BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN 201

A GEOLOGICAL SYNTHESIS OF PAPUA NEW GUINEA

D.B.DOW

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ABSTRACT

The main island of Papua New Guinea has been formed by interaction between the Australian Plate in the southwest, and the Pacific Plate in the northeast. Between these two major crustal elements—the *platform* and the *oceanic crust and island arcs*—is a highly deformed *mobile belt.*

The platform comprises stable continental crust of Palaeozoic crystalline rocks overlain by mostly undeformed Mesozoic and Tertiary sedimentary rocks. The mobile belt was the site of a geosyncline and of widespread igneous activity, and has been deformed from time to time since at least the late Mesozoic. Several fault wedges in the mobile belt contain Mesozoic rocks similar to those of the platform, and may be detached fragments of the platform. In the oceanic crust and island arcs, the rocks comprise an ophiolite sequence—probably representing upfaulted Mesozoic and Early Tertiary oceanic crust—and the products of island-arc volcanism; they have been broadly folded, and faulted along major widely separated crustal fractures.

During the Mesozoic to Eocene, shelf-type sediments were deposited over the platform, and geosynclinal sediments and minor volcanics were deposited in a trough established by the Late Cretaceous along its northern and northeastern margins. In the oceanic crust and island arcs the oldest rocks are Late Cretaceous ophiolites and island-arc volcanics.

In the late Eocene or the Oligocene, the rocks of the mobile belt were metamorphosed during a major orogeny resulting from increased plate interaction. This event was reflected in the platform by erosion and non-deposition, and in the oceanic crust and island arcs as widespread island-arc volcanism.

Sedimentation resumed in the early Miocene: shelf sediments (mainly limestone) were deposited in the oceanic crust and island arcs and the platform, and trough-type sediments were deposited along the mobile belt, where widespread volcanism in the middle Miocene was not reflected in the shelf sediments of the platform and the oceanic crust and island arcs.

By the late Pliocene the main landmasses of Papua New Guinea had been formed. The later history is notable for the widespread volcanism which for the first time affected all three provinces simultaneously.

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Front cover: Lavas, pyroclastics, and volcanolithic sediments of the middle Miocene Yaveufa Formation (background ridge), derived from the Maramuni Volcanic Arc, overlie a thick (4000 m) sequence of fine to coarse calcareous volcanolithic sediments of the middle Miocene Movi Beds (bedded strike ridge in centre, and foreground), deposited at the northern end of the Aure Trough. Asaro River about 7 km north-northwest of Lufa. (GB/1343)

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Erratum for Bulletin 201: page 39, column 1, end of 1st line:

Insert: where the gold originated in Miocene conglomerates, and in the Morobe Goldfield,

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SUMMARY

The main island of Papua New Guinea has been formed by long-continued interaction between the Australian Plate in the southwest, and the Pacific Plate in the northeast. Between these two major crustal elements, whose components in Papua New Guinea are referred to as the *platform* and the *oceanic crust and island arcs,* is a highly deformed *mobile belt* about 150 km wide.

The platform consists of stable continental crust of Palaeozoic crystalline rocks overlain by Mesozoic and Tertiary sedimentary rocks, which—because they have been protected by the crystalline basement from the deforming forces so active in the mobile belt—are mostly flat-lying or only gently warped.

The mobile belt, in contrast to the platform, has been deformed from time to time since at least the late Mesozoic and so has been an unsettled sedimentary environment. It was the repository of a great variety of geosynclinal sediments markedly different from those of the platform, but probably its most striking feature is its great intensity of faulting. It has also been the site of widespread igneous activity—in contrast to the platform, in which there was no igneous activity from the early Mesozoic until the onset of volcanism in the Pliocene. Several fault wedges in the mobile belt contain Mesozoic rocks similar to those of the platform, and may be detached fragments of the platform.

The oceanic crust and island arcs provides a third contrasting geological environment. The fundamental fault zones forming the northeastern margin of the mobile belt mark an abrupt change from rocks with continental affinities (metamorphosed geosynclinal sediments and associated plutonic rocks) to rocks with oceanic affinities, which consist of: (i) an ophiolite sequence, probably representing upfaulted Mesozoic and Early Tertiary oceanic crust; and (ii) the products of island-arc volcanism consisting of Tertiary subaerial and submarine lavas, pyroclastics, and volcanolithic sediments. The rocks of the oceanic crust and island arcs have reacted to stress generally by broadly folding, and faulting along major widely separated crustal fractures.

During the Mesozoic, sedimentation followed a fairly consistent pattern: shelf-type sediments were deposited over the platform, and geosynclinal sediments and minor volcanics were deposited in a trough established by the Late Cretaceous along its northern and northeastern margins. The oldest rocks in the oceanic crust and island arcs are Late Cretaceous ophiolites and island-arc volcanics.

The same pattern persisted into the Eocene, until a major orogeny resulting from increased plate interaction in the late Eocene—or more likely, the Oligocene—formed a belt of low to moderate grade metamorphics along the length of the mobile belt. This event was reflected in the platform by erosion and non-deposition, and in the oceanic crust and island arcs as widespread island-arc volcanism.

The early Miocene saw another fundamental change, with the deposition of shelf sediments (mainly limestone) in the oceanic crust and island arcs and the platform, and trough-type sediments along the mobile belt. Volcanic activity burst forth along the length of the mobile belt in the middle Miocene, but was not reflected in either the oceanic crust and island arcs or the platform, where limestones continued to be deposited.

By the late Pliocene the main landmasses of Papua New Guinea had been formed, and the later history is notable for the widespread volcanism which for the first time affected all three provinces simultaneously.

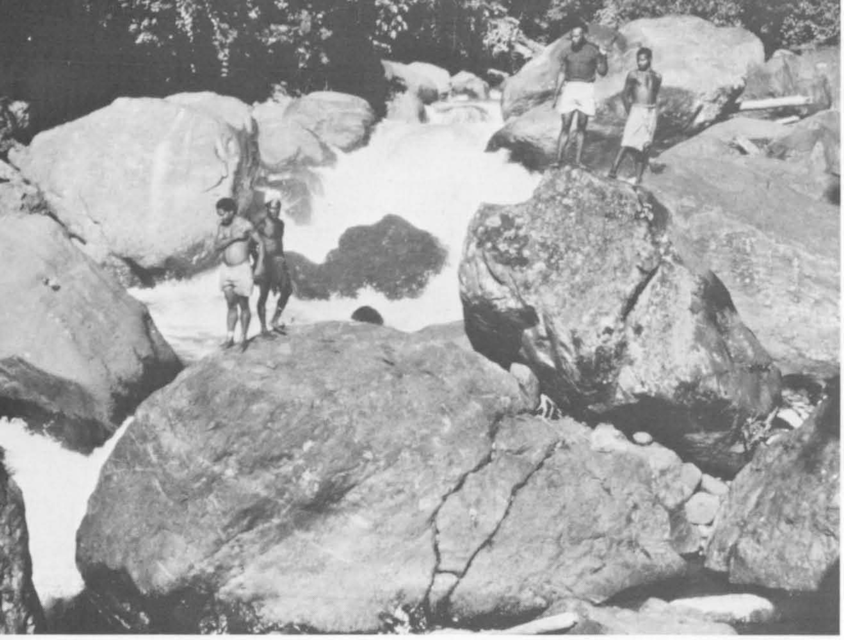


Fig. 1. Rough going in the lower Simbai River, New Guinea Highlands. Many streams in the mountains are just as difficult to traverse and inevitably are blocked by gorges or waterfalls which can be bypassed only by climbs of hundreds of metres through dense jungle. (G/5236)

Fig. 2. Kompiam patrol post in 1960. Airstrips such as the one seen here commonly provide the only access other than days of laborious walking. (G/3616)

Fig. 3. First contact being made with natives in the headwaters of the Bamali River, a tributary of the April River. Their offer of food was a gesture of friendship, but they never co-operated to the extent of showing their tracks to the traverse parties; this might have been due to lack of communication, for only sign language was possible. (GA/473)

INTRODUCTION

Papua New Guinea until recently was one of the least explored countries in the World. Even as late as the early 1960s, large areas had not been explored, and the geology of the mountainous highlands and offshore islands was known from only a few sporadic reconnaissance traverses. The lack of knowledge is not surprising when the difficulties confronting the exploration geologists are considered: rugged inaccessible mountain terrain, dense jungle cover, and a wet tropical climate —all commonly compounded in the early days by hostile and warlike tribes. A lack of reliable base maps for most of the country placed almost insuperable difficulties in the way of regional mapping parties, and only when systematic aerial photography started in the 1950s was it possible to envisage mapping the whole country. Even so, continual cloud cover frustrated efforts to photograph many critical highland areas, until side-looking radar imagery became available in 1971 and provided for the first time reliable maps of these areas.

Difficulty of access is the main problem facing the geologist in Papua New Guinea, and, as dense jungle covers most of the terrain, fresh exposures are confined to stream channels; consequently the geologist spends a large part of his energy negotiating cascades and waterfalls (Fig. 1). Access to a region is generally gained by using airstrips which service government posts and mission stations (Fig. 2), but thereafter geological traverses are done on foot, using a small number of local people to carry camping equipment and food. Much of the work has been done in trackless jungle necessitating highly mobile, lightly laden traverse parties, and with the gradual evolution of lightweight camping equipment a geologist accompanied by only 5 carriers can now travel up to 10 days away from a source of supply.

The success of the Bureau of Mineral Resources (BMR) and Geological Survey of Papua New Guinea (GSPNG) mapping has depended on the co-operation of the local people, who were generally willing to carry the geologists' equipment for nominal pay and to allow access to their land. Tense situations were not uncommon when first contact was made with natives who had never seen white men before (Fig. 3), but no field party experienced any real trouble.

In some of the more remote areas, airdrops were the only practicable means of replenishing supplies (Fig. 4), but, as loads had to be kept to a minimum, base-camps were at best rudimentary (Fig. 5). In other areas such as the south Sepik region, logistics were an even greater problem and larger base-camps had to be set up with regular supply runs (Fig. 6). Jet boats (Fig. 7) were a successful innovation, and enabled geologists to penetrate deep into the unexplored mountains south of the Sepik River.

