient control of the water-table, particularly in peat soils to prevent undue shrinkage. It would yield fertile land of high capability for arable crops and improved pastures, and probably of moderate capability for tree crops.

Land Use Capability Group 14.—This group comprises mainly low to high mountains, almost wholly above 9000 ft (Wilhelm, Giluwe, Kubor, and Ialibu land systems), but also the low hills of Limisate land system. Because of very steep slopes, low temperatures (except in Limisate land system), rockiness, and shallow soils there is no capability for arable crops, no or very low (Limisate land system) capability for tree crops, and a very low or no (Kubor, Ialibu land systems) capability for improved pastures. It could be possible to use the alpine grasslands of Wilhelm and Giluwe land systems for rough grazing, or to improve these grasslands for grazing, but their very isolated position militates against this. Moreover these areas, together with Kubor and Ialibu land systems, are important catchments so that grazing would have to be strictly controlled.

This group, apart from Limisate land system, is of great scenic value for the development of a tourist industry, and Wilhelm land system in particular has a definite potential for recreational development. Preservation of wildlife also is an important aspect of land use in this group.

III. Descriptions of Land Use Capability Classes and Subclasses

(*a*) *General*

Land in classes I–IV is suitable for cultivation, in decreasing order, class IV land being marginal for this form of land use. Land in classes V–VII is not suitable for cultivation but is suitable in decreasing order for tree crops and/or improved pastures and for forestry. Class VIII land is unsuitable for any form of agricultural land use. It should be noted that class II–IV land is always very suitable for improved pastures, but its suitability for tree crops depends on the subclass (nature of limitation).

The estimated areas and distribution of the land use capability classes and subclasses are given in Table 23. This shows the great preponderance of class VI, VII, and VIII land, which is largely due to the large proportion of steep hilly and mountainous terrain in the area (e subclasses). However, it should be remembered that whilst classes VII and VIII consist of very poor land indeed, much of class VI land could be profitably developed for grazing, tree crops, and forestry. The area of class I land is very small indeed (less than 1 %), indicating that nearly all land in the area has limitations of one kind or another. There is a sizable area of class II–V land (altogether 16 %) which, being largely concentrated in the valleys and foothills, offers the best possibilities for early development.

With respect to the nature of the limiting factors, and not considering class VIII land, it is clear that erosion hazards and topographic limitations (e) are by far the most common and apply to about 3300 sq miles of the area. Next in importance are physical soil limitations (st, stoniness; so_2, droughtiness; so_3, slow permeability), which occur in an estimated 750 sq miles, commonly overlapping with the erosion limitations. By comparison, limitations due to excessive water (d, poor drainage; f, flooding) are of minor areal extent (about 300 sq miles) but are important in that reclamation of such land commonly results in a large increase of its productivity.

(*b*) *Class I Land*

This 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 flooding. It is suited to most types of land use.

(*c*) *Class II Land*

This is good land that is not subject to flooding but requires simple special farming practices to maintain or reach optimum productivity when cultivated. It can generally be used without special limitations for other types of land use, but tree crops will require special measures where drainage is imperfect.

