Explanatory Notes to the Geomorphological Map of Papua New Guinea

By E. Löffler

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MAP

EXPLANATORY NOTES TO THE GEOMORPHOLOGICAL MAP OF PAPUA NEW GUINEA

By E. LÖFFLER*

I. INTRODUCTION

The aim of the geomorphological map of Papua New Guinea is to give a graphic representation of the distribution of land forms as part of a natural resources inventory covering the whole country. It is thus a first attempt at a systematic synthesis of the geomorphology of this country. This involved summarizing and integrating existing work on geomorphology and extending this over areas previously not covered by land resources surveys. The principal sources of information were the existing land system maps and reports in the CSIRO Land Research Series (listed on back cover) which cover about 40% of the country (Fig. 1). The remainder of the area was newly mapped on aerial photographs and radar imagery. Geological maps published by the Bureau of Mineral Resources provided valuable additional information, in particular on rock types.

This paper is only a supplement to the map and is by no means exhaustive. A detailed treatment of the geomorphology of Papua New Guinea is in preparation. The short bibliography includes recent publications, to which the reader is referred for further information.

In contrast to developments in Europe, where a great number of geomorphic maps at different scales have been produced and great efforts are made to unify the legends of these maps (Klimaszewski 1963; Gellert 1969), little such work has been done in humid tropical areas like Papua New Guinea. Some exceptions are the work of German geomorphologists in Africa, where a thematic mapping programme at a scale of 1 : 1,000,000 of different environments is in progress (Mensching 1968), and of Tricart and collaborators in South America (Tricart and Michel 1965). However, the geomorphic problems and properties of the African landscape with its old erosional surfaces, inselbergs, and pediments are so different from those of New Guinea with its young mountain system and active depositional plains that the legends could not be made compatible.† Tricart's work in the South American Andes, on the other hand, being based on extensive field studies, is much too detailed (scale 1 : 25,000) to be relevant here. The legend and design of the geomorphological map of Papua New Guinea are therefore based mainly on the author's own experience in New Guinea and on previous work on the geomorphology of this country incorporated in the land resources surveys.

Ideally, a geomorphic map should give information on the shape, dimension, origin, and age of land forms, and possibly also on rock types and processes. Obviously it is impossible to present all these aspects on a single map without rendering it unreadable, and the compiler must choose those factors he considers most important

* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

† The author is grateful to Dr. K. Giessner for supplying information on the designs of the geomorphic maps of the "Afrika Kartenwerk" programme.

for the characterization of land forms in his particular area. The choice will vary according to the morphotectonic and morphoclimatic region the area is part of, the state of knowledge on the geomorphology of the area, the scale of the map, the special interest of the compiler, and the potential user for whom the map is intended. In spite of considerable advances in our knowledge of land forms in Papua New Guinea during the last decade, information is still very sketchy and uneven. Field studies are greatly impeded by the very difficult terrain, especially in areas covered by rain forest, and aerial photographs and more recently radar imagery have become increasingly valuable tools in the study of land forms and other land resource assessments.

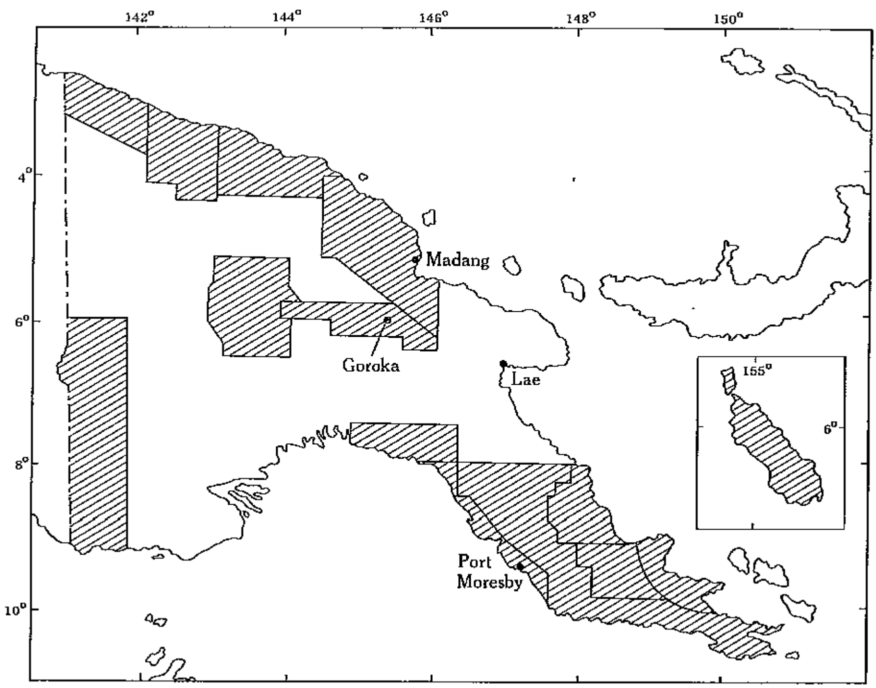

Fig. 1.—Areas of Papua New Guinea covered by land resources surveys carried out by the CSIRO Division of Land Use Research.

The geomorphic map is based very largely on air-photo interpretation and is therefore essentially a descriptive map of air-photo patterns. The main groupings are made on a very broad genetic basis, distinguishing between erosional, volcanic, and depositional land forms. The criteria used for further subdivisions are not strictly consistent as one naturally selects different criteria to distinguish between erosional land forms and between depositional land forms. The erosional land forms are distinguished according to the dominant erosional process and the kind of structural control expressed. The volcanic land forms are distinguished according to the stage of dissection, while the depositional land forms are subdivided according to the river regimes as far as can be determined from the aerial photographs. From the two main dimensional parameters, relief and slope, only relief has been incorporated for reasons of readability. However, except for a few instances relief and slope value are roughly correlated, though of course they are not directly comparable. Contours are not shown on the map because this information is not available for large parts of the country. The approximate distribution of the altitudinal zones can be seen in Figure 2. The great majority of land forms in Papua New Guinea are recent in the sense that present-day denudational processes are responsible for their formation. Some relict land forms do occur, however, such as formerly glaciated areas and relict surfaces and structurally controlled plateaux that were adjusted to different base levels of erosion from the present ones.

Rock type is included because it is considered to be one of the major factors in determining not only major land form complexes such as karst but also finer land form differences such as dissection pattern, drainage density, and slope form.

The classification of the rock types is fairly coarse and based on relatively simple criteria such as origin, predominant chemical composition, and grain size of the parent material. The four main classes are sedimentary rocks, metamorphic rocks, igneous rocks, and unconsolidated deposits. The sedimentary rocks are subdivided into calcareous and non-calcareous rocks and the latter are further separated according to the predominant grain size. Fine-grained sedimentary rocks include those composed of silt and finer sediments (siltstone, mudstone, shale, marl) while coarse-grained sedimentary rocks consist of sand and coarser material (sandstone, greywacke conglomerate).

The metamorphic rocks are subdivided according to the degree of metamorphism. Most of the metamorphic rocks in Papua New Guinea are low-grade metamorphics, mainly shales and phyllites. High-grade metamorphics occur in most areas only locally within the low-grade metamorphics, except on the islands to the east of Papua New Guinea where they form the dominant rock type.

The igneous rocks encompass volcanic rocks and intrusive rocks. The classification of the volcanic rocks is difficult as their composition varies not only from one volcanic area to another but also within one volcanic centre from one lava flow to another. The type given on the map is thus only an indication of the composition of the most commonly occurring rock and does not take into account the range in composition. In the highlands of Papua New Guinea, volcanic rocks of basic to intermediate composition (mainly basalts) can be regarded as the rule while on the islands to the north of Papua New Guinea rocks of acid to intermediate character (low silica andesites) are the most common.

The intrusive igneous rocks are not as variable as the volcanic rocks and there are extensive areas of relatively uniform rock types. Most common are acid to intermediate rocks (granite, granodiorite) and basic rocks (gabbro, diorite). Ultrabasic rocks (peridotite, pyroxenite, dunite) occur extensively in the east of Papua New Guinea.

The unconsolidated deposits include alluvial deposits which encompass all fluvially transported sediments and volcano–alluvial deposits which consist largely of fluvially redistributed volcanic products but also of lahars and ash deposits.

It is hoped that the geomorphic map will not only be useful to geomorphologists but also be of some value to all those concerned with natural resources and their

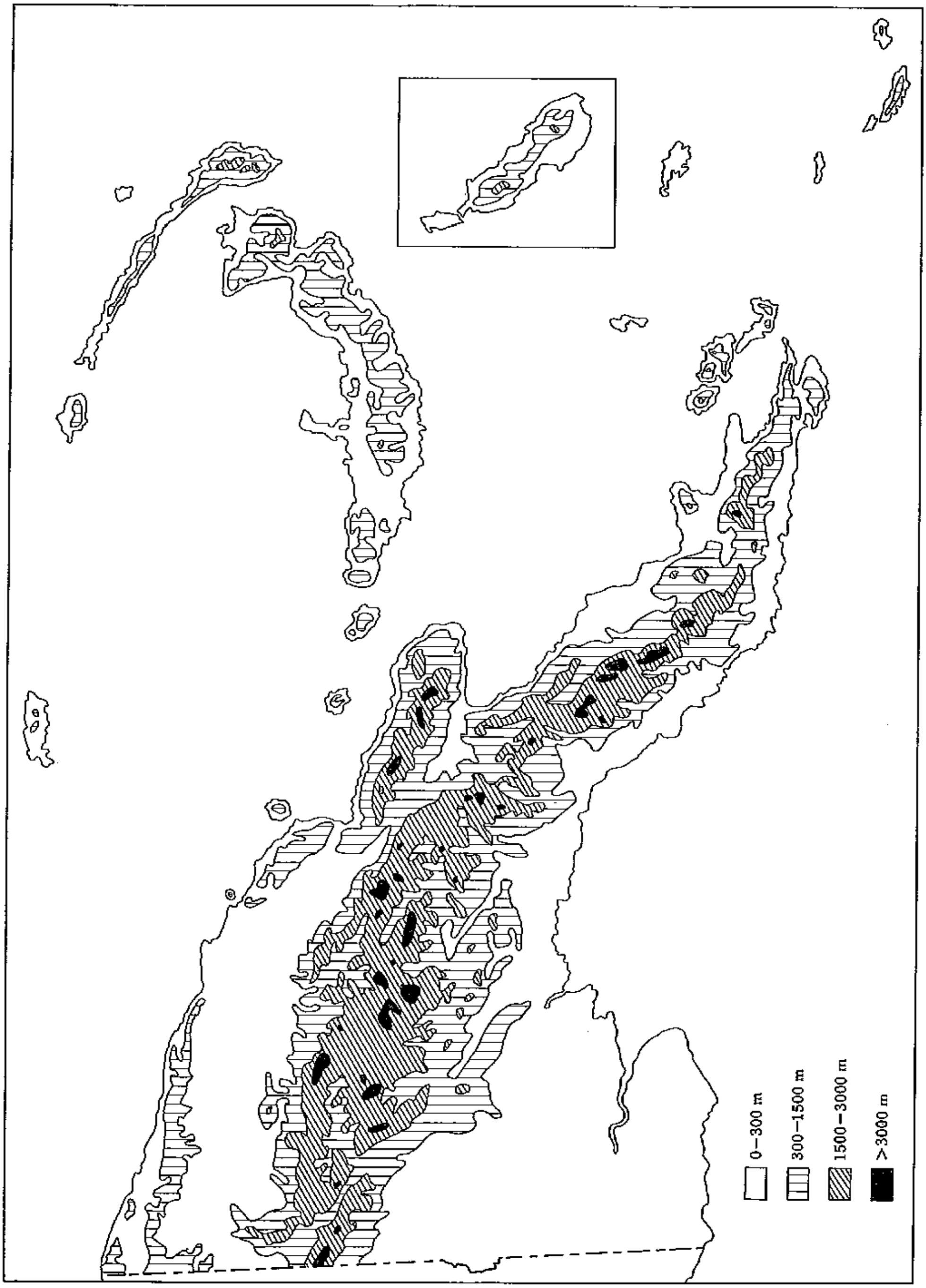

Fig. 2.—Altitudinal zones of Papua New Guinea.

development and management, such as planners, engineers, hydrologists, agriculturalists, and conservationists. The following text, therefore, is aimed more at those who are not very familiar with geomorphic maps and terms than at the geomorphologist, who will probably find the map self-explanatory to a large degree.

II. Denudational Land Forms

(*a*) *Land Forms of Fluvial Erosion and Mass Movement without or with Weak Structural Control*

(i) *Ridge-and-ravine Land Forms.*—Ridge-and-ravine land forms, also known as selva land forms or Kerbtalrelief (Sapper 1935), are clearly the most widespread land form complex in Papua New Guinea. Ridge-and-ravine land forms basically are ridges with steep slopes, narrow and sharp crests separated by V-shaped ravines, and valleys with steep gradients (Plate 1). This simple description does not account for the great variety which is incorporated in this land form complex. There are great differences in rock types, the pattern of dissection, drainage density, slope form, slope steepness, relief, and orientation and accordance of ridge crests. It would have been difficult to map all these differences consistently, especially as there are many transitional forms and overlappings.