One of the most revolutionary aids to regional mapping came with the development of the Bell 47 G3B1 supercharged helicopter, which for the first time enabled helicopter access to the highlands (Fig. 8). Helicopters were first used in Papua New Guinea for regional mapping by BMR in the New Guinea Highlands in 1963, and over the next ten years most regional mapping teams used helicopters as their main means of access. The result was a distinct increase in the rate of mapping, so that by 1971 reconnaissance mapping had covered most of the country and for the first time a geological map of the whole country could be compiled; this map was published at 1:1 000 000 scale (Bain et al., 1972). A second compilation—using the latest data up to July 1974—has been published at 1:2 500 000 scale by BMR (D'Addario, Dow, & Swoboda, 1976). This Bulletin is intended as an explanatory note for the two maps.

Acknowledgement

In making this synthesis I have drawn on the work and ideas of most geoscientists, too numerous to mention, who have worked in Papua New Guinea. Their contributions, both large and small, are sincerely acknowledged.

PHYSIOGRAPHY

Though Papua New Guinea is characteristically a land of rugged jungle-covered mountains, it offers many contrasts, for it also has open plains clothed in grass and savannah, and much of the populated highlands consist of only moderately dissected, cultivated country.

The country has quite a wide range of climate, for though the popular picture of hot steamy jungles is true of the lowland areas, particularly in the swamps of the Sepik River and the Papuan Gulf country, the highlands are generally mild to cool. The higher mountains above 3000 m can be cold and bleak, and invariably have a high rainfall.

MAINLAND

For the purpose of description, and to provide convenient regional names for the later geological synthesis, I have divided the mainland of Papua New Guinea into six very broad physiographic regions (Fig. 9):

Northern Ranges
Sepik-Ramu Plains
New Guinea Highlands
Owen Stanley Range
Papuan Foothills
Fly-Strickland Lowlands

Northern Ranges

The Northern Ranges extend along the northern coast from the Irian Jaya border to the Huon Peninsula. They are broken by swamps and plains where the Sepik and Ramu Rivers reach the sea, and again to the east near Madang, where a belt of low hills follows the Gogol Fault. Thus they consist of three separate mountain barriers, named from west to east: the Bewani, Torricelli, and Prince Alexander Mountains; the Adelbert Range; and the Finisterre and Saruwaged Ranges.

The Bewani-Torricelli Mountains form an unpopulated, rugged—though only moderately high (up to 1860 m)—jungle-covered, narrow range, over 300 km long, in which precipitous ridges and short steep streams make travelling difficult. The range is flanked by narrow foothills, which in places—particularly in the south—are heavily populated. The Prince Alexander Mountains are less rugged and lower (up to 1220 m) than the Bewani-Torricelli Mountains.

Fig. 4. Airdrop in the lower Ramu valley. Ground traverses of 10 to 14 days away from a source of supply are possible only if the party is to be kept small; airdrops are the only method of replenishing supplies in the more remote regions. (G/5255)

Fig. 5. Temporary base camp in the headwaters of the Tarua River, 1960. (GB/998)

Fig. 6. A Bureau of Mineral Resources camp in the April River (1967)—showing the helicopter pad (left of centre), and the sleeping and messing quarters on the edge of the bush. (GA/468)

Fig. 7. Jet-boat negotiating shallows in the Karawari River, a tributary of the Sepik River. (G/9348)

The Adelbert Range, too, is less rugged and lower (up to 1550 m), but is otherwise similar to the Bewani-Torricelli Mountains.

The impressively rugged Finisterre and Saruwaged Ranges make up the largest mountain barrier of the Northern Ranges; they form an imposing massif rising from sea level to a highest peak of 4160 m. Erosion is rapid, and the mountains are drained by many large and deeply incised rivers which flow in valleys flanked by cliffs many hundreds of metres high. Almost all the rivers are greatly overloaded and form extensive alluvial fans where they debouch from the mountains (Fig. 10).

Sepik-Ramu Plains

It is hard to imagine a more striking contrast than that which the broad swampy expanse of the Sepik-Ramu Plains makes with the flanking mountains. For most of their 600-km length and 100-km width the plains are near sea level and consist largely of jungle-covered swamp (Fig. 11) interspersed with small areas of better-drained alluvial plains which are commonly clothed in grass. Low hills rising out of the plains are the remnants of a sunken, moderately dissected mountainous terrain underlying the Sepik swamps.

With their hot and humid climate, unrelieved jungle cover, and myriads of insects, the swamplands provide a hostile environment which has not been adequately traversed by geological parties. In some places, such as the lower reaches of the Sepik River, mosquitoes descend in swarms on the traveller throughout the day and discourage lengthy stops at the few outcrops.

To the southeast the plains pass into a narrow flat-floored valley which follows the Ramu-Markham Fault Zone, between the Northern Ranges and the New Guinea Highlands. The valley nowhere rises more than a few hundred metres above sea level, and, in contrast to the plains to the northeast, is mostly floored by well drained alluvium which provides good grazing and agricultural land.

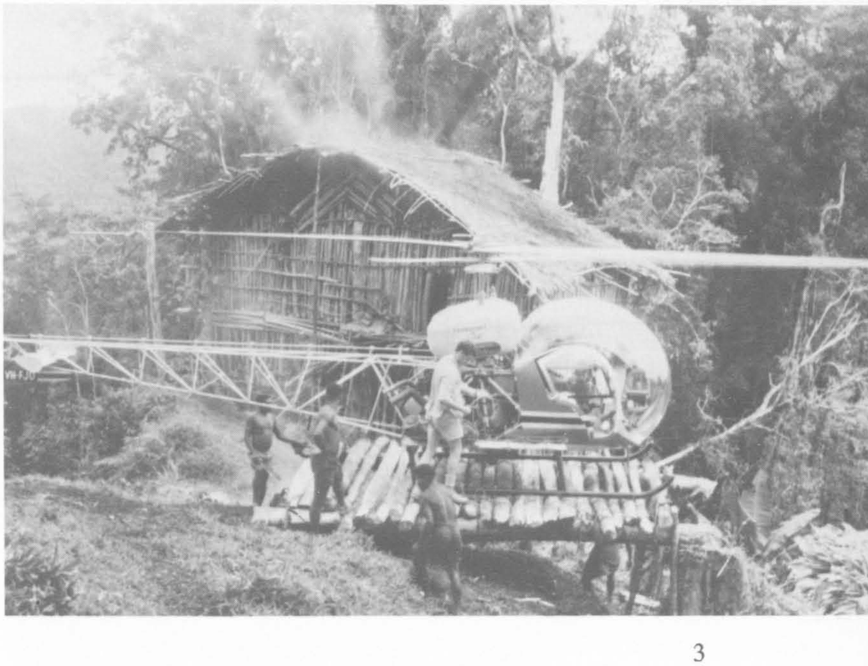


Fig. 8. A helicopter pad constructed near the head of the Salumei River, New Guinea Highlands. River beaches are the most common landing sites, but in many regions—notably the mountains south of the Sepik River and in New Britain—landing pads have to be cleared at a predetermined locality at the end of a traverse. More often than not the clearing has to be made in virgin jungle—a task requiring a hard day's work for the whole party. (GA/638)

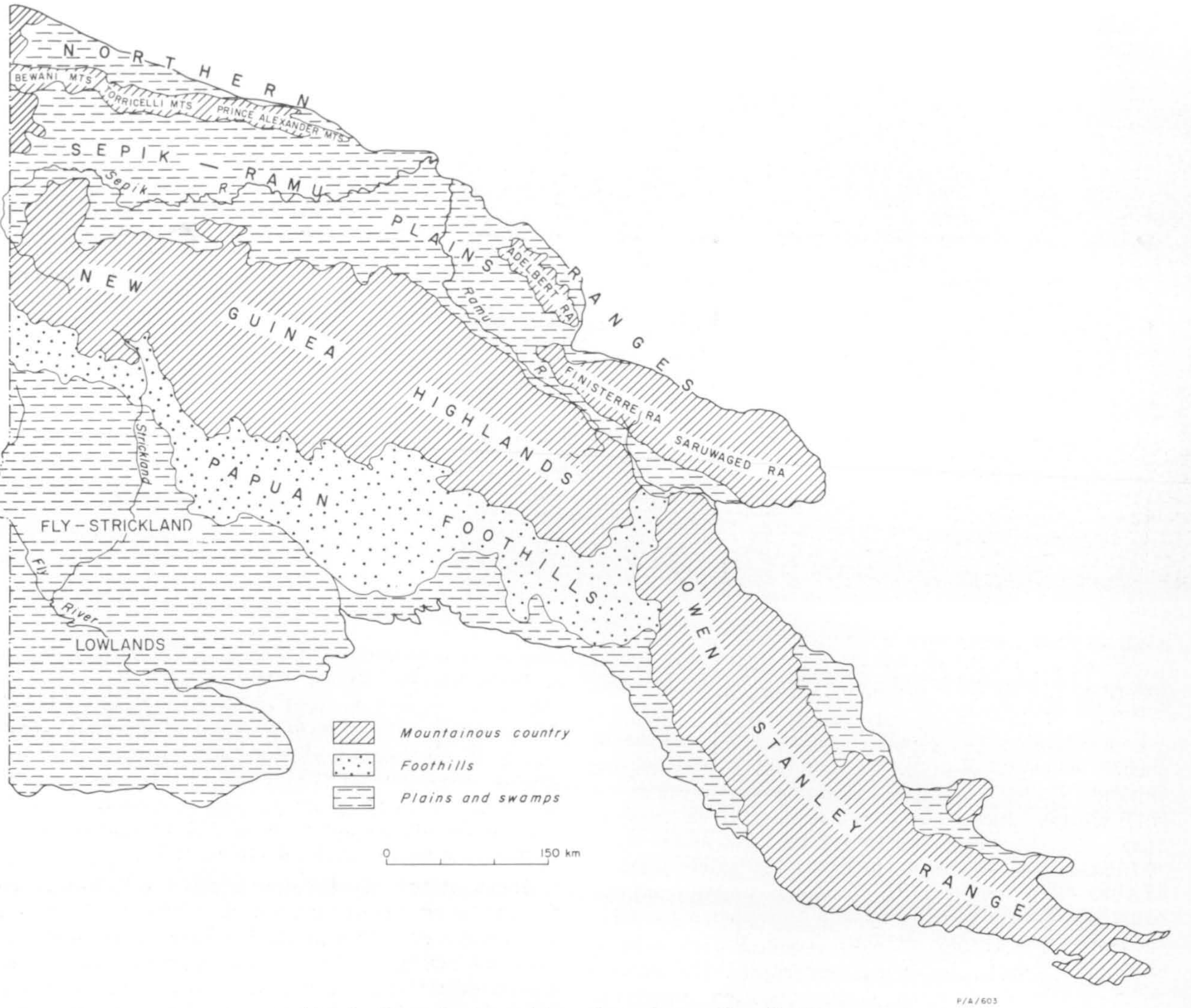


Fig. 9. Main physiographic regions, Papua New Guinea.