TABLE 23

ESTIMATED AREA AND DISTRIBUTION OF LAND USE CAPABILITY CLASSES AND SUBCLASSES

Land Class	Subclass	Area (sq miles)	Areal Distribution over Land Systems (sq miles)
I		40	Tari (18), Goroka (6), Kaugel (4), Bismarck (3·5), Moruma (3), Aiyura (1), Banz (< 1)
II		190	
	e	90	Tari (22), Teiga (15), Goroka (10), Nunga (9), Kumun (8·5), Omahaiga (8), Abiera (6·5), Bismarck (3·5), Moruma (3), Womei (2), Kaugel (1), Aiyura (1), Lai (< 1), Okapa (< 1), Banz (< 1), Tambul (< 1)
	e,st	2	Womei (2)
	st	< 1	Banz (< 1)
	so_2	15	Goroka (10), Moruma (3), Tari (1), Minj (< 1), Banz (< 1)
	d	80	Tari (23), Makuntus (11), Ko (11), Kinjibi (10), Teiga (7), Kaugel (5), Ogu (2), Omahaiga (2), Nunga (1), Tambul (< 1), Lai (< 1), Moruma (< 1), Banz (< 1), Okapa (< 1), Limisate (< 1), Winjaka (< 1)
III		160	
	e	90	Teiga (27), Nemarep (10), Omahaiga (9), Kumun (8·5), Yonki (7), Womei (4), Abiera (4), Tari (4), Bismarck (3·5), Pira (3), Moruma (3), Lai (1), Birap (1), Korambogl (1), Doma (< 1), Winjaka (< 1), Kaugel (< 1), Tambul (< 1)
	e,st	4	Womei (2), Oga (1·5), Kaugel (< 1)
	e,so_2	< 1	Minj (< 1)
	st	< 1	Banz (< 1)
	d	65	Kinjibi (15), Ko (10), Tari (8), Aiyura (5), Banz (5), Kumun (4), Omahaiga (3), Kaugel (3), Womei (3), Yonki (2), Ogu (2), Makuntus (2), Moruma (2), Okapa (1), Goroka (< 1), Tambul (< 1), Limisate (< 1)
IV		310	
	e,so_2	20	Abiera (13), Yonki (4), Korambogl (< 1), Kinjibi (< 1), Minj (< 1), Moruma (< 1)
	e,so_3	110	Abiera (29), Koge (24), Kumun (21), Womei (12), Omahaiga (7), Bismarck (3·5), Aiyura (3), Moruma (3), Yonki (2), Kaugel (2), Korambogl (2), Kinjibi (< 1), Minj (< 1)
	so_2	10	Moruma (6), Wahgi (1), Tari (1), Minj (< 1), Limisate (< 1), Banz (< 1)
	so_3	90	Makuntus (20), Banz (20), Kinjibi (10), Goroka (6), Kaugel (6), Tari (6), Womei (5), Aiyura (5), Kumun (4), Pira (3), Teiga (3), Moruma (2), Minj (1), Okapa (1)
	so_3,so_2	40	Tari (30), Minj (6), Abiera (4), Moruma (2), Korambogl (1)
	f	20	Kaugel (10), Wahgi (9), Ko (1), Goroka (< 1), Tambul (< 1)
	f,d	20	Wahgi (15), Kinjibi (3), Ko (1), Tambul (< 1)

V		25	
	st	4	Womei (2), Elimbari (1), Oga (1)
	f,d	10	Kaugel (10)
	d	10	Wilhelm (5), Kaugel (2), Ko (1), Goroka (< 1), Tambul (< 1)
VI		960	
	e	700	Bismarck (260), Koge (200), Teiga (80), Pira (26), Yonki (19), Okapa (17), Nemarep (12), Ambum (12), Kwongi (11), Omahaiga (10), Ogu (7), Korambogl (7), Moruma (7), Nunga (6), Elimbari (5), Abiera (4), Tari (4), Goroka (2·5), Winjaka (2·5), Birap (2), Womei (2), Doma (1·5), Minj (< 1)
	e,st	10	Elimbari (10), Winjaka (< 1)
	e,so_2	110	Koge (50), Ambum (24), Bismarck (17), Kumun (13), Yonki (4), Abiera (3), Womei (2), Moruma (< 1), Korambogl (< 1)
	e,so_3	100	Abiera (29), Kumun (25), Bismarck (17), Okapa (8), Womei (7), Moruma (4), Pira (4), Ambum (4), Goroka (3), Korambogl (< 1), Minj (< 1)
	d	40	Wahgi (12), Ko (11), Abiera (5), Tari (4), Kwongi (2), Tambul (1·5), Aiyura (1), Moruma (1), Ogu (< 1), Winjaka (< 1)
	f	< 1	Banz (< 1)
VII		1850	
	e	1560	Bismarck (940), Koge (150), Ambum (130), Pira (60), Yonki (57), Kubor (50), Kwongi (30), Nemarep (17), Okapa (17), Omahaiga (16), Moruma (14), Wilhelm (14), Ialibu (13), Doma (11), Teiga (8), Goroka (7·5), Nunga (6), Korambogl (6), Elimbari (4), Giluwe (2), Womei (2), Birap (2), Ogu (2), Makuntus (1), Minj (< 1), Winjaka (< 1), Tambul (< 1)
	e,st	10	Elimbari (10)
	e,so_2	220	Bismarck (140), Koge (50), Limisate (10), Pira (7), Okapa (4), Abiera (3), Goroka (3), Korambogl (1), Moruma (1)
	d	60	Wahgi (31), Ko (10), Abiera (5), Ogu (5), Nunga (2·5), Tambul (2), Winjaka (< 1)
VIII		700	Bismarck (350), Kubor (115), Ialibu (52), Wilhelm (45), Ambum (30), Koge (25), Lai (14), Doma (12), Nemarep (10), Kaugel (8), Giluwe (6), Limisate (6), Yonki (5), Pira (4), Elimbari (4), Ko (4), Tari (2), Wahgi (2), Kinjibi (2), Moruma (2), Banz (1·5), Ogu (1), Minj (1), Okapa (1), Makuntus (< 1), Goroka (< 1), Korambogl (< 1), Oga (< 1), Tambul (< 1)