Relief and rock type which are consistently used for all land form complexes are particularly important properties to further distinguish between the ridge-and-ravine land forms. Though detailed investigations on the interrelationship between rock type, drainage density, dissection pattern, and slope form have not been made, it is certain that rock type in its response to weathering and erosional processes determines a great number of these properties. The following qualitative generalizations are the result of experience over large areas of Papua New Guinea where land resources surveys have been made.

On igneous rocks, drainage systems are generally coarse and slopes are relatively straight, smooth, and of a rather uniform steepness, varying between 30° and 40° (Plate 1). In areas of high relief this is better developed than in areas of low relief. Good examples of this massive igneous ridge-and-ravine land form complex are found in the central parts of the Bewani and Torricelli Mountains, in the southern fall of the Saruwaged Ranges, and in parts of the Bismarck Ranges.

Deeply weathered igneous rocks which occur on some relict surfaces have, however, a much denser drainage system and gentler slopes and appear to be more like sedimentary rocks in their response to erosional processes.

Sedimentary rocks vary greatly in composition, in degree of induration, and in bedding and, as a great variety of them are interbedded in many areas, any generalizations are difficult to make. The following can be said of relatively uniform sedimentary rocks. Fine-grained sedimentary rocks such as marl, mudstone, and shale normally have very irregular, intricately dissected slopes with slope angles varying enormously over short distances (Plate 1). The softer the rock the more chaotic the slopes tend to be. This slope irregularity is more pronounced on the ground than on the aerial photos where it is masked by the dense forest canopy. The slope irregularities are caused by slumping which is a process of relatively deep-seated slope failure along a concave slip plane with typical backward rotation of the slip block. Dissection pattern and drainage network are fine-grained.

Slopes developed on coarse-grained sedimentary rocks such as greywacke and sandstone are less irregular and less dissected than on fine-grained sedimentary rocks. Deep-seated slumps also occur and are often considerably larger in extent than on fine-grained rocks where they tend to be more numerous but smaller. The drainage is relatively coarse.

Slopes on limestone are straight and very little dissected. Rock outcrops are frequent and drainage densities very coarse. However, ridge-and-ravine land forms on limestone are rare, as in most limestone areas karst land forms or strike ridges are developed.

General statements on metamorphic rocks are particularly difficult as there is great variation in composition and degree of metamorphism. The drainage network is mostly coarse and the slopes are relatively smooth, steep, and straight. Superficial landslides are more common than slumps but this also depends on the degree of weathering. Good examples of coarse-grained ridge-and-ravine land forms occur in the Owen Stanley Ranges and in the north-western parts of the Central Ranges.

(ii) *Ridge-and-ravine Land Forms associated with Relict Surfaces.*—Relict surfaces are widespread features in the Owen Stanley Ranges, mainly on the principal watershed but also on some off-branching divides (Plate 2). They vary considerably in altitude and rise from about 200 m at the eastern end of Papua New Guinea to an average of 2800–3400 m at Mt. Albert Edward from where they fall gradually to between 1500 and 2000 m around Lake Trist and Mt. Missim. These relict surfaces are not former peneplains but are also ridge-and-ravine land forms with a distinctly lower relief, less steep gradients of the rivers, and, as far as the limited field observations show, a more mature and thicker weathering profile than the surrounding landscape. The transition from the older surfaces to the younger ridge-and-ravine land forms is mostly abrupt and often marked by distinct breaks of slope in the rivers, occasionally giving rise to waterfalls and a clear change in the pattern of dissection from a fine-grained pattern on the surfaces to a much coarser-grained pattern in the younger landscape below. The older surfaces have obviously not been reached by the present cycle of erosion and were adjusted to base levels different from the present ones.

It is not certain whether all these surfaces are contemporaneous but, as nowhere have two surfaces developed above one another and as they can be traced along much of the main watershed, it is assumed that they represent the relicts of one major erosional cycle.

Observations by Smith (1970) in the Milne Bay area have shown that some of these surfaces are developed on Miocene and also possibly Pliocene rocks. The surfaces are thus post-Miocene, possibly late Pliocene, and indicate a period of relative tectonic stability allowing the formation of these landscapes relatively close to sea level. This was followed by strong uplift in the late Pliocene and Pleistocene resulting in vigorous erosion which all but destroyed these surfaces.

(*b*) *Land Forms of Fluvial Erosion and Mass Movement with Prominent Structural Control*

In this mapping complex the land forms are at least partly a topographic expression of the structure of the underlying rock or tectonic processes, or both. The great majority of structurally controlled land forms in Papua New Guinea reflect such structural features as bedding, foliation, joint patterns, and fault patterns. There are also some examples of purely tectonic forms such as the spectacular fault plane of the Owen Stanley fault. However, such tectonic forms are normally too small in extent to be mapped out separately.

(i) *Homoclinal Ridge-and-ravine Land Forms.*—The most common types of structurally controlled land forms are homoclinal ridges (Plate 3). Here the original bedding of the sediments and subsequent folding, faulting, and tilting along major structural axes have guided the erosional processes so as to produce asymmetrical ridges with gentler dip slopes and steeper outcrop slopes. The dip slopes of the homoclinal ridges generally range from 10° to 25°. The most commonly occurring rock types are well-indurated mudstone and sandstone and limestone often interbedded with layers of less indurated rock. Although some dip slopes may appear very smooth and regular on the aerial photos, on the ground they are mostly irregular owing to slumping and gullying.

(ii) *Strike Ridges and Hogback Ridges.*—The distinction between these and the homoclinal ridges is somewhat arbitrary and more a matter of degree than of principle. Strike ridges and hogback ridges have dip slopes generally exceeding 25° (Plate 4). With increasing steepness of the dips the ridges may approach a symmetrical form as both the dip and outcrop slope approach the angle of the repose. The dominant rock type is limestone which produces some very spectacular strike ridges in the western parts of the Central Ranges.

(iii) *Structural Plateaux.*—Structural plateaux are high-lying, generally irregular surfaces on essentially flat-lying or gently dipping rock (Plate 5). They are formed on relatively resistant rock such as limestone and owe their existence to the fact that the fluvial incision has not kept pace with the rapid uplift.

The erosion along the edges of the plateaux is vigorous, being exemplified in frequent stream capture and continued reduction of the extent of the plateaux. It must be stressed, however, that these structurally controlled plateaux are with few exceptions not surfaces of the original bed-rock. The present land surface nearly always cuts across the bed-rock structures so these plateaux are, strictly speaking, relict surfaces. Extensive structural plateaux occur in the Saruwaged Ranges and in the western parts of the Central Ranges. Most structural plateaux have been strongly modified by karst processes and so are included in the land forms of karst erosion.

(iv) *Sloping Structural Surfaces.*—These are essentially similar to structural plateaux except that they consistently slope in one direction (Plate 6). Like the plateaux, these surfaces are irregular in detail but their level of accordance forms an excellent plane. The two main examples of this land form complex are the limestone surfaces along the northern flanks of the Huon Peninsula and the spectacular surface of the Dayman Dome in east Papua.

(*c*) *Land Forms of Karst Erosion*

Large areas of Papua New Guinea are formed on limestone and in most of these, though not in all, karst land forms are present. Karst land forms are the result of the solution of limestone by rain, surface water, and ground water and are characterized by the absence or poor development of a surface drainage network. Most of the karst land forms are developed on structural plateaux. To avoid complex mapping units all structural plateaux dominated by prominent karst land forms have been included in this mapping category.

Jennings and Bik (1962) observed that there is an altitudinal zonation of karst development in certain karst areas in Papua New Guinea. The typical karst forms in the lowest zone (0–200 m) are small, roughly hemispherical hills or cones with typical star-shaped depressions (Plate 7). This type of karst is regarded as typical for humid tropical lowlands.

In the intermediate zone (200–2000 m), the dominant land forms are steep-sided pyramidal hills and spire-crowned towers with precipitous slopes. Structural lineations are prominent. In other areas in this zone enclosed conical or bowl-shaped depressions more similar to the European doline karst are present.

In the highest zone (about 3000 m), there appear to be three types of karst, doline karst, pyramid karst, and a most spectacular type consisting of vertically walled, knife-edged aretes and pyramids of bare limestone. While Jennings and Bik (1962) admit that this altitudinal zonation is not clear-cut but is complicated by differences in lithology, evolutionary history, and structure, it is also possible that large differences in the composition, structure, and thickness of the limestone strongly override climatic factors and the different karst forms are a reflection of the great variety of lithologies of the limestone.

(i) *Polygonal Karst.*—The most widespread land forms are plateaux or broad ridges dotted with steep-sided pyramidal hills, spire-crowned towers, or roughly hemispherical hills surrounding enclosed depressions roughly polygonal in shape (Plate 7). In spite of the great variety in positive forms the depressions are relatively uniform and, according to recent investigations by Williams (1972), appear to be the main loci for karst development. The term polygonal karst is used to describe collectively all the above-mentioned land forms.

(ii) *Plateaux with Karst Corridors.*—Another type of karst land form is the flat-topped plateau with narrow corridors cut into the limestone preferentially along joints, faults, and other lines of weakness (Plate 8). Here karst erosion is not the sole process; fluvial incision is equally important. However, as the drainage network is not fully integrated (though some permanent surface streams are present) the land forms are still regarded as karst. The occurrence of this land form is restricted to the Darai Plateau north-west of Kikori and Bougainville Island.

(iii) *Karst Plains.*—Karst plains or karst border plains are flat to gently undulating plains on limestone and occur where the base level of karst erosion, the sea level, or main river (Vorfluter) has been reached (Plate 7). A veneer of alluvium of variable thickness generally covers these plains and seals off the limestone surface.

(iv) *Doline Karst.*—Dolines are closed depressions, circular to oval in plan, and conical to bowl-shaped in cross-section. They vary greatly in size from a few metres to over 100 m in width and depth (Plate 5). Doline karst is used to describe land forms characterized by frequent occurrence of these depressions. However, as these dolines in most cases represent only minor modifications of the general land surface, doline karst is not mapped as a separate category, but the presence of dolines is indicated by a symbol.

(d) Land Forms of Glacial Erosion

Owing to the dominance of a single erosion process, glaciation, land forms of glacial erosion present another group of land forms. Although there are no contemporary glaciers or permanent snowfields in Papua New Guinea, during the Pleistocene, when temperatures were about 5–6 degC lower than today and the snowline was at about 3550 m, relatively extensive glaciers covered most of the higher peaks (Löffler 1972). The largest areas covered by ice were on Mt. Giluwe (188 km^2), Mt. Wilhelm (107 km^2) (Plate 9), Mt. Albert Edward (90 km^2), the Saruwaged Range (80 km^2), Mt. Scratchley (28 km^2), the Kubor Range (27 km^2), and Mt. Hagen (21 km^2). The total area covered by ice amounted to some 600 km^2. Glacial features such as cirques, overdeepened rock basins, U-shaped valleys, and moraines are very well preserved and give the landscape its distinctive alpine character (Plate 9), strongly contrasting with the ridge-and-ravine landscape below the formerly glaciated area.

Most of the glacial features were formed during the last glacial period but there is some evidence, mainly from Mt. Giluwe, to indicate that there was an earlier period of glaciation.

III. Volcanic Land Forms

Active and recently active volcanoes (Quaternary volcanoes) are prominent features of the Papua New Guinea landscape. They occur in widely separated areas as either irregular clusters on the mainland or chains of volcanoes, so-called volcanic arcs in the Bismarck Sea.

The larger volcanoes characteristically rise 1500–2000 m above their surroundings. The great majority of these are stratovolcanoes built up of lava flows and pyroclastics; they include both ash-flow and ash-fall deposits. The stratovolcanoes are typically conical in shape with steep sides dissected by narrow gullies leading down to broad, gently concave volcano–alluvial fans. Examples include Mt. Bagana, Bougainville, which is in an almost continuous state of eruption; the active volcanoes of Mt. Ulawun, New Britain, and Manam (Plate 10), an island north-west of Madang; the extinct Mt. Bosavi volcano, western Papua; and in south-east Papua, Mt. Lamington, which erupted in 1951, and Mt. Victory, which was last active in the 1890s. These and other similar volcanoes have well-developed radial drainage patterns. Many have smaller parasitic volcanoes on their flanks and summit areas, marring the generally smooth profile of the stratovolcano. In some cases stratovolcanoes coalesce to form composite cones such as Mt. Balbi, Bougainville.