New Guinea Highlands

I have included in the New Guinea Highlands all the high mountains west of the Papuan peninsula. Though the highlands are made up of a diverse range of landforms, they can best be described as a faulted and, in places, deeply dissected high plateau, most of which is above 1500 m (Fig. 12). Mountains over 3000 m elevation are common throughout the highlands, the highest being Mount Wilhelm (4510 m).

Deeply dissected country such as that pictured in Figure 13 is common, but intermontane valleys are a striking feature (Fig. 14) and in the lower altitudes generally support large populations.

As the New Guinea Highlands support a large proportion of the population of Papua New Guinea, large areas are devoted to agriculture (Fig. 12), or are clothed in grass (Fig. 13) as a result of periodic burning off. Very large stretches of virgin forest, however, remain, especially on the northern front of the highlands, which slopes precipitously to the Sepik-Ramu Plains.

The climate varies considerably throughout the highlands, but, because of the elevation, temperatures are generally moderate; the high mountains, though, can be unpleasantly cold and bleak. A feature common to all the highlands is high rainfall, so that a day without rain is quite uncommon. None of the mountains is high enough to have permanent snow, but frosts are common at night above 3500 m, and snow often lies for several days on the summit of Mount Wilhelm. All the mountain peaks above 3500 m have a cover of alpine scrub and grasses.

Owen Stanley Range

The Owen Stanley Range forms the mountain spine of the Papuan mainland; it is above 3000 m for most of its length, and culminates in Mount Albert Edward, 3992 m above sea level. For most of its length it consists of a well defined mountain range with precipitous deeply dissected flanks.

Intermontane valleys are common and are exemplified by the Waria valley, which is over 50 km long and less than 10 km wide confined between the Bowutu Mountains to the northeast and the Owen Stanley Range to the southwest (Fig. 15). The valley floor is about 1500 m above sea level, and is mostly flat and grass-covered.

Papuan Foothills

The Papuan Foothills are characterized by long strike ridges of moderate relief which are rarely more than 1500 m high and almost invariably have a heavy jungle cover broken only by sporadic small garden clearings (Fig. 16). Being relatively low they have a hot, wet, and humid climate, and have only a sparse population.

Fig. 10. Foothills of the Saruwaged Range—looking north from the Markham valley. The main range is obscured by cloud and rain beyond the top of the picture. The Leron River with its great overload of detritus and consequent braided channels is typical of the streams draining the mountain massif. (GA/9604)

Only in their higher parts do they support many people, and there the jungle cover is broken by extensive garden clearings and areas of secondary scrub and grass.

Many of the ridges, particularly in the west, are composed of steeply dipping limestone which in most places forms steep scarps resulting in a very rugged terrain. Where the limestone is gently dipping an impenetrable jungle-covered karst topography is developed.

Between the New Guinea Highlands and the Owen Stanley Range, the foothills are higher and have greater relief, but are generally much lower than and form a distinct physiographic break between the flanking mountains, which are 3000 m and higher. The country is characterized by sharp, deeply dissected, and bush-covered ridges separated by open grass-covered valleys (Fig. 17).

The foothills are surmounted by several Quaternary stratovolcanoes (Fig. 24), of which Mount Bosavi is by far the largest at 2398 m above sea level.

Fly-Strickland Lowlands

South of the New Guinea Highlands is a low-lying region over 350 km wide drained by the Fly and Strickland Rivers; I have called it the Fly-Strickland Lowlands. It consists of a slightly dissected piedmont alluvial plain which was formed by the major rivers draining the region, and ranges in altitude from sea level at the south coast to about 100 m near the mountains in the north (Blake & Ollier, 1971).

South of the Fly River, the plain is little-dissected, flat to slightly undulating, and generally less than 30 m above sea level; north of the Fly River, only small remnants of the original plain are preserved, and almost the whole terrain comprises closely-spaced narrow ridges and valleys of maximum elevation about 8 m in the south and up to 100 m in the north.

Open savannah characterizes the southern part of the Fly-Strickland Lowlands, but to the north dense tropical jungle predominates.

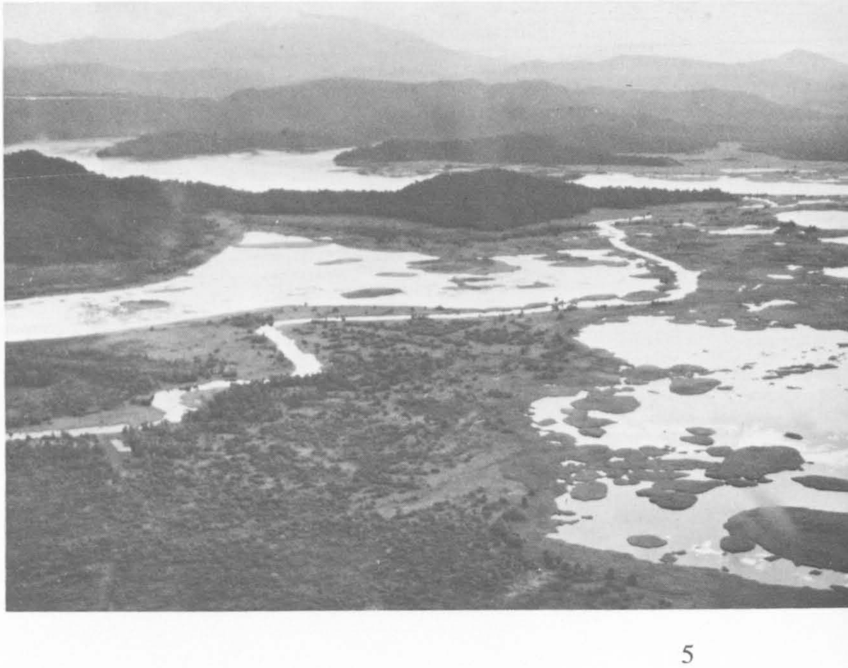


Fig. 11. Swamps and lakes of the Sepik Plains south of Ambunti. The hills rising out of the swamps are the remnants of a recently drowned topography. The characteristic floating grass islands and levee banks built by streams coming into the lakes are well illustrated. (GA/469)

Fig. 12. View of the New Guinea Highlands—looking west from the western margin of the Aure Trough. The aspect of a moderately dissected plateau can readily be seen.
On the right the flat-floored Ramu-Markham valley, which is only about 150 m above sea level, is separated from the highlands (mostly over 2000 m elevation) by the steep Ramu fall. Mount Wilhelm, at 4510 m the highest mountain in Papua New Guinea, is in the far distance beyond the cloud-covered Goroka valley.
Kainantu township, though it cannot be seen in the photograph, is on the right-hand side of the broad grass-covered valley (middle distance) which is drained by the Ramu River, seen flowing towards the Ramu fall on the right-hand edge of the photograph.
The youthful river flowing to the left is the Lamari River—one of the headwaters of the Aure River, which flows to the Gulf of Papua.

ISLANDS

The main offshore islands—New Britain, New Ireland, and Bougainville—though of only moderate elevation, have very rugged mountainous spines which, owing to their dense jungle cover, high rainfall, and short, steep streams, provide some of the most difficult travel in Papua New Guinea. Flat-lying limestone occurs extensively, especially in New Britain, and forms impenetrable karst limestone topography.

Volcanic landforms are prominent along the north coast of New Britain and form a large part of Bougainville. In addition most of the smaller offshore islands are of volcanic origin and many show recent volcanic features.

Narrow coastal plains and terraces are a conspicuous feature of the larger islands and provide most of the arable land.

GROSS TECTONIC FRAMEWORK

An understanding of the geology of Papua New Guinea is possible only if one appreciates that the main island has been formed by long-continued interaction between the Australian Plate in the southwest and the Pacific Plate in the northeast. Between these two major crustal elements, whose components in Papua New Guinea I have referred to as the *platform* and the *oceanic crust and island arcs,* is a highly deformed *mobile belt* about 150 km wide (Fig. 18).

THE PLATFORM

As described here the platform is that part of mainland Papua New Guinea underlain by Palaeozoic sialic crystalline rocks of the Australian Plate, and Mesozoic and Tertiary sedimentary rocks. In the southwest (Western Papuan Shelf of Thompson & Fisher, 1965), the sedimentary rocks of the platform are flat-lying or only gently warped, having been protected by the crystalline basement from the deforming forces so active in the mobile belt, but the outer margin of the platform—to the north and east—has reacted to stress by broad folding and some faulting. This outer margin includes a belt of complex folding and thrust-faulting —the Papuan Fold Belt (APC, 1961; Fig. 28)—which probably does not extend far into the underlying basement rocks. The folding and thrust-faulting probably resulted largely from gravity-sliding of the sediments when the mobile belt was uplifted in the Pliocene.

The northern limit of the Palaeozoic crystalline basement is probably marked by the Lagaip Fault Zone (Fig. 28), which extends from the Irian Jaya border southeastwards for 350 km to where it disappears beneath the Quaternary volcanics of Mounts Hagen and Giluwe.

Farther southeast the margin of the Palaeozoic crystalline basement is obscured by thick Neogene sediments of the Aure Trough, so it cannot be accurately located, but is considered to roughly coincide with the eastern limit of shelf limestone deposition.