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

IIe,st.—This land combines the limitations of subclasses IIe and IIst.

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

$IIso_2$.—The soils have a layer of iron concretions at shallow depth, disrupting water relations and root penetration, thus causing the soils to be droughty. A range of crops adapted to the prevailing climate can be grown if particular attention is paid to increasing and maintaining the water-holding capacity, which amounts to the incorporation of organic matter into the soil, or mulching, and probably also disturbing the concretion layer by deep ploughing.

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

(*d*) *Class III Land*

This is moderately good land, which is not flooded but requires intensive special farming measures to improve or maintain its productivity when cultivated. In many cases class III land can be used without special limitations for other forms of land use but, when the land is poorly drained, intensive measures are required for tree crops, less intensive for pastures.

IIIe.—The degree of erodability requires intensive erosion control measures when the land is cultivated, such as frequent rotation with grasses or legumes or intensive terracing. Crops that promote rapid erosion should not be grown.

IIIe,st.—This land combines the limitations of subclass IIIe and subclass IIst or IIIst.

$IIIe,so_2$.—This land combines the limitations of subclass IIIe and $IIso_2$.

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

IIId.—This land requires strongly improved drainage for arable crops and tree crops, less for pastures. This can be achieved by a system of fairly closely spaced deep drainage trenches.

(*e*) *Class IV Land*

This is fairly good land that can be cultivated occasionally and usually with more than normal hazards or that is suitable only for a very limited range of arable crops. Most of this land is best kept under perennial vegetation, but it is mostly rather poor land for tree crops.

IVe,so_2.—This land combines the limitations of subclass $IVso_2$ with those of subclass IIe or IIIe.

IVe,so_3.—This land combines the limitations of subclass IVso_3 with those of subclass IIe or IIIe.

IVso_2.—The soils are so droughty, usually because of dense concretion layers at shallow depth, and sometimes because of shallow depth of the soils or shallow coarse-textured subsoils, that the land should generally be kept under perennial vegetation to improve and maintain the water-holding capacity. In addition, this land may have an erosion hazard according to subclass IIe or IIIe. It can be cropped once every few years and the choice of crops is likely to be limited. It is good for pasture land but poor for tree crops.

IVso_3.—The soils are poorly drained because of their very slow permeability and locally because of strong seepage. It appears to be very difficult to improve the drainage significantly. The land is good pasture land and can be cropped to a limited range of crops after proper improvement of the surface drainage. It does not appear to be very suitable for tree crops.*

IVso_2,so_3.—This land is droughty in dry periods because of a dense concretion layer, and poorly drained in wet periods because of a slowly permeable clay layer. It requires surface drainage and should generally be kept under perennial vegetation to improve and maintain the water-holding capacity. It is suitable for pastures, little suited for tree crops, and can be cropped occasionally with a limited range of crops.