Lava shields, another type of large volcano, have broad convex profiles and are formed predominantly of highly fluid lava flows. Mt. Giluwe, in the highlands, is an extinct lava shield rising from 2200 m to 4368 m. It has numerous parasitic volcanoes on its flanks and has a well-developed radial drainage pattern; however, its summit area has been modified by subsequent late Pleistocene glaciation (Blake and Löffler 1971).

Several volcanoes formed mainly of pumice occur on New Britain. They are broad and relatively low cones with gently sloping sides, and commonly have central calderas.

Calderas, volcanic depressions several kilometres across and bounded by walls which may be several hundred metres high, are common along the southern Bismarck Sea volcanic arc. Examples include Rabaul and Dakatoa calderas on New Britain.

Various types of small volcano occur mainly as parasitic cones on large volcanoes. Scoria cones and mounds, generally less than 200 m high, are common and may mark the eruptive sites of fluid lava flows. Lava domes, steep-sided and formed of viscous lava, have convex profiles with no summit craters and may be several hundred metres high and in diameter. Maars are craters that extend below general ground level and are considerably wider than they are deep. All three types of volcano occur as parasitic volcanoes on the Managalase Plateau in south-east Papua.

The volcanoes are in various stages of dissection. Those still active are generally little eroded, apart from gullies and narrowly incised valleys at their flanks. In several cases, however, one or more incised valleys become wider upslope to form large amphitheatre-headed valleys. Extinct volcanoes have suffered more erosion although most are still relatively well preserved.

(*a*) *Volcanic Cones and Domes*

Mapping was based on differences in form and degree of dissection rather than on genetic type of volcano. The partly dissected volcanic cones and domes include all volcanoes where the original surfaces are preserved or at least partly preserved as flat but steeply sloping interfluves (Plate 10). They include most of the younger volcanoes and all the recently active ones. Active and extinct craters and calderas are shown by special symbols. The strongly dissected volcanoes (Plate 11) encompass volcanoes where the original surfaces have been reduced to narrow ridge crests and only the crest accordance and the radial drainage pattern indicate the volcanic land form.

(*b*) *Volcanic Foot Slopes and Volcano–Alluvial Fans*

Volcano–alluvial fans have been subdivided in a similar manner. As implied by the name, volcano–alluvial fans are not solely the result of volcanic activity but are largely formed by fluvial redistribution of volcanic material at the foot of the volcanoes. Nevertheless, the fan formation is closely linked with the formation of the volcano and they have therefore been included in this land form complex.

(*c*) *Volcanic Plateaux*

Volcanic plateaux are another type of volcanic land form, being formed of thick successions of flat-lying lava flows. As with structural plateaux, the present land surface is not the original surface of the bed-rock but has been substantially modified by erosional processes. Volcanic plateaux occur east of Port Moresby and in the Central Ranges west of Mt. Hagen where they form the Sugarloaf Plateau.

IV. Depositional Land Forms

This group includes land forms which owe their existence to processes of fluvial and littoral deposition. It includes dynamic land forms where the depositional processes are still going on and relict depositional surfaces that are above flood level or sea level due to tectonic events or changes in fluvial regime and are now subject to denudational processes.

(a) *Recent Alluvial Plains*

Most recent alluvial plains in Papua New Guinea consist of a central flood-plain and wide marginal plains, mostly so-called back plains. Where possible the flood-plains have been mapped separately from the associated plains as they represent a distinctively different environment. Where, because of the small size of these land forms, only the whole complex could be mapped, they have been called composite recent alluvial plains.

(i) *Meander Flood-plains.*—Meander flood-plains consist of a highly meandering channel, numerous cut-offs forming oxbow lakes and swamps, low discontinuous levees, point bars, and many scroll complexes (Plate 12). The meanders move freely and frequently within the meander belt but the main channel can also completely alter its course by forming a new flood-plain across the flanking back plain. A recent example of this kind of event is the change of the lower course of the Angabunga River (Speight 1965), but more examples can be traced on aerial photographs.

(ii) *Levee Plains.*—Levee plains form a more stable type of flood-plain consisting of a single channel and bordering levees (Plate 13). Levees in Papua New Guinea are generally low and are commonly topped by the rivers during floods. Levee plains are usually very small in extent, forming only a narrow band parallel to the river and only in the case of the lower Fly River has the levee plain been distinguished from the back plains. All other levee plains have been mapped as levee–back plain complexes called composite levee plains.

(iii) *Back Plains.*—Back plains are associated with meander plains and levee plains (Plate 14). They are slightly lower than their central flood-plain and thus are subject to frequent flooding during high water level. They receive very light deposits, however, as most of the suspended load of the river is deposited on the levees and scrolls bordering the central channel.

(iv) *Back Swamps.*—Back swamps are swamps whose drainage is impounded or impeded by their central levee or meander plain (Plate 12) or along the coast by beach ridges (Plate 19). Most back swamps are thus genetically the same as back plains except for their different drainage status. They are continuously swampy throughout the year irrespective of the flood regime of the central flood-plain. The most extensive back swamps are along the Sepik and Ramu Rivers.

(v) *Blocked Valley Swamps.*—A typical feature associated with major flood-plains is blocked valley lakes and swamps of smaller tributaries (Plate 14). The mouths of these tributaries are blocked by the more rapid and powerful flow and more effective sedimentation of the major rivers which have much larger catchment areas. In the Fly–Strickland area, for example, all rivers rising within the lowlands are being blocked at their mouths by the Fly, Strickland, or Bamu Rivers. The two largest blocked valleys are Lake Murray and the Aramia River.

(vi) *Undifferentiated Swamps.*—This includes all swamps that cannot be classified as either back swamps or blocked valley swamps. Most of these undifferentiated swamps occur in karst areas where they occupy basins without drainage or with poor drainage.

(vii) *Braided Flood-plains or Bar Plains.*—Braided flood-plains are distinctly different from the plains mentioned above. They are characterized by numerous braiding shallow channels, sand bars, and mud bars which are constantly shifting (Plate 15). The channels are very shallow and unnavigable by even small craft. The gradients are high (0·5–3 %) even for larger rivers and large quantities of sediment are moved rapidly during flood.

These flood-plains are typically associated with the formation of fans in tectonically active regions such as the Finisterre and the Saruwaged Ranges.

(*b*) *Composite Recent Alluvial Plains*

As mentioned above, in many cases the flood-plains could not be mapped separately from the surrounding plains and in such cases the whole complex was mapped as a composite alluvial plain. The different types of plain making up the composite plains have already been described and the following section is therefore brief.

(i) *Composite Meander Plains.*—Composite meander plains consist of a central meander plain and flanking back plains and swamps. The drainage status varies greatly, depending on local conditions, from poorly to well drained. Composite meander plains are widespread throughout Papua New Guinea.

(ii) *Composite Levee Plains.*—This type consists of a central levee plain and marginal back plains (Plate 13). It is a more stable plain than the meander plain but is typically very poorly drained. It is the most common type of alluvial plain in the southern lowlands where it extends inland from the estuarine plains.

(iii) *Composite Bar Plains and Fans.*—Composite bar plains consist of a braided flood-plain and an associated plain generally constituting an active alluvial fan. These land forms occur mainly along the north coast and in the Markham graben area and are indications of active uplift of the area. Fans are typically conical in shape with the apex at the point where the stream leaves the mountain (Plate 15). Their gradients are high and they are composed of coarse sediments. The distinction between active and relict fans (see below) is sometimes difficult to draw as certain areas of a fan may be active while other parts of the same fan may be relict. The boundaries shown are therefore arbitrary in some cases.

(*c*) *Relict Depositional Land Forms*

(i) *Relict Alluvial Plains.*—This group comprises older alluvial plains that are being eroded at present by fluvial erosion and mass movement. They are thus transitional in character between the depositional and erosional land forms. However, their character as extensive depositional plains has been largely preserved in the form of undulating plain land or as even summit levels. Relict alluvial plains are very extensive in the Fly–Strickland area where they range from gently undulating plains (relief 0–10 m) to intricate patterns of low accordant ridges and narrow valleys (relief 10–30 m) (Plate 16). Some flat-topped plateaux representing the surface of the former continuous alluvial plain have been preserved in watershed areas. The degree of dissection is approximately indicated by the relief.

(ii) *Relict Alluvial Fans.*—Relict fans are basically similar to relict plains but form a segment of a cone with its apex at the point where the stream leaves the mountains (Plate 17). They consist of irregularly bedded sediments of silt, clay, and gravel unconformably overlying planed surfaces of older beds. Fans are typical features of tectonically active areas. Most fans are developed in the Markham–Ramu graben area and the northern flanks of the Sepik depression. The relief gives an approximate indication of the degree of dissection. Undissected fans have a relief of 0–10 m, while the dissected fans have a relief of 10–30 m or 30–100 m.

(*d*) *Recent Littoral Land Forms*

(i) *Marshes and Estuaries.*—With few exceptions these are extensive only along the south coast which is relatively stable and where the post-glacial rise in sea level has led to drowning of these shores. The major estuarine environments include parts of the Fly River delta, the so-called delta country in the Gulf of Papua, and several smaller estuaries along the south coast of Papua New Guinea. They are generally an extension of alluvial plains inland and their deposits range seaward from silt to clay with increasing salinity. The drainage is tidal and consists of a strongly meandering interconnected network of channels (Plate 18). Mud banks along these channels are colonized by mangroves which bind them and trap tidal and fluvial sediments, thus contributing to the gradual increase in land area. A zonation of mangrove species from the seaward side inland reflects a decrease in the frequency and salinity of tidal inundation.

(ii) *Beach Ridge Complexes and Beach Plains.*—Beach ridge complexes consist of long parallel ridges and swales often extending for several tens of kilometres along the coast (Plate 19). The relief is mostly 2–3 m and gradually decreases inland. If there is no discernible relief the complex is called a beach plain. Beach ridge complexes are formed by sand transported by long-shore drift and are most common where there is strong wave transport. Beach ridge complexes often occur at the mouths of estuaries along the south coast and are the most favoured areas of human settlement. They are, however, also common along the north coast where their material is generally coarser, reflecting the greater sediment supply from the inland rivers due to the continuous uplift of the area.

(iii) *Coral Reefs.*—Reefs are abundant along most of the coastline of Papua New Guinea and around the islands. A barrier reef extends around the coast of south-east Papua New Guinea, reaching 30 miles in width in the Tagula barrier reef of the Louisiade Archipelago. Behind the outer rampart with its characteristic grooves, the interior is dotted with flat platforms and patch reefs with sand and coral debris. More broken reefs extend around the D'Entrecasteaux Islands. In spite of their great extent and beauty the New Guinea reefs are surprisingly little known.

(*e*) *Relict Littoral Land Forms*

Littoral land forms are, with the exception of coral reefs, not very stable once they have become inactive and fossil. Subsequent processes quickly modify these land forms and it is therefore not surprising to find very few relict littoral land forms other than uplifted coral platforms. There are no relict estuaries and there are only two areas of fossil beach ridges (south of Fly River mouth and near mouth of Tari River).

(i) *Beach Ridges.*—Fossil beach ridges are those which are some distance inland and separated from the present beach ridge complexes. In the strict sense, of course, only the very first beach ridge of a complex is active and all the successively older beach ridges behind it are inactive. However, because of the very limited extent of these land forms it was not possible to map this kind of detail. Relict beach ridges are clear indicators for seaward extension of the land.

(ii) *Uplifted Coral Reefs and Associated Back Reef Plains.*—Coral reefs are in contrast very well preserved mainly because of their porosity which allows water to infiltrate quickly, thus inhibiting surface flow and fluvial erosion. Raised coral reefs are typical land forms along much of the north coast (Plate 20) and around the islands of the Bismarck and Solomon Seas. These raised coral reefs give abundant evidence of active uplift as they are found in altitudes of up to 700 m above present sea level. A spectacular flight of coral terraces along the Huon Peninsula (Plate 20) has been dated with modern radiometric methods and given rates of uplift of about 3 m per 1000 yr (Veeh and Chappell 1970). This, however, represents an averaged figure over a period of 200,000 years and the actual rate of uplift may be periodically much higher. Similar but undated terrace staircases are found along the south coast of New Britain.

Most uplifted coral reefs form only narrow bands in front of a steeply rising hinterland. In the western part of New Britain, however, the uplifted reef surface continues inland as marine depositional plain formed on soft calcareous marl and mudstone. This plain represents a back reef formation.