THE MOBILE BELT

The mobile belt, in contrast to the platform, has been deformed periodically since at least the late Mesozoic and so has been an unsettled sedimentary environment. It was the repository of a great variety of geosynclinal sediments, markedly different from those of the platform, but probably its most striking feature is its great intensity of faulting. It has also been the site of wide-

Fig. 13. Panorama looking south towards Mount Hagen volcano (covered in clouds in the distance). The Baiyer River follows the gorge curving in from the left and joins the Lai River (in the bottom of the gorge to the right of centre) out of the picture to the left.
The grassy patches are a common feature throughout Papua New Guinea; though they were probably originally cleared by cultivation, they are perpetuated by seasonal burning off. The broadly convex landform making up most of the photograph is composed of lahar and outwash fans from Mount Hagen volcano. The prominent ridge in the middle distance is composed of the Chim Formation.
A recently cleared and fenced garden is seen in the foreground. (GA/9518-20)

Fig. 14. Andebare River east of Tari (lat. 5°50′S, long. 142°55′E), in the New Guinea Highlands. Broad grassy valleys such as this are not uncommon at high altitudes in the highlands. The valley floor is nearly 3000 m above sea level, and the lack of forest is apparently due to a 'frost-hollow' effect—i.e., the settling and accumulation of cold air along the valley floor.
In the foreground, the river flows from right to left through a cave in the low limestone ridge. (GA/1080)

spread igneous activity—in contrast to the platform, in which there was no igneous activity from the early Mesozoic until the onset of volcanism in the Pliocene.

It is difficult to imagine a greater contrast than that which the mobile belt makes with the platform: uniform shallow-water shelf-type sediments of the platform, little disturbed over large areas and almost completely lacking in volcanic rocks, give way in a distance of a few tens of kilometres to intensely faulted, folded, and partly metamorphosed trough-type sediments intercalated with major volcanic sequences and intruded by multiple dykes, stocks, and batholiths.

The boundary between the platform and the mobile belt is the northeastern limit of the Palaeozoic crystalline basement, and is marked by a major fault zone, the Lagaip Fault Zone, for much of its length. The boundary between the mobile belt and the oceanic crust and island arcs is also marked by complex faulting: the Bewani-Torricelli Fault System from the Irian Jaya border to the mouth of the Sepik River, the Ramu-Markham Fault Zone to the northeast, and the Owen Stanley Fault System to the southeast (see Fig. 28); these fault zones are fundamental breaks in the Earth's crust which separate rocks of oceanic and island-arc affinities from the metamorphosed geosynclinal sediments and igneous rocks of the mobile belt.

Several large fault wedges in the Bismarck Range are composed of Mesozoic rocks similar to those of the platform; they may be fragments of the platform which have been split off the crystalline basement block, and are therefore probably underlain by the same crystalline rocks as the rest of the platform. The only Palaeozoic crystalline rocks exposed in the mobile belt are farther south, in the core of the Kubor Anticline, which in this synthesis is interpreted as a detached fragment of the platform.

Though the Mesozoic sedimentary cover in these wedges is similar to that of the platform, there are some noteworthy differences: the sedimentary rocks in the wedges are thicker, and contain an angular unconformity and two volcanic units not known in the platform; and a small unnamed granodiorite/diorite intrusion on the southeastern extremity of one of the fault wedges near Goroka has given Rb/Sr isotopic dates of 180 to 190 m.y. (Early Jurassic). Thus, the rocks comprising these wedges were formed in an environment less stable than that of the platform—probably on the outer edge of the Australian Plate, which, apparently, was interacting with the Pacific Plate even in the Jurassic.

Two other wedges possibly underlain by Palaeozoic crystalline basement are also known: one in the mountains south of the Sepik River where a small area of unaltered Upper Jurassic Sitipa Shale is strikingly anomalous in the middle of the Lower Tertiary Salumei metamorphics; the other along the Irian Jaya border north of the Sepik River where boulders of Permian granodiorite and diorite are shedding from across the border. Because of their Permian age, and their association with pebbles of dacitic volcanics which are known only from the platform in the New Guinea Highlands, the granodiorite and diorite probably come from a displaced wedge of Palaeozoic crystalline basement.

Apart from these fault wedges of Mesozoic rocks, the oldest exposed rocks in the mobile belt are turbidites and intercalated volcanics which were deposited in Late Cretaceous and Eocene times along the length of the mobile belt in a marginal trough.

Fig. 15. Waria valley, a narrow intermontane valley along the Owen Stanley Fault System. The Owen Stanley Range on the left is over 3500 m high, and the valley floor about 1500 m.

THE OCEANIC CRUST AND ISLAND ARCS

A third contrasting geological environment is that of the oceanic crust and island arcs. The fundamental fault zones forming the northeastern margin of the mobile belt mark an abrupt change from rocks with continental affinities (metamorphosed geosynclinal sediments and associated plutonic rocks) to rocks with oceanic affinities, which are of two types:

(a) an ophiolite sequence which is probably upfaulted Mesozoic oceanic crust; the sequence is associated with the Papuan Ultramafic Belt, which is thought to be an overthrust segment of the Earth's mantle (Thompson & Fisher, 1965; Davies, 1971) that Thompson & Fisher (op. cit.) called the Papuan Ophiolite Province; and

(b) the products of island-arc volcanism consisting of subaerial and submarine lavas and pyroclastics and volcanolithic sediments which I have called the Bismarck Volcanic Province.

Papuan Ophiolite Province

The name Papuan Ophiolite Province was first used by Thompson & Fisher (1965) to include 'all intrusive, extrusive, and sedimentary rocks derived from or deposited on oceanic crust away from the influence of clastic sedimentation from large land masses', and the ultramafic and mafic plutonic rocks of the Papuan Ultramafic Belt. In this synthesis the Papuan Ophiolite Province also includes the Goropu Metabasalt and Emo

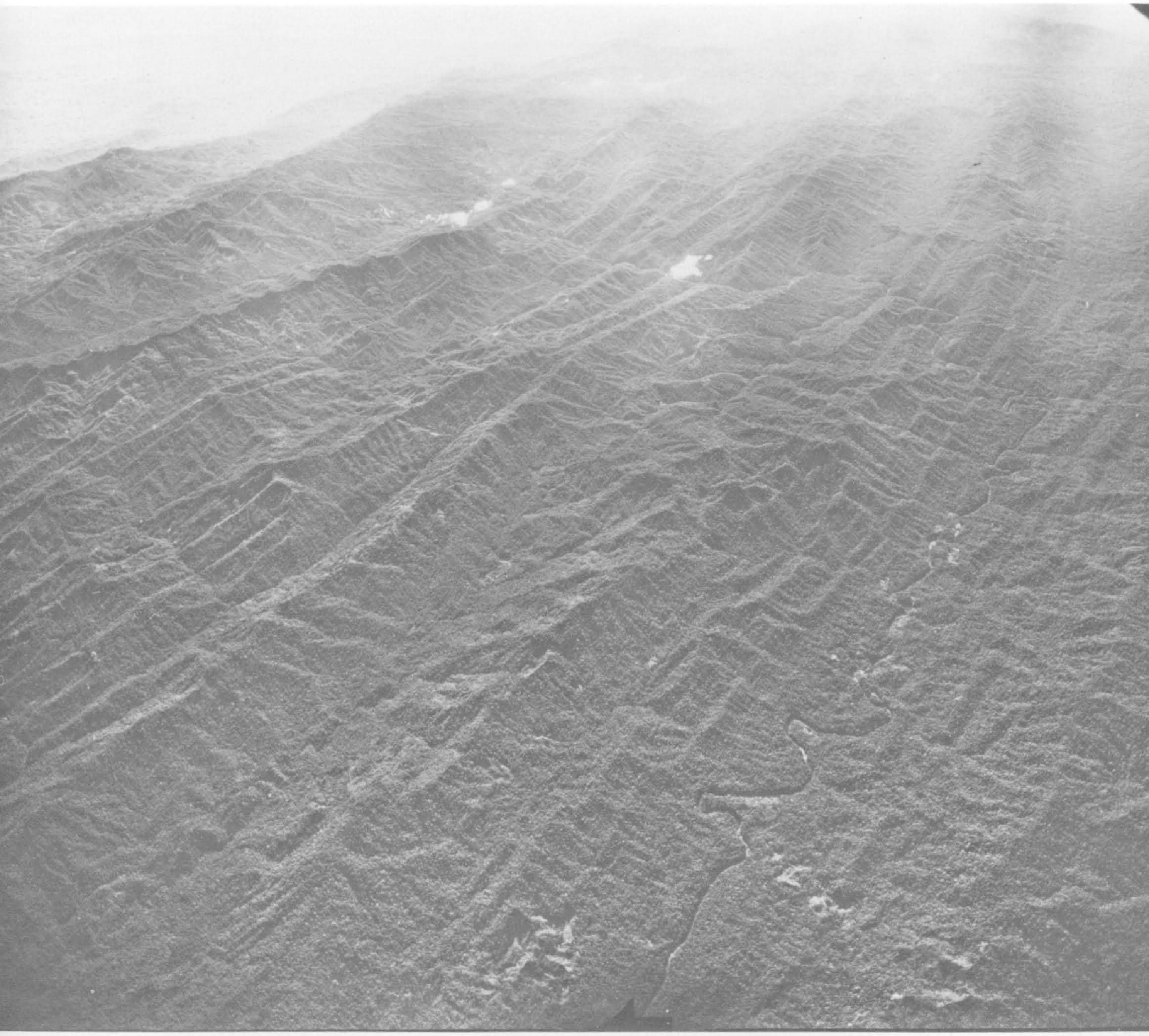


Fig. 16. Papuan Foothills—looking southeastwards towards Kerema. The river in the foreground is the Lohiki River, a tributary of the Vailala River. The long strike ridges of moderate relief clothed in dense tropical jungle with sporadic small garden clearings are typical of the foothills.

Metamorphics, which are greenschists thought to be metamorphosed ophiolites.