IVf.—Non-destructive floods are likely to occur each year during the wet season and flood control is not feasible. There is a flood-free period during the dry season sufficiently long for the land to be cropped without undue hazards. The choice of the crops may be limited by the length of the flood-free period. This land is suitable for grazing and some of it may be suitable for tree crops.

IVf,d.—This land combines the limitations of subclass IVf with those of subclass IId.

(*f*) *Class V Land*

This land is unsuitable for cultivation for reasons other than erosion hazards. It is good grazing land that can be managed without special limitations, apart from surface drainage of poorly drained land. This land is usually unsuitable for tree crops.

Vst.—This land is too stony for cultivation and the stones are too numerous to be removed. It may also have erosion hazards according to subclass IIe or IIIe. It is suitable for pastures and locally for tree crops.

Vd.—This land is too poorly drained for arable or tree crops and the drainage cannot feasibly be improved because of low topographic position or strong seepage. The land is suitable only for pastures.

Vf,d.—This land is flooded too regularly to carry out the intensive drainage improvement measures that would be required for cultivation. It is suitable only for pastures.

* It appears from more recent experience that some soils in this class in the Wahgi valley respond better to artificial drainage than was anticipated.

(*g*) *Class VI Land*

This land is not suitable for cultivation and is subject to moderate limitations for pastures. One subclass is also suitable for tree crops with moderate limitations. Most subclasses are suitable for forestry.

VIe.—This land has such serious erosion hazards that it is suited for tree crops or pastures only under careful management. It is also suitable for forestry. It can have stoniness according to subclass IIst or IIIst.

VIe,st.—This land is similar to subclass VIe, but has in addition stoniness according to subclass Vst. This tends to make the establishment of tree crop plantations and improved pastures more difficult.

VIe,so_2.—This land is similar to subclass VIe, but has in addition droughty shallow soils according to subclass IVso_2.

VIe,so_3.—This land is similar to subclass VIe, but has in addition poorly drained slowly permeable soils which render it much less suitable for tree crops.

VId.—This land is so poorly drained and so difficult to reclaim that it has only a limited suitability for pastures under careful management. In several areas it is also subject to flooding in the wet season.

VIf.—This land is so frequently flooded that it has only a limited suitability for grazing.

(*h*) *Class VII Land*

This is not cultivable and is subject to severe limitations for grazing. Most subclasses are suitable for forestry under careful management, and where possible this appears to be the best use to which this land can be put. But where the class is determined by poor drainage, the land is unsuitable for forestry. One subclass can be used for tree crops if intensive measures are taken to prevent erosion.

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.

VIIe,st.—This land combines the limitations of subclass VIIe and Vst, and is suitable only for extensive grazing or forestry.

VIIe,so_2.—This land combines the limitations of subclass VIIe with those of subclass IVso_2. It is suitable only for extensive grazing under careful management and has a limited suitability for forestry.

VIId.—This comprises very poorly drained land, which could be used only as poor grazing land if the surface drainage were improved. In some areas it is also flooded in the wet season.

(*i*) *Class VIII Land*

This land has such unfavourable characteristics as to be unsuited to cultivation, tree crops, grazing, or forestry. In many cases it is important for water-shed protection. Small areas are covered by good forests, but their exploitation would be very difficult. No subclasses are indicated for this land class as the limiting factors are only of academic interest and can be deduced easily from the land system descriptions. Much of this land, together with large areas of class VII land (except subclass VIId), is of scenic interest and thus of value for the tourist industry. It includes alpine areas and limestone features with a substantial potential for recreation. It is also of great importance for wildlife conservation.

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Fig. 1.—Rugged mountains of the Kubor Range (Bismarck land system), covered with mixed lower montane rain forest and beech forest. Tufted *Cordyline* and plumed heads of sword grass mark the edge of a garden at 8000 ft above sea level.