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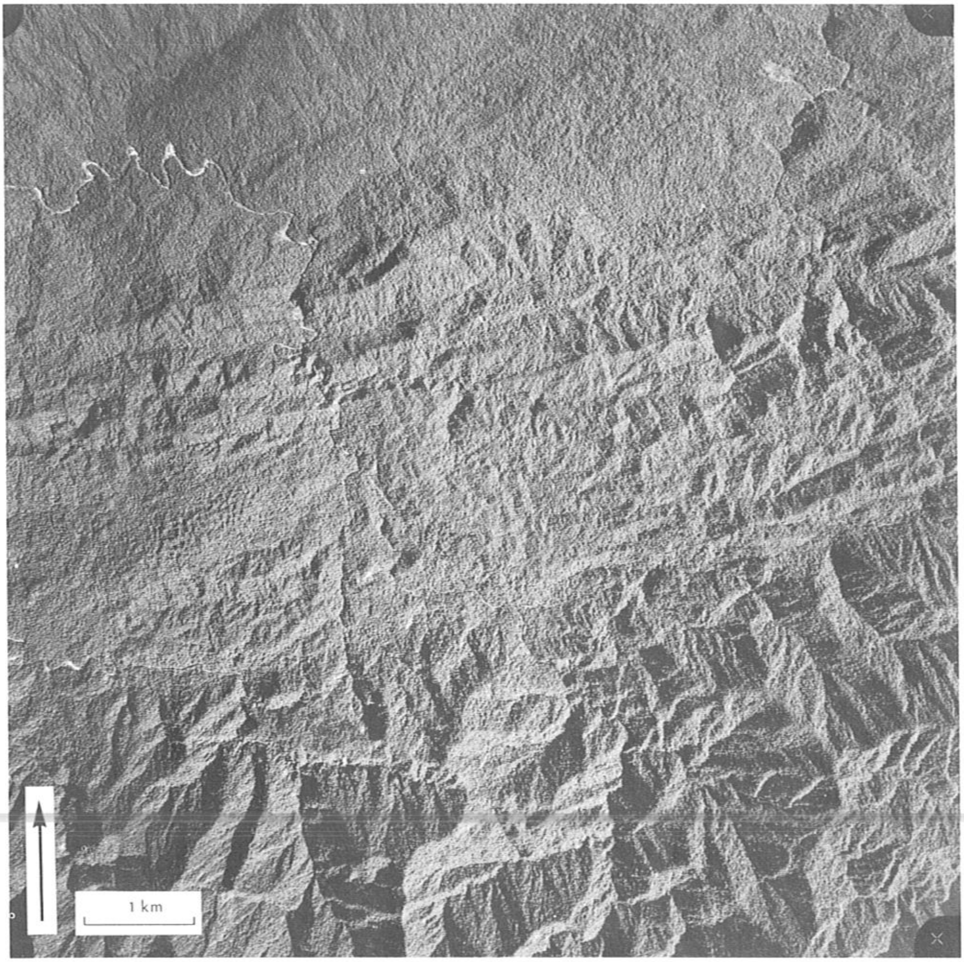
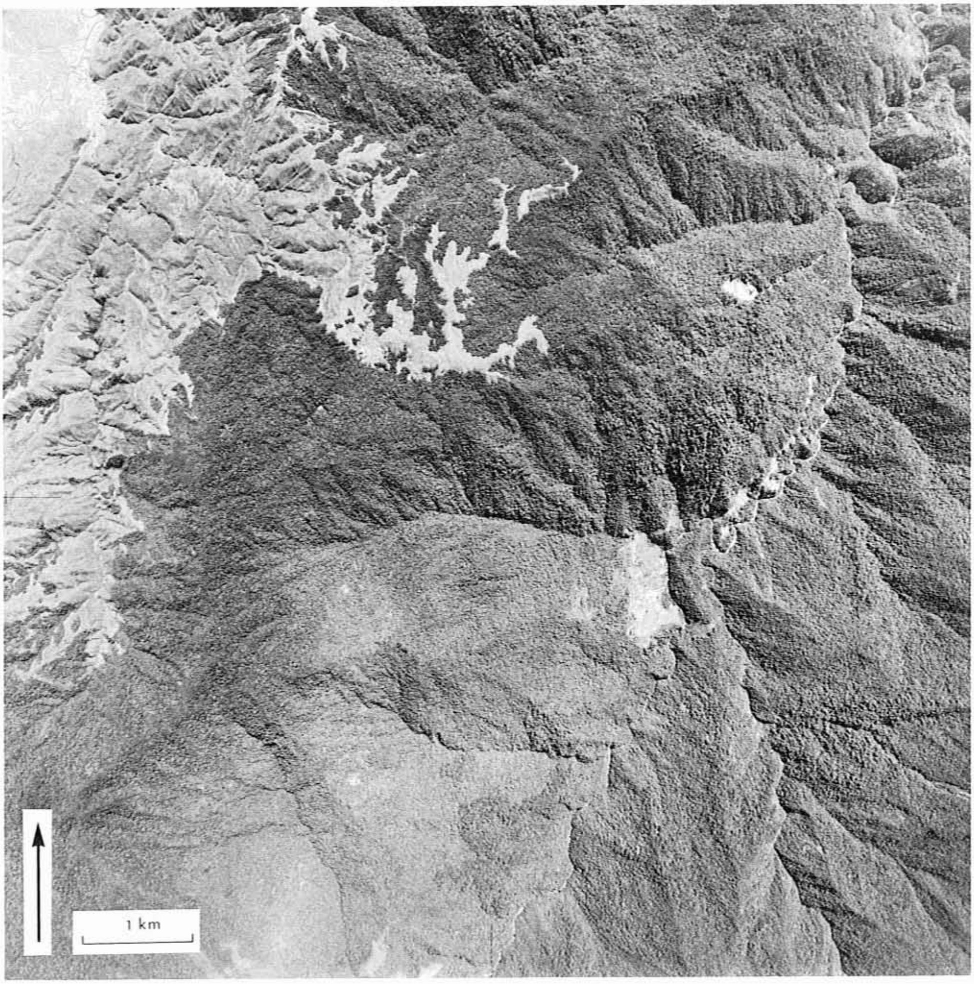
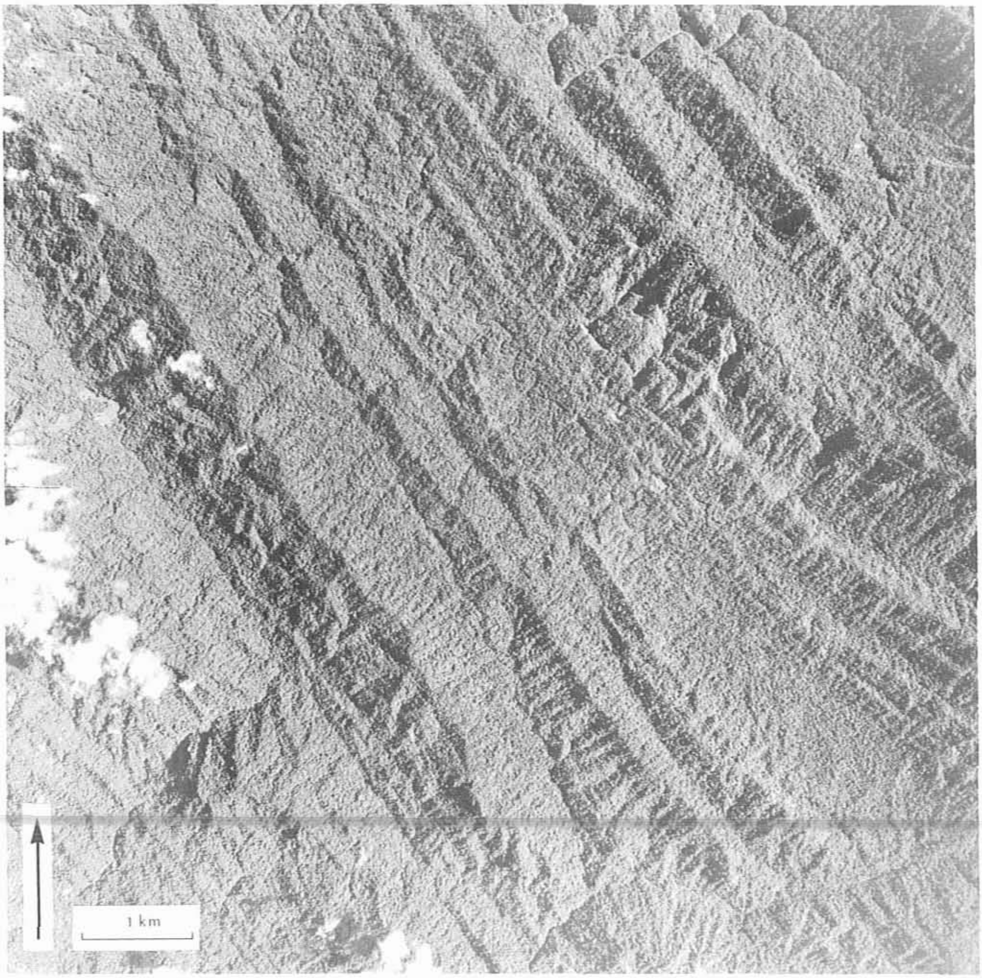


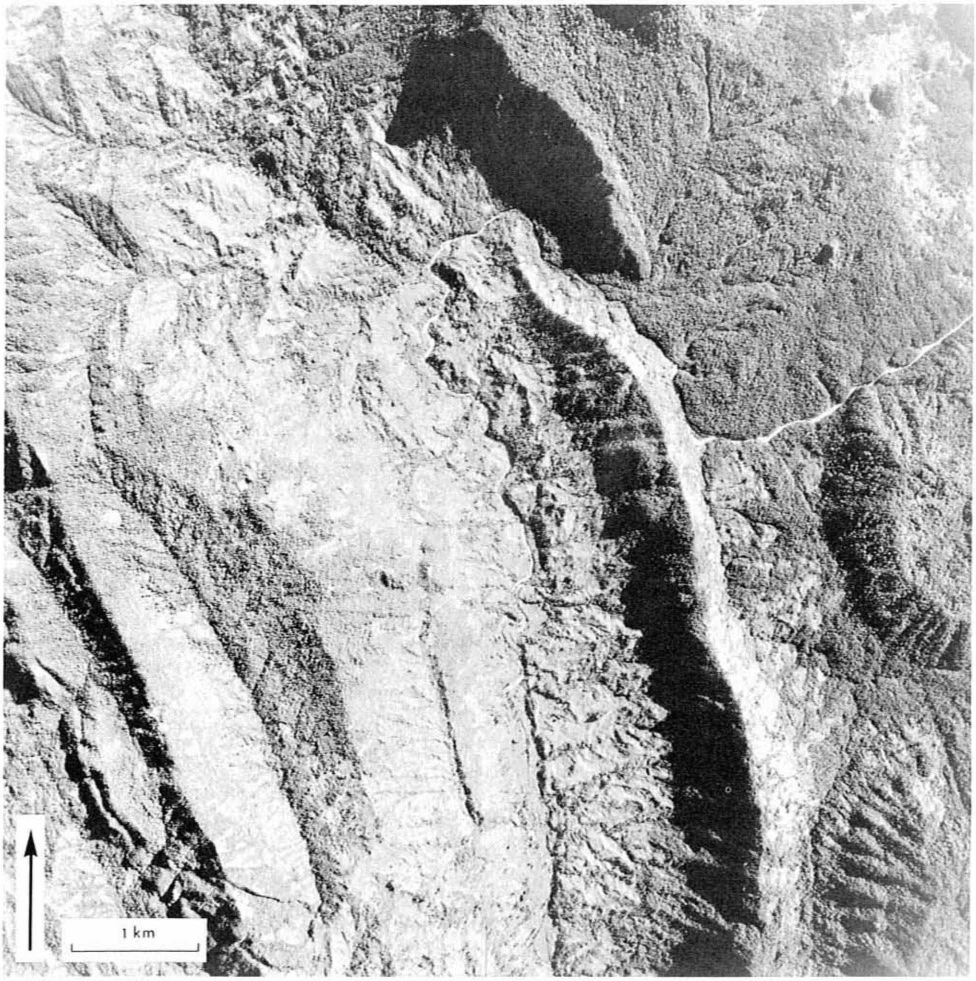
Ridge-and-ravine land forms. A typical example from the Bewani Mountains. To the south are massive high ridges with relatively straight and uniform slopes varying in steepness between 30° and 40°. The drainage pattern is coarse. This is characteristic for igneous rocks. In the centre the ridge-and-ravine pattern is developed on mudstone and a fine-grained dissection pattern and drainage network result. Irregular and densely dissected slopes with greatly varying slope angles are characteristic. To the north are broad ridges on limestone with incipient karst development.