The province therefore includes the rocks of the Papuan mainland northeast of the Owen Stanley Fault System, and the submarine lavas which make up the eastern extremity of the Papuan peninsula. I have also included the offshore islands, including the D'Entrecasteaux group and the Louisade Archipelago, even though some regard the metamorphics making up the bulk of the islands as showing continental affinities. Woodlark Island is thought to be more typical of the Bismarck Volcanic Province.

Bismarck Volcanic Province

Though much of the region to the north and east of the mobile belt probably consists of oceanic crust, the volcanic island chains surmount extensive welts of much thicker crust which are regarded as accumulations of island-arc volcanism, and constitute a separate province which I have called the Bismarck Volcanic Province. The province includes from west to east: the coastal region north of the Bewani-Torricelli Fault System, the Adelbert and Finisterre Ranges, Huon Peninsula, and all the offshore islands except those off southeast Papua.

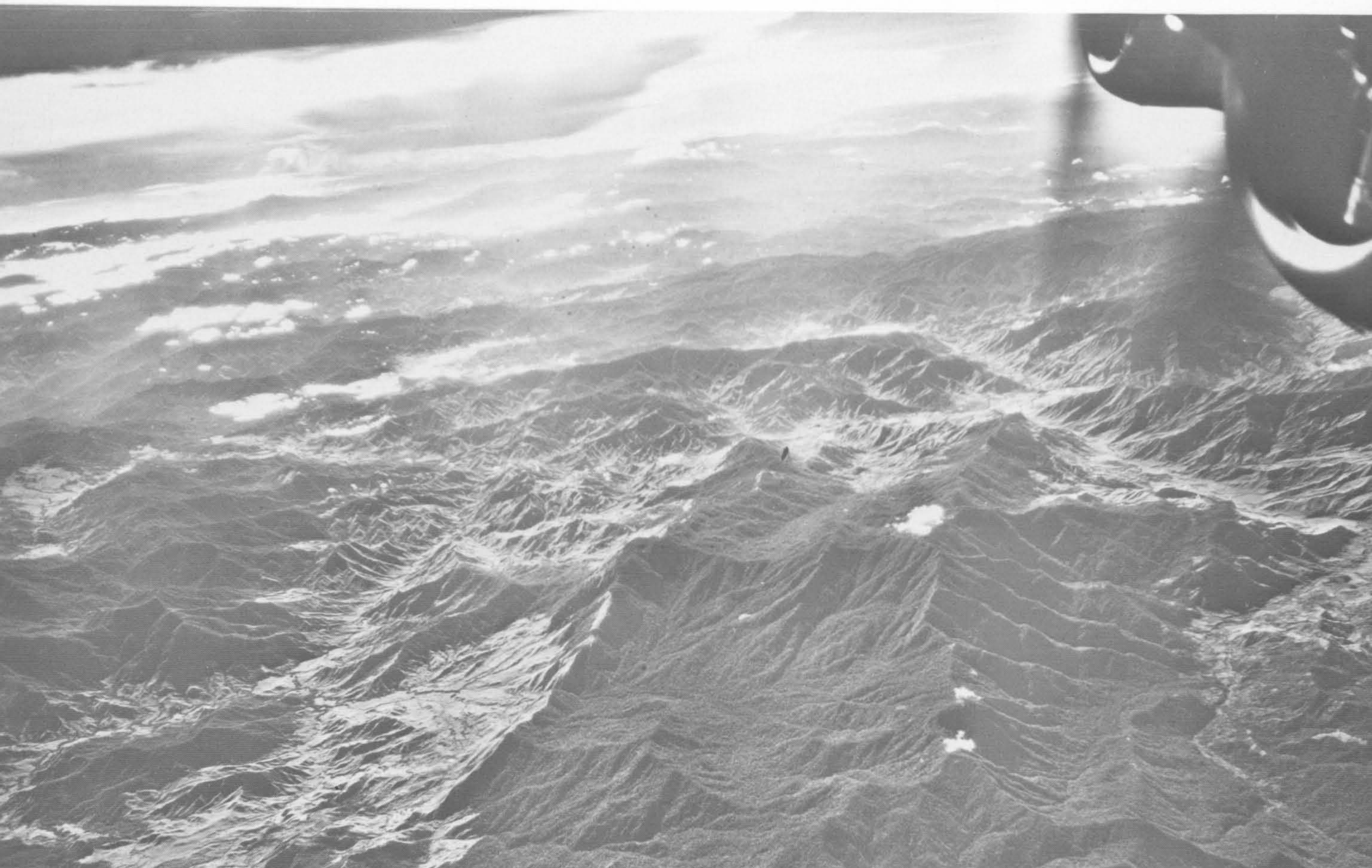


Fig. 17. Papuan Foothills—looking eastwards towards the Owen Stanley Range, in the distance. The rivers in the foreground and middle distance are the headwaters of the Tauri River. The massive strike ridges in the middle are Miocene turbidites of the Aure Trough.

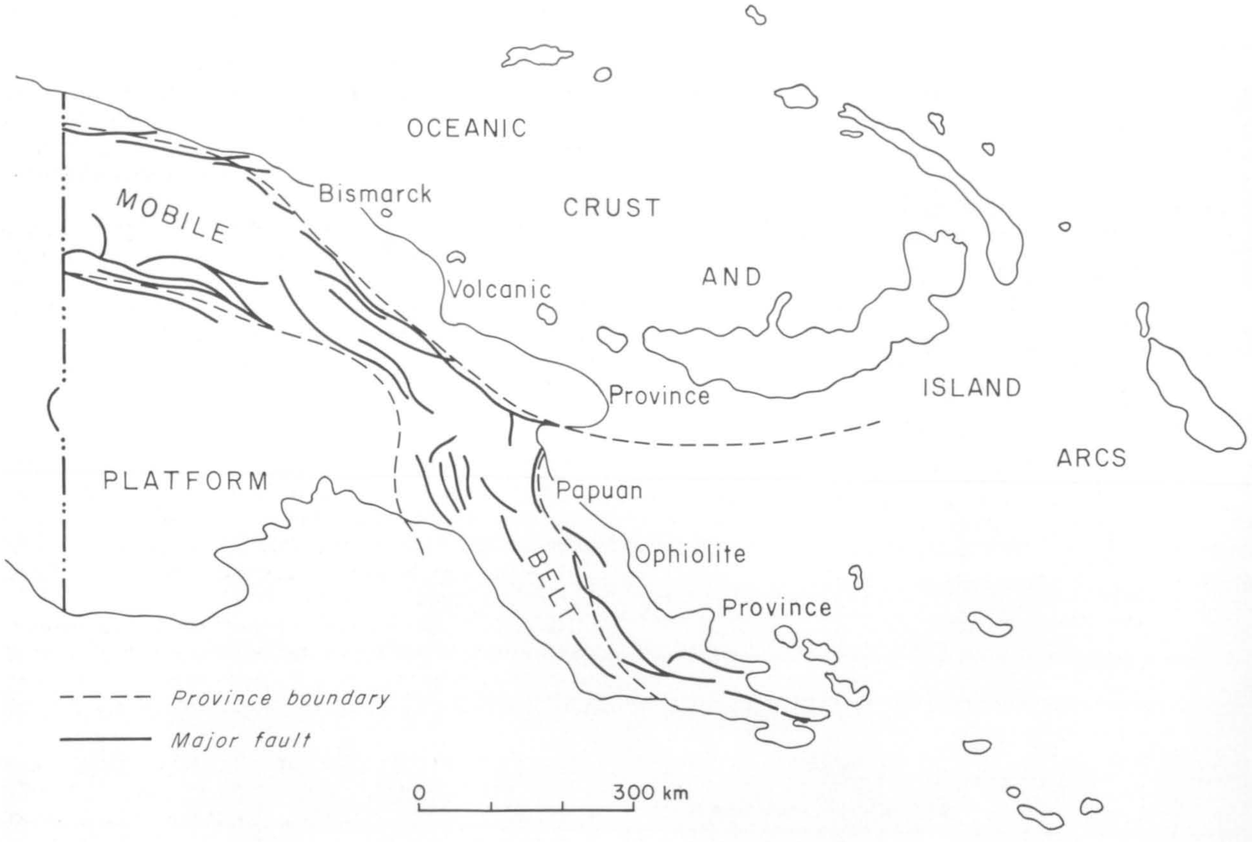


Fig. 18. Major geological provinces of Papua New Guinea.

GEOLOGICAL HISTORY

The following synthesis should be read in conjunction with the diagrammatic patterns of sedimentation (Plates 1 to 8), which have been derived from the 1:2 500 000 geological map of Papua New Guinea recently published by BMR (D'Addario et al., 1976).

The synthesis is presented chronologically as a geological history in which the major subdivisions of time have been determined, as far as possible, by regional geological events. The main subdivisions, therefore, are as follows: (1) pre-Cretaceous, (2) Cretaceous and Eocene, (3) Oligocene, (4) early Miocene, (5) middle and late Miocene, and (6) Pliocene to Holocene.

In making this synthesis I have used many of the publications listed by Manser (1974), but the main source of recent data has been the BMR and GSPNG explanatory notes (published and unpublished), which accompany the 1:250 000 geological maps. A compilation of the stratigraphic tables which presents in summary form the data used in the synthesis has been made by Skwarko (in press).

Standard Tertiary epochs have been used when referring to geological time and are correlated with Tertiary letter stages and planktonic foraminiferal zones (Fig. 19).

(1) PRE-CRETACEOUS

Rocks older than Cretaceous are known only in the platform, and as fault wedges in the mobile belt, which, as mentioned above, are thought to be detached fragments of the platform.

Many of the rocks of the Papuan Ophiolite Province, and the extensive ultramafic rocks in the mobile belt, are thought to have originated as oceanic crust and mantle, and were probably formed before the Cretaceous, but as they were emplaced in the Tertiary they will be discussed in that context.

Palaeozoic basement rocks

The sedimentary rocks of the platform are underlain by a crystalline basement which is known only from three exposures: the Badu Granite on the south coast near Daru; the Strickland Granite in a small exposure in the Strickland Gorge; and in the core of the Kubor Anticline (interpreted as a detached fragment of the platform), where the Kubor Granodiorite intrudes the Omung Metamorphics. In addition, granite has been penetrated by several petroleum exploration wells. From this sparse data it is concluded that the whole of the platform is underlain by remnants of metasediments intruded by granitic rocks.