Fig. 2.—Steep dissected slopes of Pira land system in the Chimbu area, with native food gardens and fallow vegetation, notably groves of *Casuarina* trees.

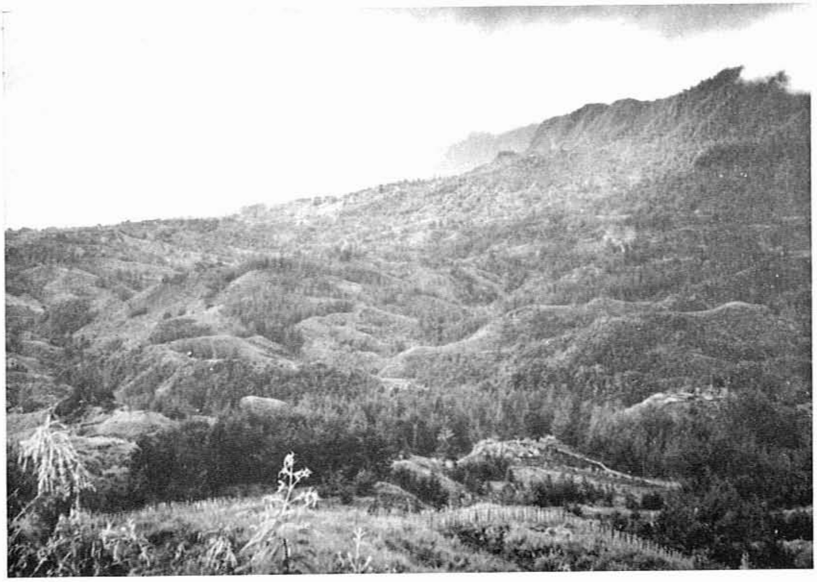

Fig. 1.—The irregular, slumped hilly country of Kumun land system (foreground) merges into the strongly slumped low mudstone hills of Womei land system at the foot of the limestone escarpment of Elimbari land system (background). Groves of planted *Casuarina* trees are abundant throughout.

Fig. 2.—Short grassland and remnant beech forest with emergent *Araucaria* pines in the steep hilly uplands of Okapa land system, with graded rivers and a dense drainage pattern. The village is situated on a terrace remnant.

Fig. 1.—Tussocks of alpine grassland in the summit area of Mt. Hagen (Giluwe land system), with outliers of montane rain forest and subalpine scrub, at 11,000 ft above sea level. Lava outcrops mantle the outer slopes of the old crater rim.

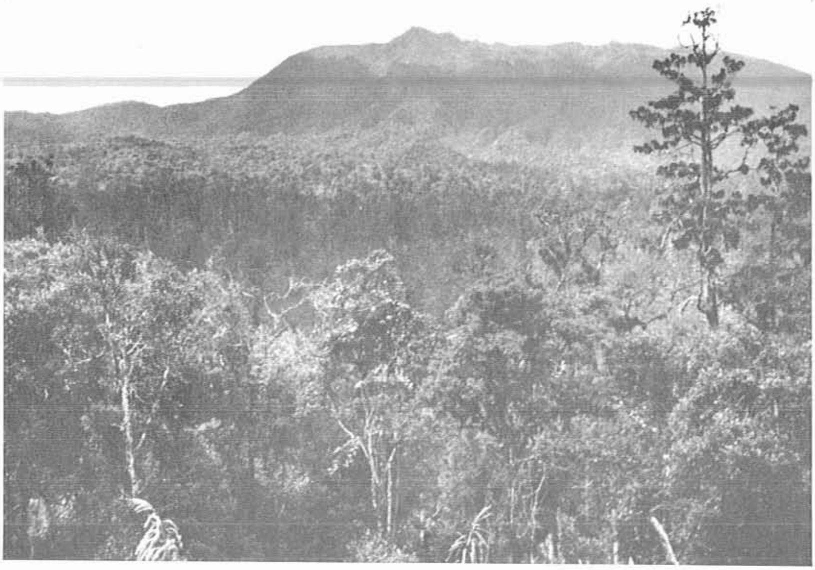

Fig. 2.—Forested headwater basin of the Nebelyer River (Nemarep land system) at 8500 ft above sea level, with Mt. Hagen in the background. *Papuacedrus* form tall emergents over a mixed broad-leaf canopy.