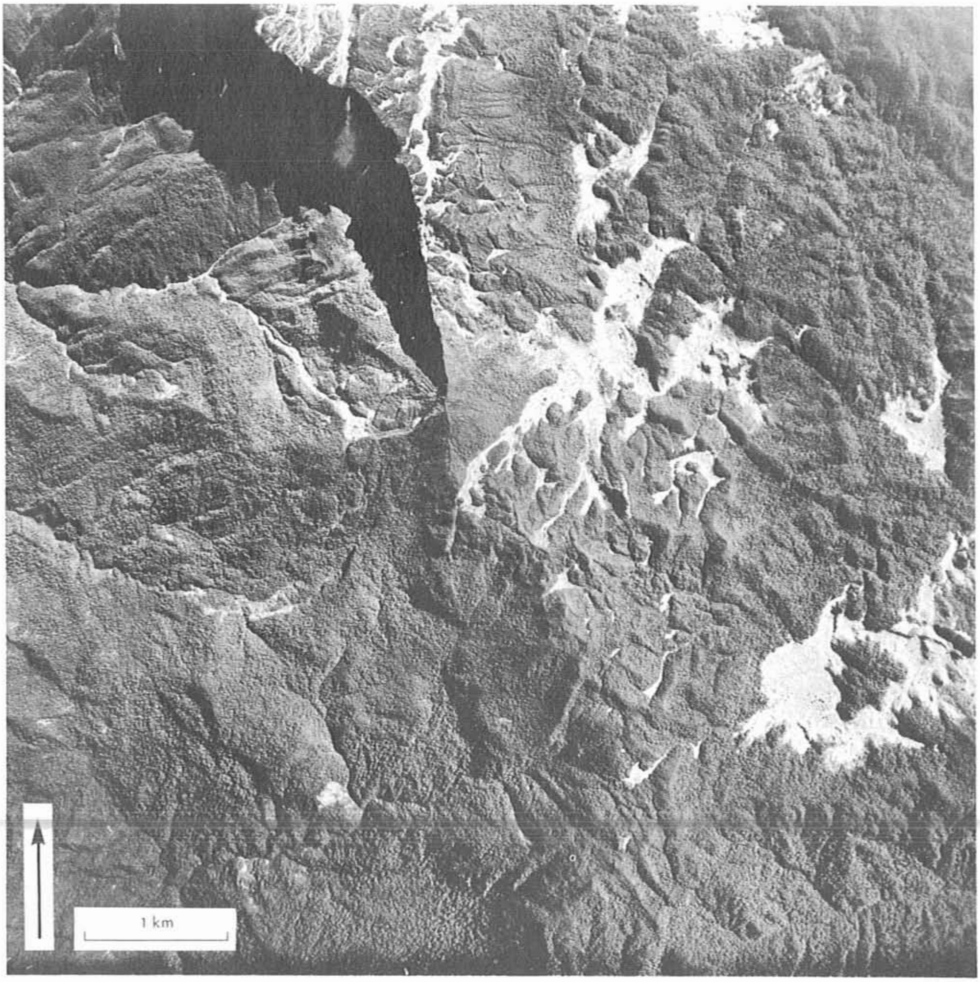
Ridge-and-ravine land forms associated with relict surfaces. An example from the Owen Stanley Ranges where relict surfaces form relatively extensive areas along the main watershed. The relict surface (north-west) is also a ridge-and-ravine land form but with a distinctly lower relief and less steep gradients of the rivers. The transition from the older to the younger surface is abrupt, marked by a distinct break of slope and a clear change in the dissection pattern from a fine-grained pattern on the surface to a coarse-grained pattern in the younger landscape.



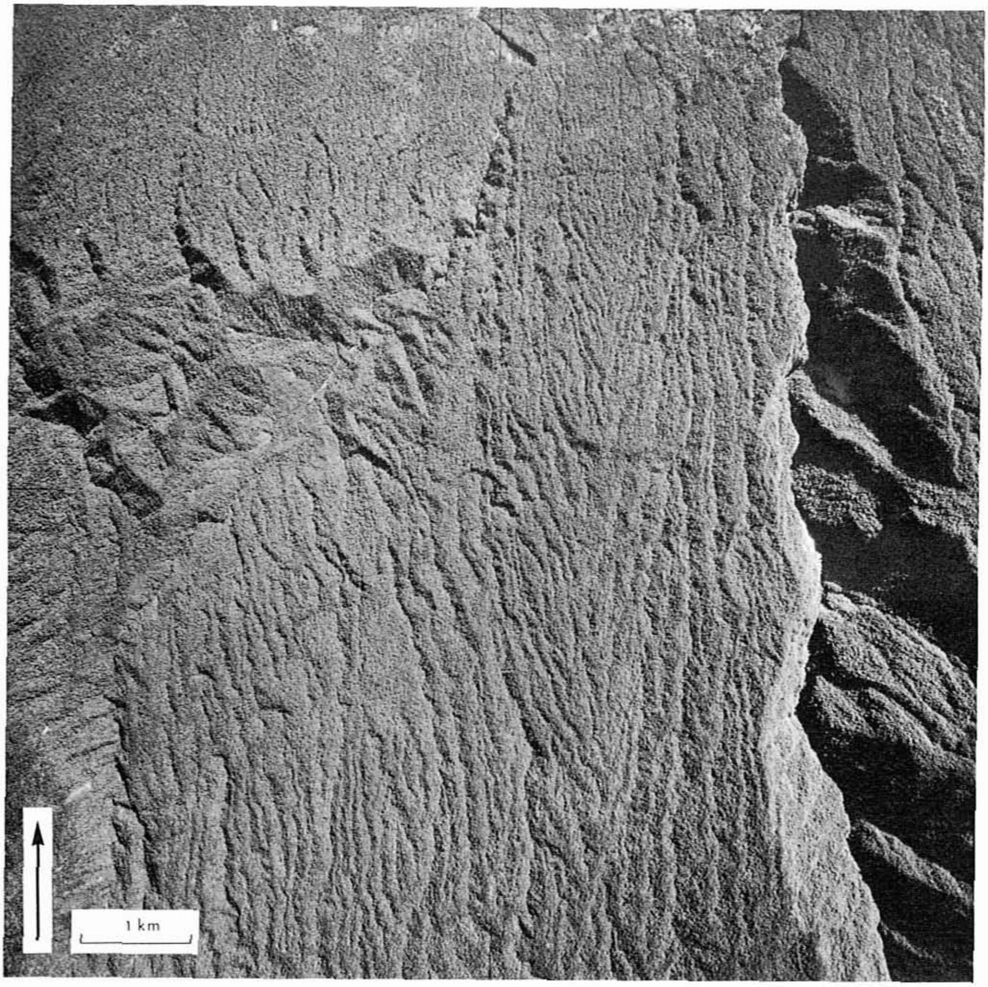
Homoclinal ridge-and-ravine land forms. Example from the Aure trough area north of the Gulf of Papua. The area is characterized by tight folding with south-westerly overturned folds. The gentler dip slopes (10°–25°) face north-east while the steeper outcrop slopes (30°–40°) face south-west. The outcrop slopes are irregular and densely dissected by short steep gullies, while the dip slopes appear smooth and little dissected. On the ground the dip slopes are, however, also highly irregular due to slumping and gullying. Rock types are sandstone, greywacke, and mudstone.



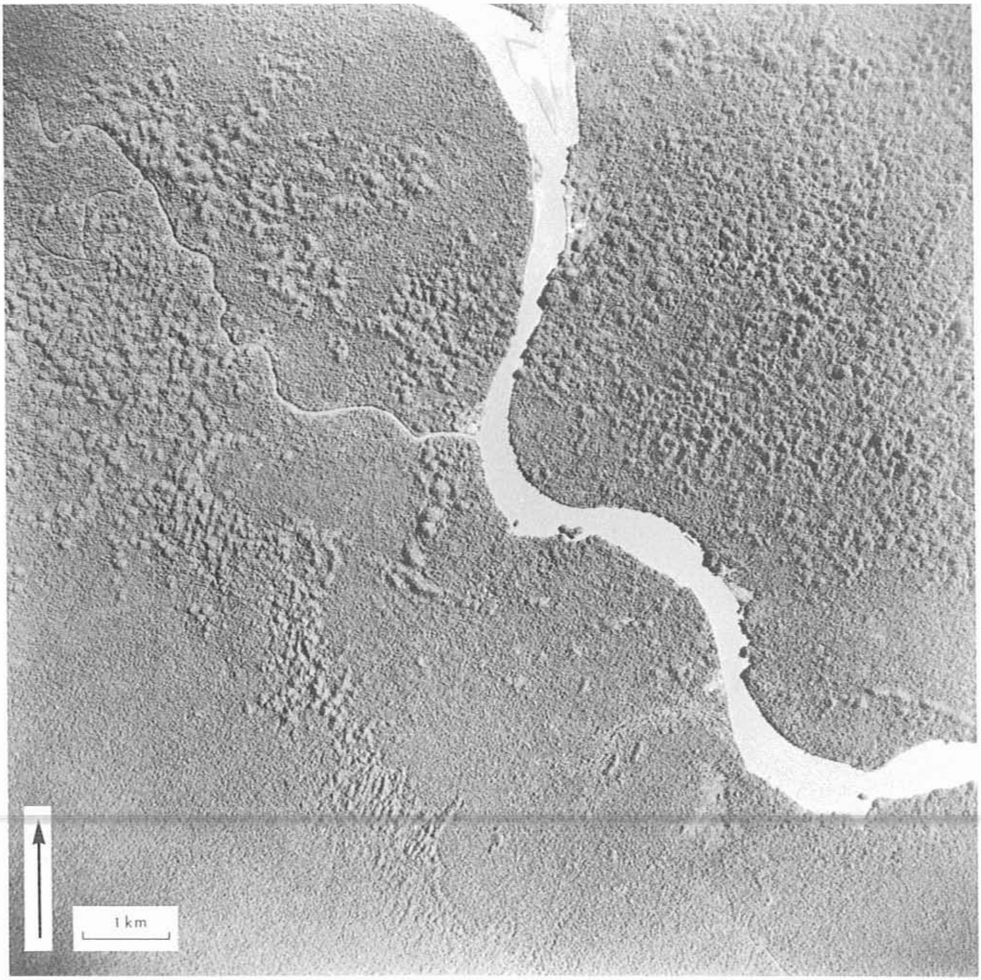
Strike ridges and hogback ridges. Strike ridges and hogback ridges are similar to homoclinal ridges but have dip slopes generally exceeding 25°. The photograph shows strike ridges in the western highlands formed by steeply eastward-dipping limestone. The strike ridges are separated by ridge-and-ravine land forms developed on sandstone and mudstone.



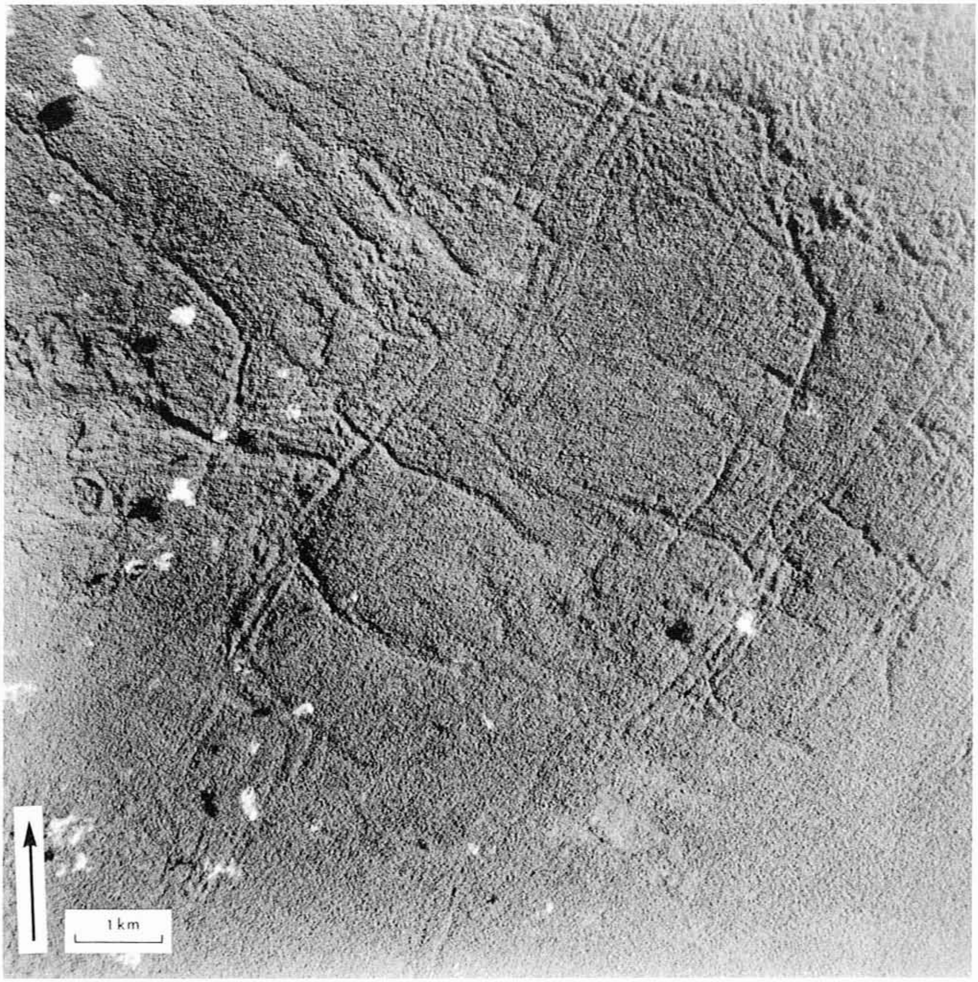
Structural plateau. Part of the summit plateau of the Saruwaged Range developed on a thick sequence of flat to gently dipping limestone beds. The plateau is bounded by steep escarpments several hundred metres high and its extent is being continually reduced by vigorous headward erosion from the edges of the plateau. Although the formation of the plateau is clearly controlled by the rock structure, the present plateau surface is not an original structural surface but an erosional surface formed when the base level of erosion was much lower than at present. The structural plateau is therefore also a relict surface. Numerous small dolines occur in the mostly grass-covered drainage lines but the drainage network is still integrated.