Isotopic dating shows the granitic rocks to range in age from Carboniferous to Permian, similar to granites of Cape York Peninsula.

Mesozoic sedimentary cover

The platform was a stable sedimentary environment during most of the Mesozoic, when shallow marine or lacustrine shale, siltstone, and well sorted clean quartz sandstone were deposited. The fault wedges of the Bismarck Range to the north attest to a similar sedi-

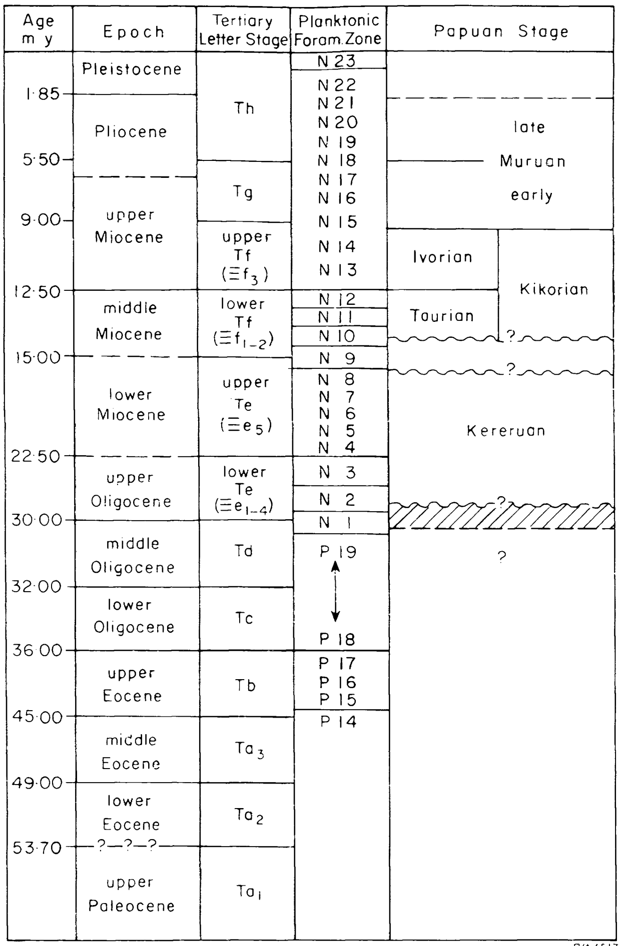


Fig. 19. Cainozoic time scale.

mentary environment, though sedimentation there commenced earlier (in the Late Triassic) and the sediments are considerably thicker.

There is now no record of pre-Cretaceous rocks throughout the rest of the mobile belt or in the oceanic crust and island arcs, so any interpretation of the pre-Cretaceous history of these regions must be purely speculative. However, it seems unlikely that the Palaeozoic crystalline basement block extended much farther north of its inferred present-day limits; consequently, Mesozoic sedimentation north of the platform probably took place on oceanic crust.

Late Triassic

Limestone, sandstone, and arkose of the Kuta Formation, which rests unconformably on the crystalline basement rocks of the Kubor Anticline (eastern end of the New Guinea Highlands, see Plate 1), were originally thought to be Permian in age, but later work (Skwarko, Nicoll, & Campbell, 1976) has shown that they are probably late Norian to Rhaetian.

Shale and arenaceous sediments (Yuat Formation of late Anisian age), and shallow-water, predominantly arenaceous sediments containing much carbonaceous material and a rich Late Triassic macrofauna (Jimi Greywacke), accumulated farther north, and later became incorporated in the Bismarck Range fault wedges, which are presumed to have been part of the outer margin of the platform. Though these rocks are apparently older than the Kuta Formation, their base has not been seen, but they probably unconformably overlie crystalline basement at no great depth.

The close of the Triassic saw a great outpouring of dacitic and andesitic volcanics and derived sediments called the Kana Volcanics (dated as Carnian to Norian in part), which are also exposed only in the fault wedges in the Bismarck Range and in the Kubor Anticline—though 80 m of dacite penetrated at the bottom of Komewu No. 1 well might be a southerly extension of them.

A quite remarkable feature of the geology of Papua New Guinea is the absence of further volcanic activity in the platform until the Pliocene (when the great stratovolcanoes of the New Guinea Highlands erupted) even though the mobile belt immediately to the north was the site of extensive activity during the Mesozoic and Tertiary.

Early Jurassic

After the Kana Volcanics were deposited a period of erosion persisted until the Early Jurassic, when shallow seas transgressed the fault wedges of the Bismarck Range. Here, greywacke, feldspathic sandstone, and siltstone of the Balimbu Greywacke rest unconformably on the Kana Volcanics.

The only known possible Lower Jurassic sediments in the platform were penetrated in Aramia No. 1 well: basal feldspathic sandstone, and thin carbonaceous shale with coal laminae and a possible Early Jurassic flora.

Elsewhere in the platform the main transgression appears to have been in the Middle Jurassic, and in the region of the Kubor Anticline it was late in the Jurassic as shown by the Upper Jurassic Maril Shale, which rests unconformably on the Kana Volcanics.

An unnamed granodiorite and diorite intrusion which is overlain by the Eocene Chimbu Limestone near Goroka has been isotopically dated by the Rb/Sr method as 180 to 190 m.y., which indicates that igneous activity accompanied the earth movements that caused the unconformity between the Kana Volcanics and the overlying sediments. The Karmantina Gneissic Granite, which intrudes metamorphic rocks farther southeast and has been dated as 172 m.y., probably was also intruded during these earth movements.

Middle to Late Jurassic
(Plate 1)

Middle and Late Jurassic sediments are exposed along the northern margin of the platform and in the fault wedges, and have been penetrated by petroleum exploration wells at widely scattered localities in the platform. In the southwest, lacustrine and terrestrial conditions prevailed, as shown by the common occurrence of coal, lignite, and carbonaceous sandstone and siltstone; to the north and northeast, shale with sandstone lenses was deposited in a marine environment.

Farther north, along the margin of the platform, the Jurassic sediments, though thicker, are still predominantly shallow marine; their greater thickness probably reflects downwarping of the continental margin consequent on the formation of a geosynclinal trough to the north, in the mobile belt (see p. 15). These thicker sediments are exposed extensively in the New Guinea Highlands from the Irian Jaya border to the Aure Tectonic Belt (see p. 28; Fig. 28), and consist of an inner belt about 1000 m thick of interbedded micaceous sandstone, siltstone, and mudstone of the Kuabgen Group, which grades northwards into an outer belt comprising the much thicker (about 3000 m) and finer grained Om Beds.

To the northeast, in the fault wedges of the Bismarck Range, a lens 250 m thick of basaltic agglomerate, pillow lava, and volcanolithic clastics of the Mongum Volcanics occurs conformably between the Balimbu Greywacke and the Upper Jurassic Maril Shale; it is, therefore, assumed to be Middle Jurassic in age. The Maril Shale consists of fossiliferous non-indurated shale, siltstone, and subordinate quartz sandstone, and is a correlative of the upper parts of the Om Beds to the west. It varies considerably in thickness, and in the Kubor Anticline oversteps the older Mesozoic sediments and rests unconformably on the Kana Volcanics.

The Sitipa Shale is a sequence of non-indurated grey micaceous shale and siltstone occurring as a small fault wedge within the Tertiary Salumei metamorphics south of the Sepik River. Plentiful bivalves show unequivocally that the Sitipa Shale is a correlative of the Maril Shale, and its anomalous position within a large area of younger metamorphics can be explained only by large displacements along the major faults of the region.

Even though no rocks of Jurassic age are known in the rest of the mobile belt (see Plate 1), the sedimentary trough which was established along the margin of the continental block by the Late Cretaceous may have existed during the Jurassic. If so, then the sedimentary record has been removed by faulting and metamorphism.

(2) CRETACEOUS AND EOCENE

(Plates 2, 3, and 4)

Rocks of Cretaceous and Eocene age are the oldest known in both the mobile belt (excluding the fault wedges) and the oceanic crust and island arcs.

In the platform the shallow shelf environment characteristic of the Triassic and Jurassic persisted during the Cretaceous and Eocene, but during this time the mobile belt was the site of a sedimentary trough in which were deposited turbidites and marine volcanics.

In the oceanic crust and island arcs, only volcanic rocks are preserved: in the Papuan Ophiolite Province they consist of thick pillow basalts and minor fine-grained sediments thought to have been deposited in a remote deep-ocean environment; in the Bismarck Volcanic Province, thick marine volcanics and volcanolithic sediments—probably the products of island-arc volcanism—were deposited.

THE PLATFORM AND FAULT WEDGES

During the whole of the Cretaceous, stable sedimentary conditions prevailed over the platform. Near the northeastern margin, however, a much less stable geological environment is indicated by much thicker sediments and a thick intercalation of marine volcanics around the periphery of the Kubor Anticline and in the fault wedges of the Bismarck Range.

The beginning of the Tertiary saw a major change in sedimentation, for in the Paleocene and Eocene most of the platform was emergent, and only in a small restricted shallow basin on the northeastern margin, called here the Mendi Shelf, was there any deposition at all. By the Oligocene the seas had contracted even farther, and the only records of Oligocene sedimentation are limited siltstone and shale outcrops along the northeast margin.

Cretaceous

(Plates 2 and 3)

The Cretaceous sediments of the platform are notable for the prevalence of lenses of clean quartz sandstone interbedded with siltstone and mudstone. Shallow-water sedimentary features abound and many of the lenses of sandstone were probably part of marine sand-bar complexes. Many have good porosity and permeability, and are potential hydrocarbon reservoir rocks.

Over most of the platform, the Cretaceous sequence as known from exploration wells ranges in thickness from less than 400 m to 1500 m. However, in the western part of the New Guinea Highlands the Cretaceous, which crops out as the Feing Group, is over 2000 m thick in places; it consists of the basal Toro Sandstone, a clean well sorted sandstone with minor mudstone and siltstone, which is overlain by the Ieru Formation, a fine glauconitic quartz sandstone with a greater proportion of siltstone and mudstone.