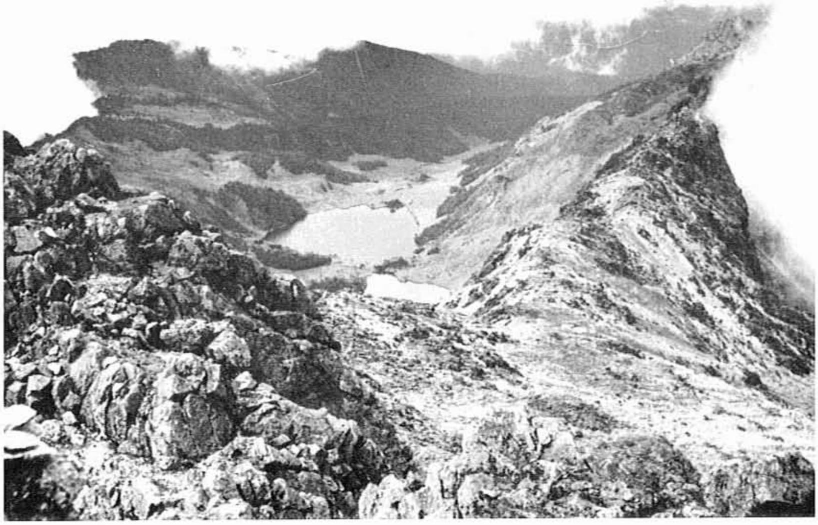

Fig. 1.—View from summit ridge of Mt. Wilhelm (Wilhelm land system) into the glacial valley of Pindaunde with stepped kar lakes and moraines. Vegetation is sparse and on the summit limited to rock crevices. Lower down are alpine grassland and the irregular pattern of montane rain forest.

Fig. 2.—Gardens occupy Pleistocene colluvial fan deposits of Omahaiga land system with *Miscanthus* sword grass and shrub regrowth, predominantly *Saurauja* sp. The oak-forested slopes in the background are in Bismarck land system.

Fig. 1.—Dissected Pleistocene lake deposits of Abiera land system in foreground and middle background, separated by a flat high terrace of Makuntus land system on which Kainantu airstrip is seen.

Fig. 2.—Deeply incised stream (Lai land system) in the volcanic ash plains of Teiga land system near Mt. Hagen; *Miscanthus* sword grass, remnant forest, and stream-bank vegetation.

Fig. 1.—Typical *Miscanthus* sword grass country as seen in the Kaugel valley (Winjaka land system). In the background are the forested lower slopes and cloud-covered summit of Mt. Giluwe. A small sedge bog is located behind the tall grass in the foreground.

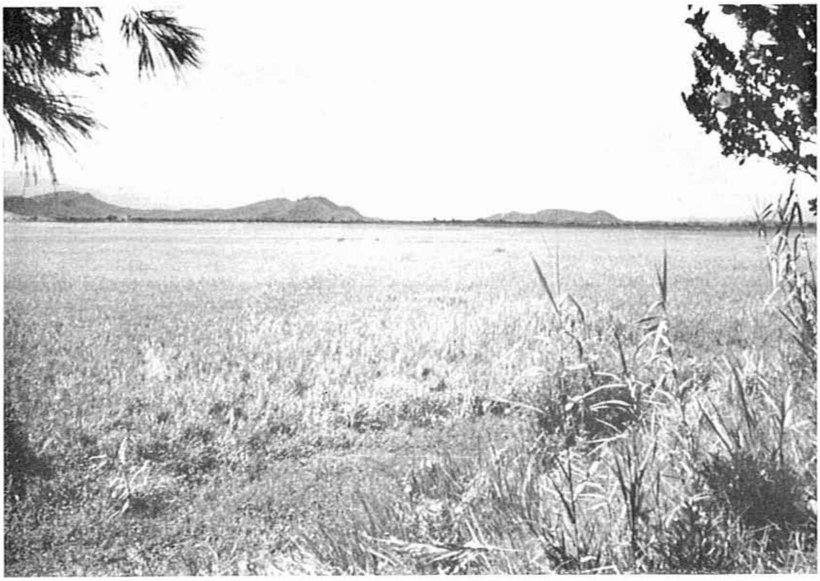

Fig. 2.—Level flood-plain swamp with *Phragmites* on peat soil in the upper Wahgi valley (Wahgi land system).