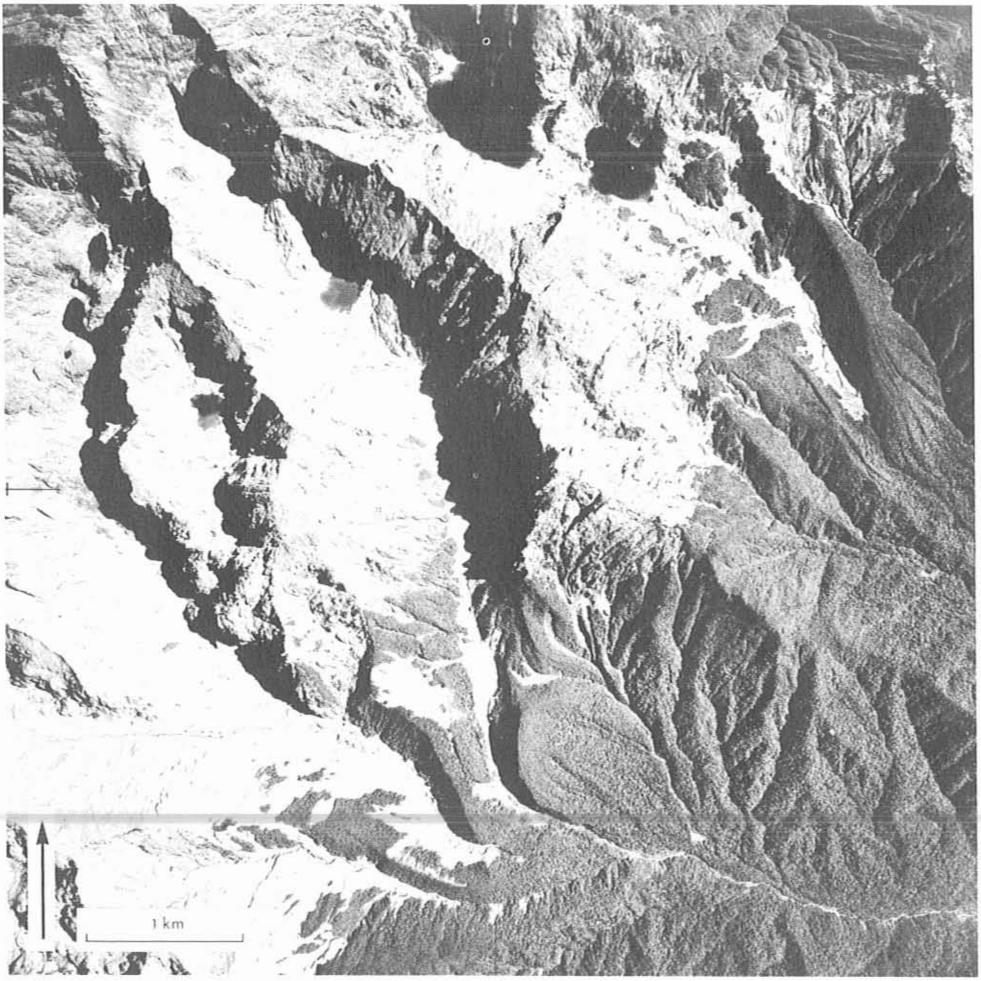
Sloping structural surfaces. These are similar to structural plateaux but their summit levels form well-defined planes which slope consistently in one direction. The photograph shows a section of the Dayman Dome in east Papua. The dome is formed of schist, the foliation of which is parallel to the dome surface.



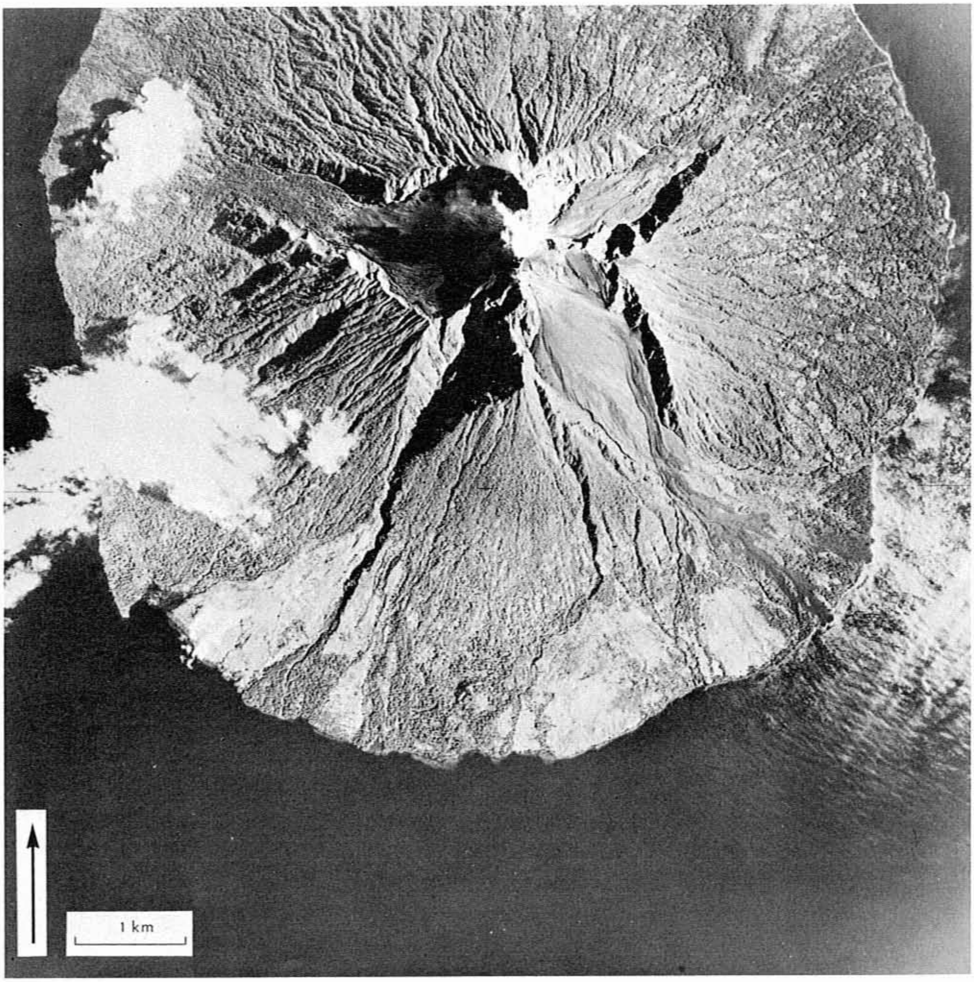
Polygonal karst. An example of polygonal karst in the Kikori area, Gulf of Papua. The land forms here are roughly hemispherical hills surrounding enclosed depressions, approximately polygonal in shape. This type is also known as Kegelkarst. The plain surrounding the hills is a karst plain, an erosional plain on limestone covered with a veneer of alluvium. Numerous isolated limestone hill remnants can be seen rising from the plain.



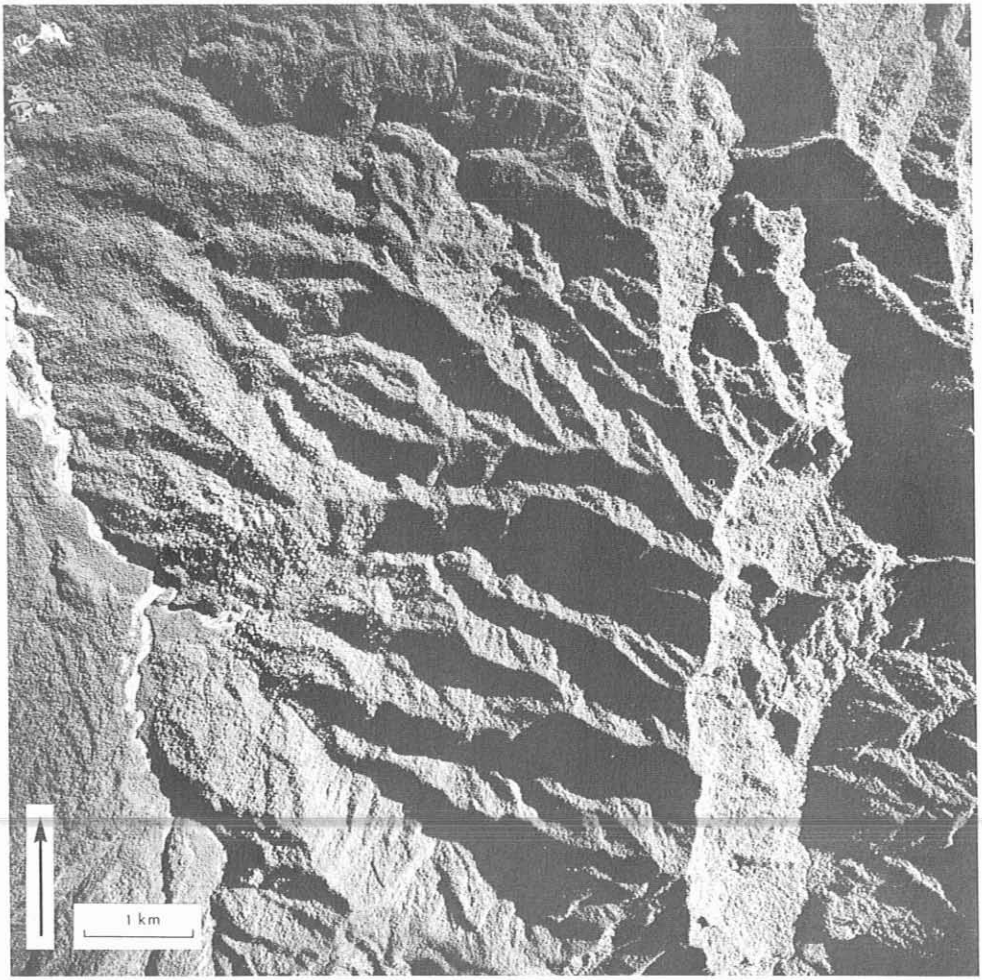
Plateau with karst corridors. An example from the Daria Plateau north-west of Kikori. Narrow corridors are cut into the limestone preferably along joints and faults but no integrated drainage network has been developed. In the north and west a gradual transition to the polygonal karst can be observed.



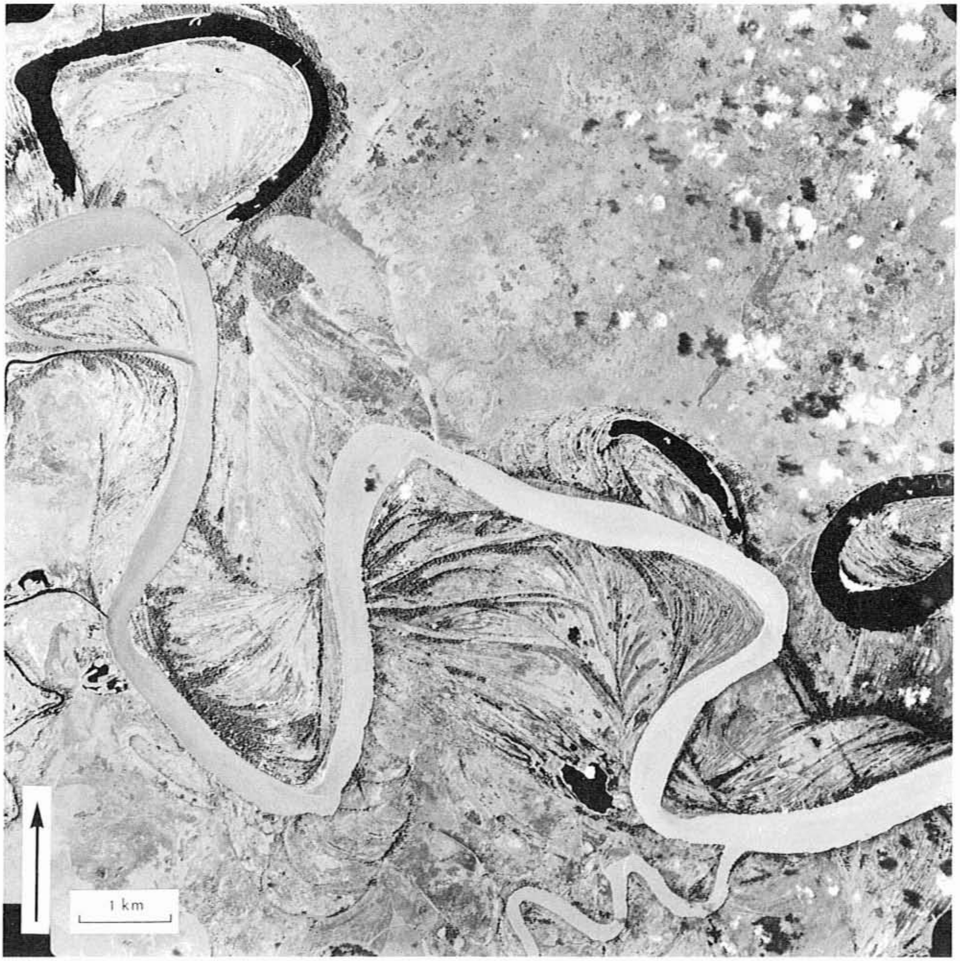
Land form of glacial erosion. The glacially modified summit area of Mt. Wilhelm. The formerly glaciated area shows up well with the broad U-shaped valleys, overdeepened rock basins, and extensive moraines forming distinct sharp-crested ridges at the lower end of the glacial valleys. Most of the formerly glaciated area is covered by grassland.