A different environment persisted in the Early Cretaceous near the northern margin of the platform, where a large thickness (up to 2500 m) of volcanolithic sediments on the flanks of the Kubor Anticline constitute the Kondaku Tuff. Minor intercalated intermediate and basic lava and agglomerate attest to nearby volcanism, but, because the unit grades southwards into the non-volcanic sediments of the platform, most of the huge volume of volcanic detritus making up the unit is assumed to have come from volcanoes to the north—probably those that supplied the Kumbruf Volcanics, about 2000 m of spilitic pillow lavas and marine agglomerate cropping out in the fault wedges north of the Kubor Anticline. Dow & Dekker (1964) thought that the Kumbruf Volcanics were Late Cretaceous as they are conformably overlain by the Upper Cretaceous to Eocene Asai Shale, but their outcrop area is highly faulted and field relations are not unequivocal. Mackenzie & Bain (1972) argue convincingly on the basis of the regional stratigraphy that the Kumbruf Volcanics are indeed Early Cretaceous in age.

The revised age of the Kumbruf Volcanics seems likely, for the Upper Cretaceous sediments of the Kubor Anticline—the Chim Formation—consist mainly of fine-grained shallow-water sediments, up to 3300 m thick, which do not appear to have any volcanic component; if the volcanoes that extruded the Kumbruf Volcanics had been active at the time, the Upper Cretaceous rocks would have been predominantly volcanic.

Paleocene and Eocene

(Plate 4)

The Paleocene and Eocene sediments of the platform are restricted to a belt 100 km wide on the northeastern margin, between Porgera patrol post (lat. 5°30′S, long. 143°08′E) to the northwest and the Aure Scarp (lat. 7°07′S, long. 145°20′E) to the southeast. The Paleocene sediments are mainly quartz sandstone at the base, which passes upwards into calcareous mudstone and siltstone (Pima Sandstone). The sediments were deposited mostly in shallow water, and were probably never much more extensive than the present area of outcrop, which has been called the Mendi Shelf.

During the Eocene the supply of detritus to the shelf had all but ceased, and only limestone was deposited. The rocks are not well known in the Mendi area, where resistant Eocene limestone forms ridges. In the northeastern part of the shelf, similar rocks have been mapped as the Chimbu Limestone and Nebilyer Limestone; both range greatly in thickness: the Chimbu Limestone from less than 200 to about 1000 m, the Nebilyer Limestone from less than 50 to about 300 m.

Although in most places on the shelf only limestone was deposited, to the southeast the sediments are generally finer and the total sequence thicker, indicating a deeper-water environment. Sedimentation continued throughout the Eocene, but only near Kundiawa have Oligocene fossils been found in the limestone, indicating a general retreat of the seas at the end of the Eocene.

THE MARGINAL TROUGH

Thick Upper Cretaceous and Eocene sediments around the northern and northeastern margin of the platform consist mostly of siltstone, shale, and greywacke which commonly show turbidite features, and it is apparent that most were deposited in a subsiding marginal trough. Marine volcanics, many of which are spilitic, occur throughout the succession and are commonly associated with shallow-water foraminiferal limestone, indicating that volcanic shoals and islands were sporadically distributed along the trough during much of the time. The rocks were faulted and folded, and metamorphosed (generally to a higher grade along the outer, northeastern, periphery of the marginal trough) during a major orogeny, probably in the Oligocene, then eroded, before sedimentation resumed in the early Miocene.

In the northwest (Sepik region), the sediments of the marginal trough constitute the Salumei Formation (Dow, Smit, Bain, & Ryburn, 1972), which consists mainly of siltstone and shale with subordinate subgreywacke and greywacke. The rocks are similar to the Chim Formation, which was deposited on the northern margin of the platform at the same time, but the Salumei Formation contains sporadic marine volcanics, and turbidite features such as graded bedding and intraformational conglomerates are common. Late Cretaceous and Eocene (Ta and Tb) Foraminifera are common in limestone lenses, but no other fossils have been found except for an Early Cretaceous ammonite fragment (*Polyptychites* or *Simbirskites*?) found in one of the rivers draining the Salumei Formation (Dow et al., 1972).

To the east, along the northern flank of the Bismarck Range, only a narrow belt of turbidites is preserved, which is believed to be a small remnant of a wider belt similar to that in the Sepik region, the rest having been removed by faulting along the Ramu-Markham Fault Zone. The sediments here are similar to the Salumei Formation, but are called the Asai Shale, in which shale and siltstone predominate and volcanics appear to be less common, and the Goroka Formation, in which slate, phyllite, and quartz sericite schist are the main rock types. Late Cretaceous and Eocene Foraminifera show the Asai Shale to be a correlative of the Salumei Formation, and even though no fossils have been found in the Goroka Formation there is little doubt that it is the same age.

Farther southeast, metamorphic rocks which make up the spine of the Papuan peninsula (Owen Stanley Metamorphics) are thought to have been originally sediments laid down in a southeasterly extension of the marginal trough.

The abrupt change in sedimentary environment from shelf-type sediments of the platform to trough-type sediments of the mobile belt is assumed to reflect the change from continental to oceanic crust during the Mesozoic. Therefore, the sediments of the marginal trough may have been laid down mainly on oceanic crust, though there is no evidence to support or refute this contention.

THE OCEANIC CRUST AND ISLAND ARCS

The oldest rocks known in the oceanic crust and island arcs are in the Papuan Ophiolite Province, where a monotonous sequence of pillow lavas, dolerite, and minor siliceous claystone, calcilutite, and chert of Late Cretaceous (Plate 3) and Eocene (Plate 4) ages constitute the Kutu Volcanics. Late Cretaceous and Eocene Foraminifera in the sedimentary intercalations provide an unequivocal age for the formation, which is several kilometres thick and is characterized in the northwest by thick pillow lavas and interbedded massive lavas. Only in the northwest of the province, near Morobe, is there any variety in the volcanics: marine dacitic and andesitic agglomerate, lava, and tuff predominate towards the top of the sequence. Eocene planktonic Foraminifera have been found in the dacitic pyroclastics, and as the Papuan Ultramafic Belt is intruded in this region by Eocene tonalite stocks (50-55 m.y. by K-Ar isotopic age determinations) the volcanics might be extrusive equivalents of the stocks. Because of their almost total lack of terrigenous material, most of the Kutu Volcanics are thought to have been extruded on the deep ocean floor in a region remote from any landmass.

In the Bismarck Volcanic Province the oldest rocks are of Eocene age and consist of intermediate and basic calc-alkaline pillow lavas (Fig. 20), agglomerate, and tuffaceous sediments with numerous lenses of coralline reef limestone containing abundant volcanic clasts. The environment, therefore, must have been one of active volcanic islands with fringing coral reefs. They have been mapped in New Britain, where they crop out extensively as the Baining Volcanics, and in the mountains north of the Sepik River, where they occur as the Bliri Volcanics in thin fault wedges in the Bewani-Torricelli Fault System.

Conspicuous features of the volcanics north of the Sepik River are the widespread granodiorite and diorite intrusions, which have been reliably dated by the K-Ar method as 35-40 m.y. old; i.e., they were apparently emplaced in the late Eocene. This points to a late Eocene or early Oligocene tectonic event, which may be a reflection of the Oligocene orogeny which so markedly affected the rocks of the marginal trough in the south.

(3) OLIGOCENE
(Plate 5)

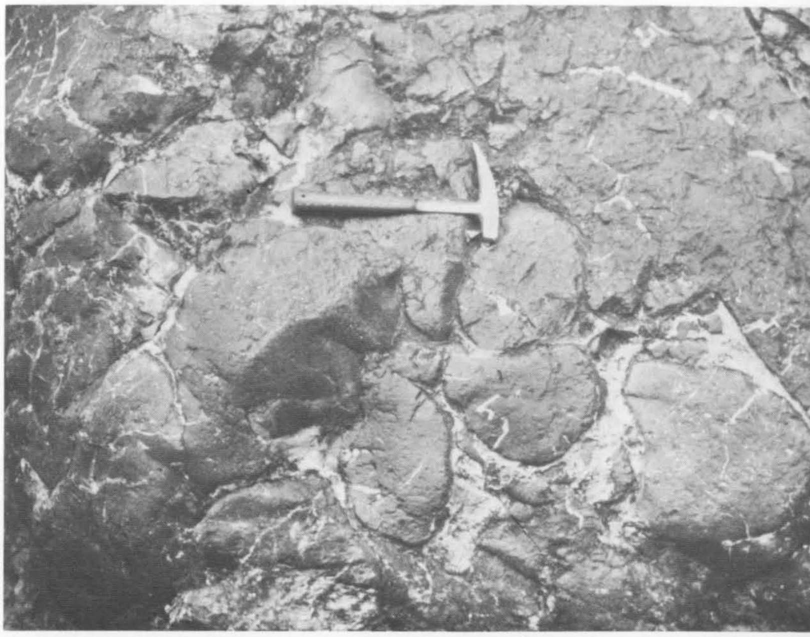
The Oligocene was a time of major tectonic activity along the marginal trough, whose sediments were in general more highly metamorphosed along the outer margin and more intensively faulted along the inner margin. The effect on the platform was quite marked, and culminated in the almost total retreat of the seas. This continued a trend first seen in the Eocene, but by the Oligocene the Mendi Shelf had shrunk to a narrow shallow marine inlet on the northeastern margin of the platform (Plate 5) in the Purari River area. The interruption to the volcanic activity and the intrusions noted before in the oceanic crust and island arcs at this time probably also reflects these earth movements.

METAMORPHICS

The mobile belt

Metamorphic rocks form a discontinuous belt extending from the Irian Jaya border to the south-

Fig. 20. Eocene pillow lavas from the mountains north of the Sepik River. The interstices consist of a foraminiferal ooze which became caught up between the pillows when they were extruded on the sea floor. (GA/6358)



eastern extremity of Papua. They range from slightly altered sediments to metamorphics of the almandine-amphibolite facies of regional metamorphism; most, however, belong to the greenschist facies of regional metamorphism. They have been mapped as the following formations listed in order from the Irian Jaya border to southeast Papua: Gwin Metamorphics; metamorphic phase of the Salumei Formation (informally called Salumei metamorphics); Asai Shale; Goroka Formation; and Owen Stanley Metamorphics. The most common rock types throughout the belt are slate, phyllite, quartz sericite schist, and chlorite schist, which in several places in the south Sepik region and in southeast Papua grade imperceptibly into the fossiliferous turbidite sequences. Metamorphosed volcanics found sporadically through the metamorphics range from barely altered intermediate and basic pyroclastics and lavas, in which volcanic textures are well preserved, to completely altered chlorite and actinolite rocks.