Edge of mixed lower montane rain forest in the Bismarck Range. Tall trees here are *Cryptocarya*, *Elaeocarpus*, *Opocunonia*, *Syzygium*, and *Podocarpus*.

Interior of tall beech forest (*Nothofagus*) in the Eastern Highlands. *Pandanus* and climbing bamboo form an under-storey.

Fringe of subalpine scrub on Mt. Wilhelm, at approximately 13,000 ft above sea level, showing silvery foliage of *Olearia* sp. and undergrowth of *Coprosma* sp.

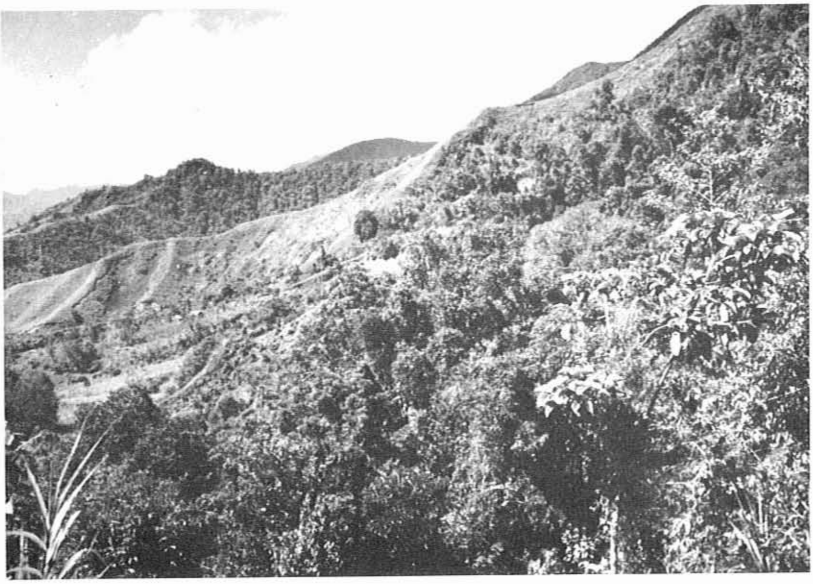

Fig. 1.—Remnant and secondary oak forest dominated by *Castanopsis acuminatissima* in the foothills of the Kubor Range (Koge land system). In the foreground is *Schefflera* sp. in flower.

Fig. 2.—A newly made garden cleared from lower montane rain forest at 7000 ft above sea level in the Kubor Range. Note the protective fence against pigs, and trenches to form the raised sweet potato beds. Acid yellow-brown clay soil with poorly developed topsoil.

Fig. 1.—Mixed short grassland of *Themeda* and *Capillipedium* with *Arundinella*. The background shows the even skyline of a dissected Pleistocene alluvial fan (Moruma land system) descending to the Wahgi River at left.

Fig. 2.—Remnant grove of *Araucaria cunninghamii* at Dunantina. Also shown are stream-bank vegetation and plantations of bamboo and *Casuarina*. Closely dissected volcanic hills with lithosols of Limisate land system form the background at left.

Fig. 1.—Arabica coffee is the most important cash crop; about 6000 tons were produced by indigenous, and 3500 tons by non-indigenous growers in 1965–66, mostly in modern factories like this one at Kundiawa.

Fig. 2.—The area possesses the densest road net in the territory, some 2200 miles frequently built by hand. Currently the main access road to the coast and other roads are being upgraded by re-survey and heavy machinery.