Volcanic land forms. Partly dissected stratovolcano forming Manam Island off the north coast of Papua New Guinea. The volcano is conical in shape and dissected by narrow gullies leading down to broad concave foot slopes. Manam volcano is an active volcano and has erupted several times this century. Young lava flows without vegetation can be seen in the south-eastern corner of the island.

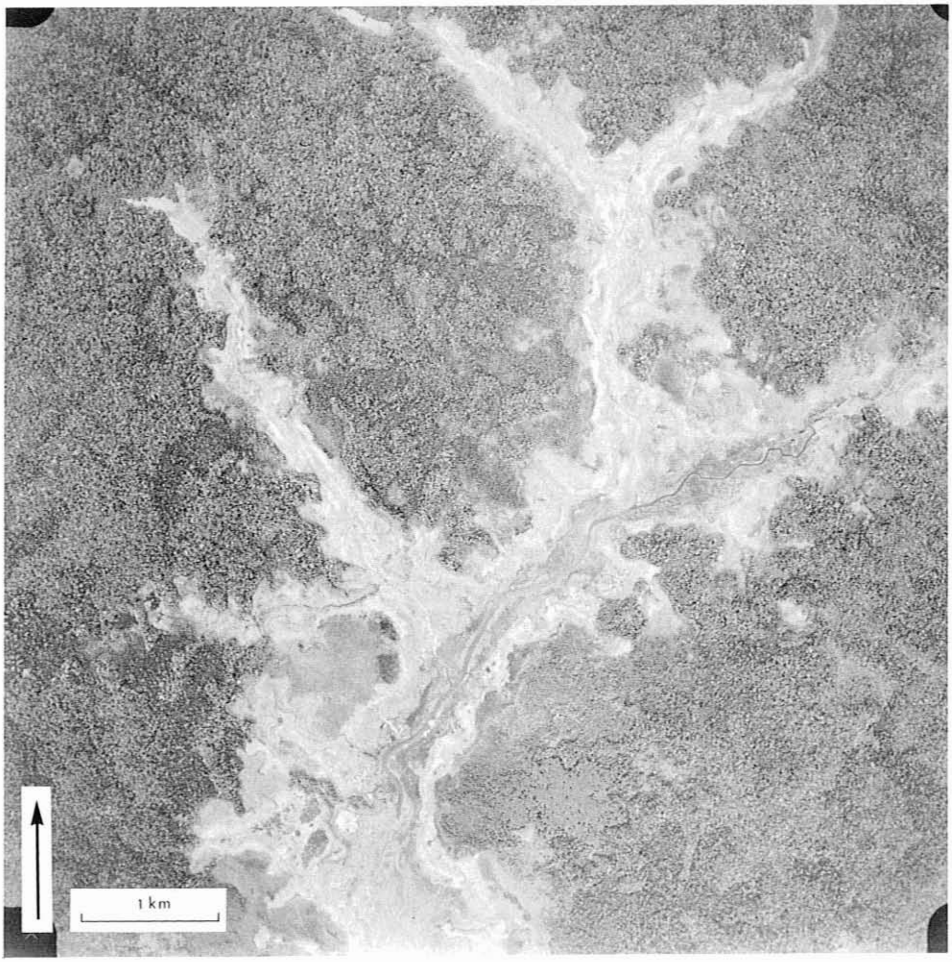


Volcanic land forms. Strongly dissected stratovolcano, Mt. Trafalgar, in east Papua New Guinea. The original volcanic surface has been reduced to narrow ridge crests and only the crest accordance and radial drainage pattern indicate the former volcanic land form.

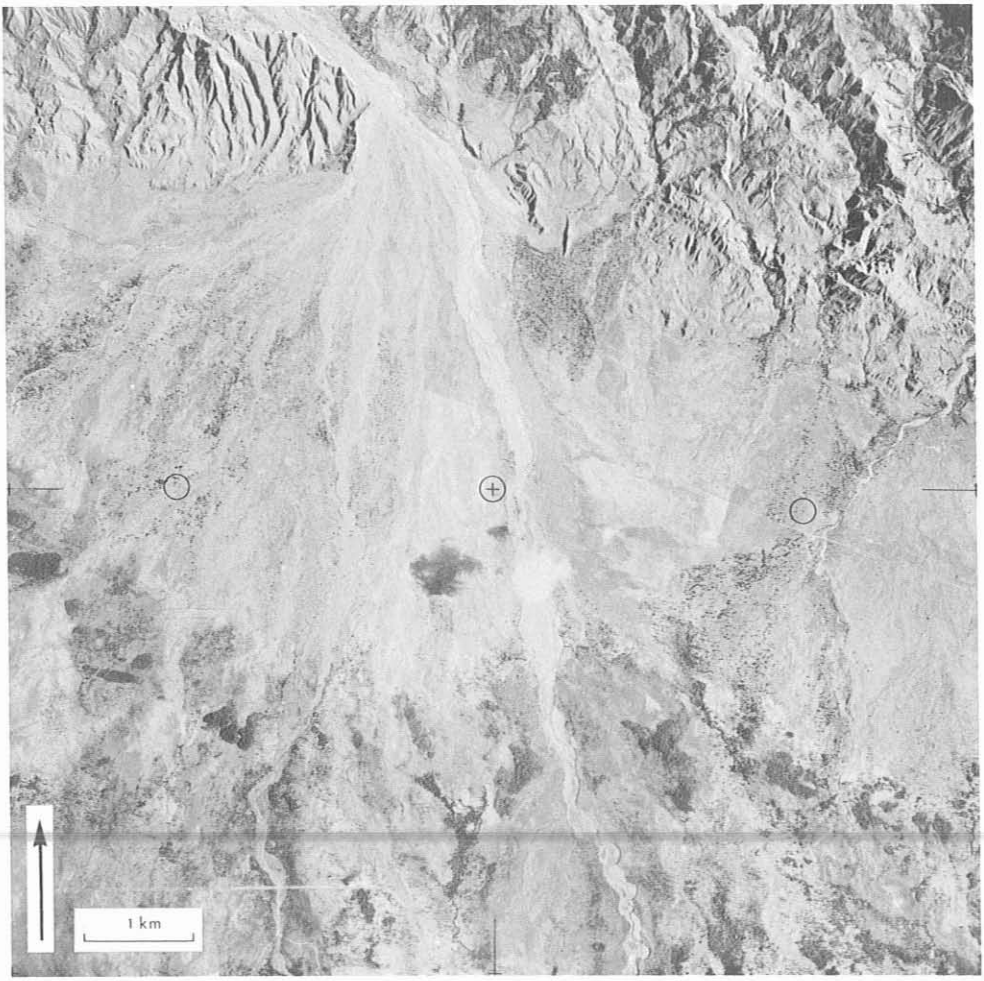


Meander flood-plain. Meander flood-plain from the Sepik River, consisting of the meandering main channel, cut-off meanders forming oxbow lakes and many scroll complexes, point bars, and low levees. It is flanked by an extensive back swamp which is slightly lower than the meander plain.

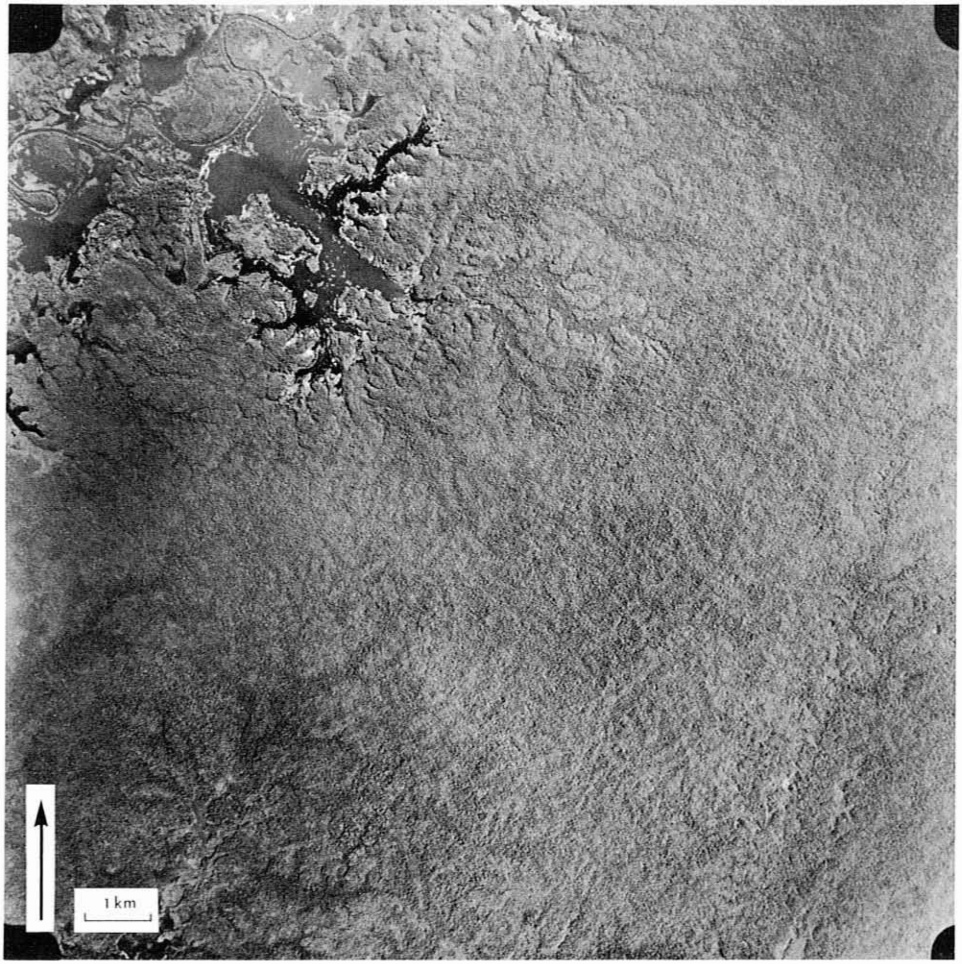
Levee plain. Example from the Turama River. Levee plains are stable flood-plains and consist of a single main channel and bordering levees. The levees are low and small in extent. On the photograph the levees coincide with the area covered by the large-crowned trees flanking the river. Behind the levees are extensive back plains characterized by poor drainage.



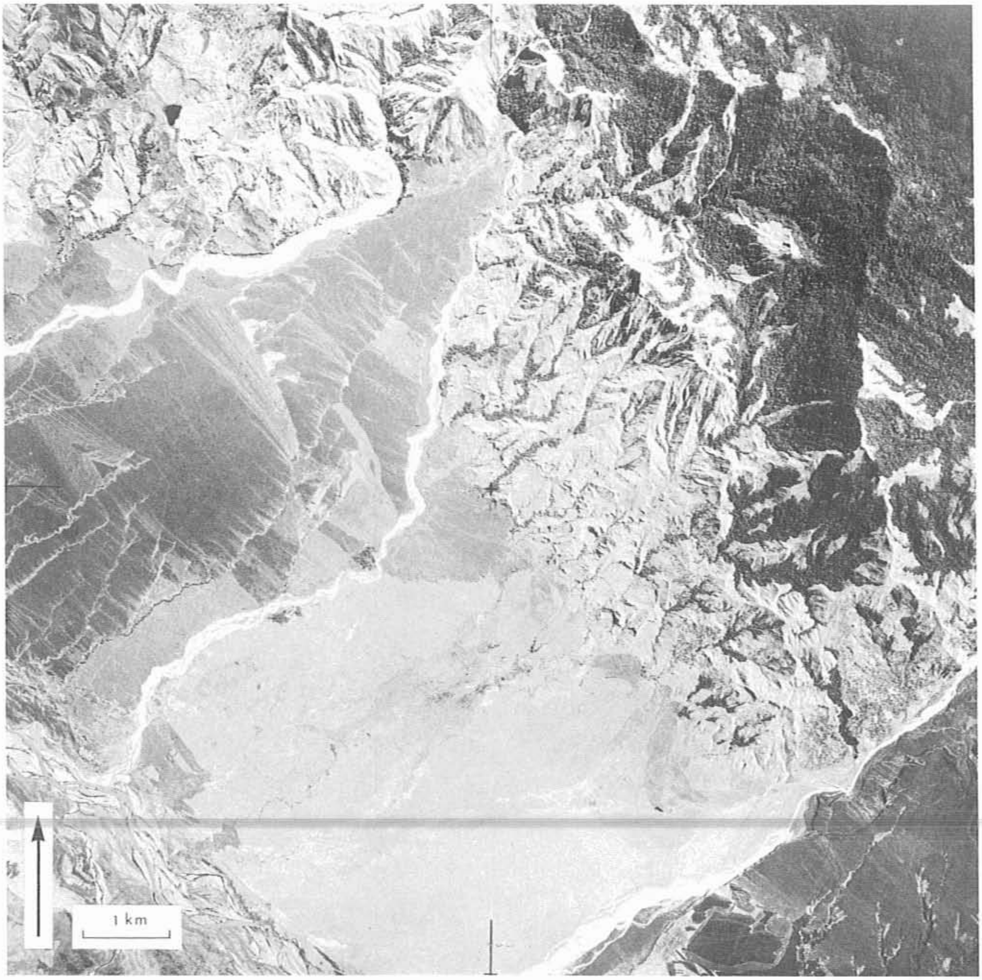
Blocked valley swamp. Example from the Aramia River area. The mouth of the Aramia River is blocked by the more rapid flow and more effective sedimentation of the Bamu River, leading to the formation of lakes and swamps in the Aramia River and its tributaries. The photograph shows the upper end of a blocked valley swamp (light grey area).



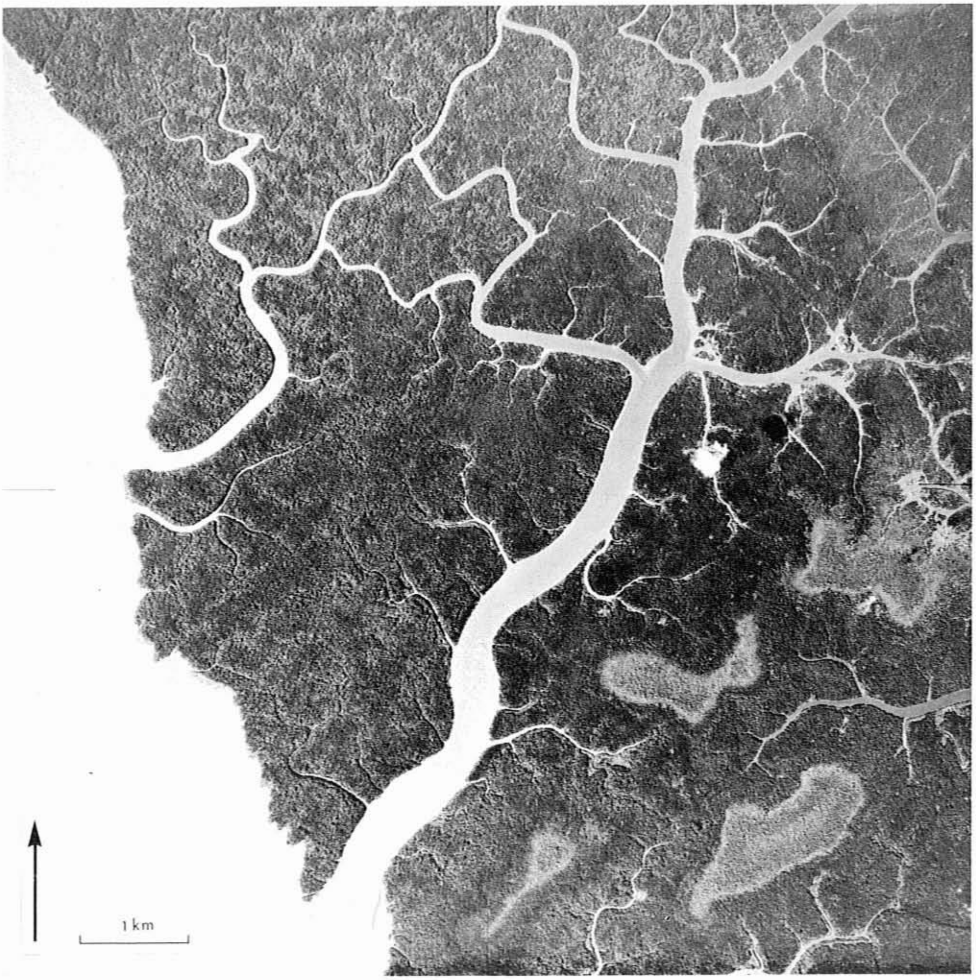
Active alluvial fan and braided flood-plain. A large fan with several braided flood-plains from the Markham trough. Some small fans are developed at the outlet of small streams directly at the mountain front. The braiding flood-plains have steep gradients and transport large quantities of coarse sediment.



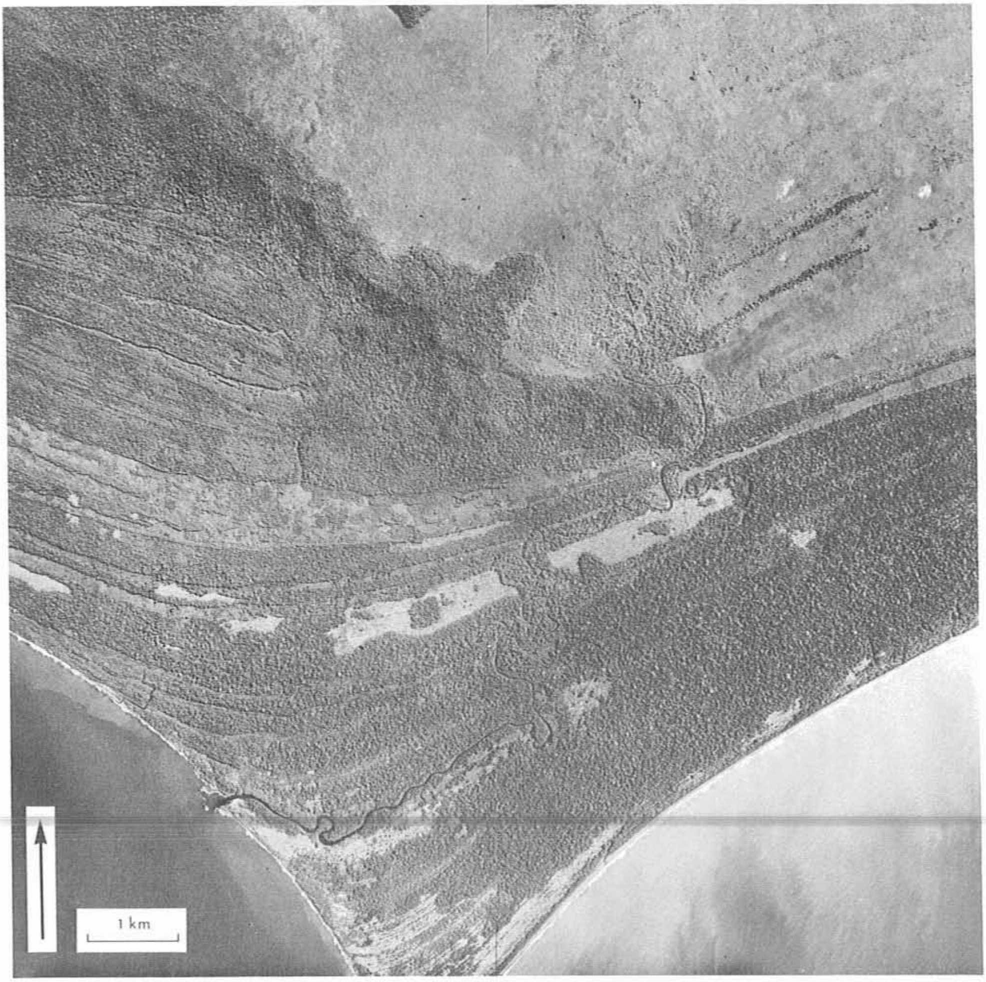
Relict alluvial plain. A section of the Fly–Strickland area where the former continuous alluvial plain has been dissected to low accordant ridges. Only the very even summit level indicates the former plain. To the south-west, a blocked valley lake and submerged levees of a tributary to Lake Murray can be seen.



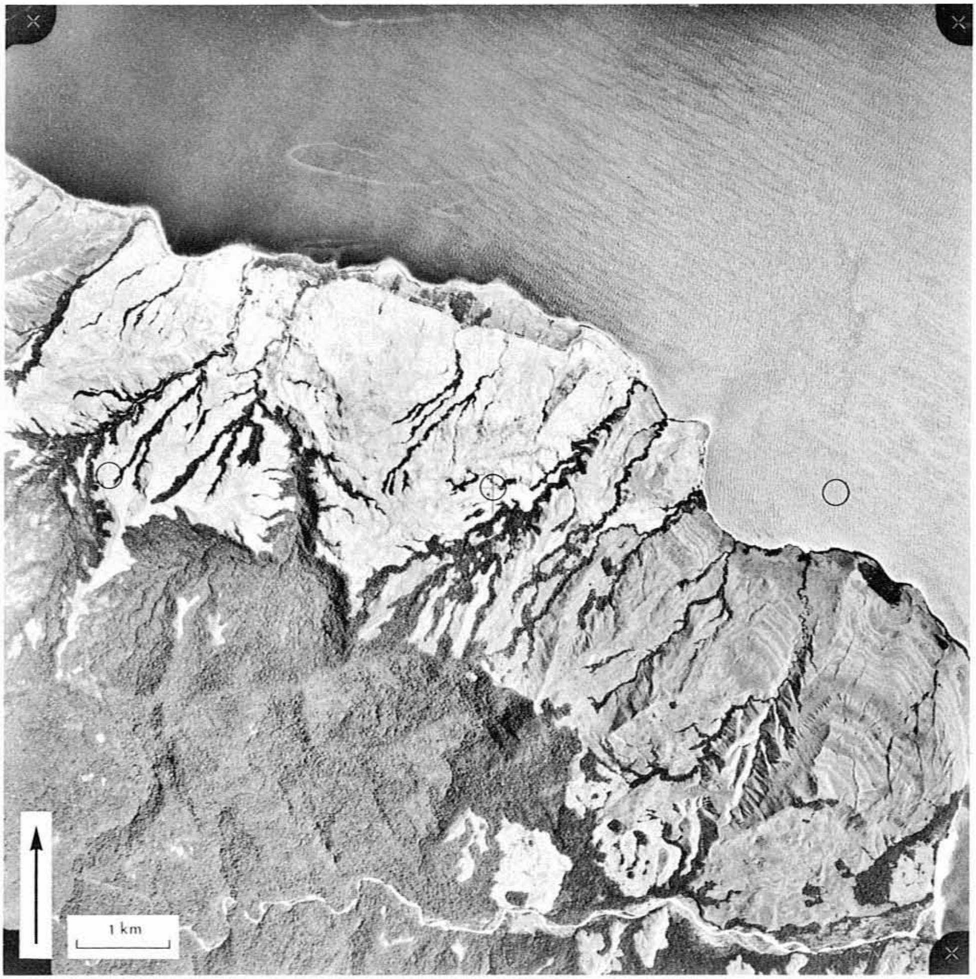
Relict alluvial fan. A series of coalescing fans in the upper Ramu valley. The fans are in various stages of dissection and no part of them is reached by present floods. They slope between 1° and 3° and consist of irregularly bedded coarse sediments predominantly gravel interbedded with sand and silt.



Marshes and estuaries. Tidal flat in the Gulf of Papua. The drainage is typically tidal with its interconnected network channels. The vegetation consists predominantly of *Rhizophora* (dark grey) and *Bruguiera* (lighter grey). The light grey patches to the west of the main channel are areas of low salinity with a vegetation of *Nypa* and sago.



Beach ridges and beach plains. Complex of beach ridges east of Abau, east Papua New Guinea, consisting of a series of low ridges and shallow swales several kilometres wide covered with littoral forest and further inland *Melaleuca*-dominated swamp forest (dense even canopy to the west). An extensive back swamp is developed behind the beach ridge complex.



Uplifted coral reefs. Series of uplifted coral terraces along the Huon Peninsula rising to 700 m above sea level. There are over 20 terraces which vary in age from early Pleistocene to Recent. The terraces have been dated with radiometric methods and the rate of uplift has been calculated as approximately 3 m per 1000 yr.