The higher-grade metamorphics crop out mainly in the southwest Sepik region, where they have been mapped as the Gwin Metamorphics. Muscovite, biotite, and garnet schists, and marble and amphibolite, are the main rock types, which may be more highly metamorphosed phases of the Salumei Formation.

Quartzofeldspathic gneiss in the Kainantu region (Bena Bena Formation) contains rocks that are, from the description of McMillan & Malone (1960), similar to the Triassic Kana Volcanics, so they are probably metamorphosed lower Mesozoic sediments and volcanics. These are the rocks that are intruded by gneissic granite which gives an Early Jurassic isotopic date (see p. 13).

Glaucophane schist occurs sporadically within the metamorphic belt, and in the south Sepik region is associated with large outcrops of eclogite. Glaucophane-lawsonite rocks are locally developed within, and grade into, greenschist facies rocks of the Salumei Formation in this region. Blueschist facies rocks indicate high-pressure, low-temperature metamorphism, and their presence along the belt might mark the site of an ancient subduction zone.

Papuan Ophiolite Province

Mount Suckling and Mount Dayman (40 km to the southeast), near the southeastern extremity of the Papuan mainland, make up a mountain block composed chiefly of low greenschist metamorphics called the Goropu Metabasalt. The rocks include slightly altered basalt, in which pillow-structures can still be distinguished, and dolerite, and minor marble and actinolite and calcic schists. Glaucophane has been recognized in some of these rocks. Limestone lenses in the lower-grade rocks contain Late Cretaceous fossils, and there seems little doubt that the metamorphics are the more highly metamorphosed equivalents of the Kutu Volcanics.

Similar rocks, the Emo Metamorphics, occur as a thrust sheet along the western side of the Owen Stanley Fault System between Kokoda to the north and Mount Brown (110 km east of Port Moresby) to the south, and are similarly regarded as regionally metamorphosed oceanic basalts. Recently Pieters (1974) has recognized two metamorphic phases in the Emo Metamorphics: an older syntectonic one during which actinolite/tremolite, chlorite, epidote/clinozoisite, lawsonite, and glaucophane were formed; and a later, partly syntectonic one during which low-grade greenschist facies mineral assemblages developed under predominantly static conditions.

Though there is no direct evidence (other than the Late Cretaceous fossils noted above) for the age of the Goropu Metabasalt and Emo Metamorphics, they form a southeasterly continuation of the Owen Stanley metamorphic belt and are of a similar grade, so there is no reason to doubt that they were formed by the same orogeny.

The islands of the D'Entrecasteaux group and the Louisade Archipelago are composed of metamorphic rocks of uncertain affinities. They have been described as sialic metamorphics of continental crustal origin (Davies & Smith, 1971), but the rocks may well have originally been oceanic basalts and accumulations of island-arc volcanics.

The metamorphics on Fergusson, Goodenough, and Normanby Islands (Davies & Ives, 1965) constitute the D'Entrecasteaux Complex; they are predominantly quartzofeldspathic gneiss, but amphibolite, calc-silicate rock, marble, and pelitic schist are common. The metamorphic grade is generally almandine-amphibolite facies, but basic granulite and eclogitic rocks occur as subconcordant lenses and sills in the gneiss. Davies & Ives proposed that the original rocks were a sequence composed mainly of arenite and acid volcanics in the lower half, and calcareous rocks, basic tuff, and rare pelitic sediments in the upper part.

On Misima Island (de Keyser, 1961) the metamorphics consist of high-grade amphibolite and quartzofeldspathic gneiss of the almandine-amphibolite facies, and lower-grade pelitic schist, chlorite-actinolite schist, calcareous schist, and marble. The rocks are similar in composition to those of the D'Entrecasteaux Complex, but in general are of lower grade; they were regarded by de Keyser as having been formed from a sequence of basic lavas and tuff overlain by thick pelitic sediments.

The metamorphic rocks of the other islands (Calvados Chain, and Sudest and Rossel Islands) are known only from very broad reconnaissance mapping, but the rocks appear to be mainly low greenschist facies rocks in which bedding can generally still be distinguished. The most common rock is quartz-sericite schist, and the rocks show more affinities with the more sialic Owen Stanley Metamorphics than the higher-grade and more basic metamorphics of the islands to the north.

There is no evidence for the age of the metamorphics of the Papuan islands, except that they are overlain on Misima Island by the Liak Conglomerate (now known to be Pliocene, D. Belford, pers. comm.) and that Panasia Island (11°10'S, 152°20'E), in the Calvados Chain, is composed of unaltered limestone of Te (probably late Te) age. It is generally accepted that the metamorphics are the same age as the Owen Stanley Metamorphics.

Age of metamorphism

The youngest fossils found in the less metamorphosed rocks of the New Guinea Highlands are Tertiary b-stage (late Eocene), which places a lower limit of about 45 m.y. on the age of the metamorphics in this region. Though the youngest fossils found in the Owen Stanley Metamorphics are Cretaceous in age, recent mapping of the metamorphics north of Port Moresby (Pieters, 1974) has shown that they grade with decreasing metamorphism into the Upper Cretaceous to Lower Eocene Kemp Welch Beds; similarly, Brown (in press) considers they may grade into the Upper Cretaceous to Eocene Auga Beds. These field relations are analogous to those in the New Guinea Highlands.

Therefore, there is little doubt that the entire belt of metamorphic rocks was formed by an orogeny which could have occurred no earlier than latest Eocene in the New Guinea Highlands and early Eocene in the Papuan peninsula. An unequivocal upper limit of about 23 m.y. is given throughout the New Guinea Highlands by unconformably overlying sediments which contain upper Te-stage Foraminifera. These sediments have been mapped near Amanab, close to the Irian Jaya border (unnamed lower Miocene sediments); in the south Sepik region (Pundugum Formation); in the Kainantu area (Movi Beds and Omaura Greywacke); and in the Aure Trough (the Omaura Greywacke, which contains abundant metamorphic clasts). There is some evidence that postmetamorphic sediments of early Te (late Oligocene) age occur in places. Unnamed sediments unconformably overlying the Salumei metamorphics near Amanab are thought to be late Oligocene in age, on the evidence of only one sample which contained diagnostic Foraminifera. The Dokuna Tuff and Bootless Inlet Limestone of late Oligocene to early Miocene age unconformably overlie Eocene rocks near Port Moresby, and, by inference therefore, were laid down after the main orogeny.

Therefore, on stratigraphic grounds the main orogeny probably took place between 45 and 23 m.y. ago. However, isotopic age determinations have been made on samples of metamorphic rocks from scattered localities throughout the mobile belt, and they give a range of values which mostly fall between 22 and 27 m.y. (R. W. Page, pers. comm., 1975). The reason for the discrepancy is not known, but the results are in sufficiently close agreement for one to be confident of an Oligocene age for the orogeny.

It is surprising that such an intense and widespread orogeny was not accompanied by igneous activity, but apart from the Sadowa Gabbro near Port Moresby, and a small unnamed gabbroic intrusion in the south Sepik region, no intrusive rocks of Oligocene age are known. By contrast, plutonic rocks of this age are widespread in the oceanic crust and island arcs (see below).

It is interesting to speculate that the widespread igneous activity along the mobile belt in the middle Miocene, which was not accompanied by tectonism, might have owed its origin to magma that was generated during the Oligocene orogeny but did not penetrate the upper levels of the crust until the middle Miocene.

The distribution of the metamorphics—as a belt between the Australian and Pacific Plates—leads to the conclusion that the metamorphism resulted from interaction between the rigid crustal elements of the Pacific Plate and the Australian Plate. Deformation, and hence metamorphism, seems to have been greatest on the outer periphery of the marginal trough.

A further corollary is that for most of its length the present-day boundary between the mobile belt and the oceanic crust and island arcs follows the outer periphery of the metamorphic belt—leading to the inescapable conclusion that the boundary was in much the same position in the Oligocene.

Oligocene to earliest Miocene of the oceanic crust and island arcs

As mentioned before, the late Eocene intrusions in the north Sepik region are evidence that the orogenic activity along the marginal trough also affected the oceanic crust and island arcs.

The evidence for a hiatus in Oligocene time is not as conclusive as in the mobile belt, mainly because the structure of the overlying and underlying rocks is virtually unknown (New Britain) or so complex (north of the Sepik River) that no structural discontinuity can be proved. However, two factors in addition to the late Eocene intrusions point to a major break in sedimentation in the late Eocene and early Oligocene:

(a) in New Britain, lower Oligocene rocks have not been recognized; upper Oligocene rocks appear to unconformably overlie more highly deformed Eocene rocks (Baining Volcanics) which in places are metamorphosed to the greenschist facies;

(b) although Foraminifera are common, there is a conspicuous lack of lower and middle Oligocene fossils (Tc and Td stages) throughout most of the oceanic crust and island arcs.

In New Ireland, the presence of Tc-stage limestone in the succession indicates that deposition continued over a longer period, possibly spanning the postulated Oligocene hiatus.

During the rest of the Oligocene the environment in the Bismarck Volcanic Province was similar to that which prevailed in the Eocene: i.e., the subaerial and marine volcanic products of active island volcanoes were deposited in complex mixtures with volcanolithic sediments and reef limestones. The volcanic activity continued for a very short time into the earliest Miocene (late Te), but ceased quite abruptly throughout the province and was followed by a short period of erosion. In the north Sepik region the erosion has been precisely dated as occurring during the planktonic foraminiferal zone N4 (earliest late Te). The dating is based on a large number of fossiliferous samples from both the volcanics and the unconformably overlying sediments. Elsewhere the dating is less precise, but in the Adelbert and Finisterre Ranges, New Britain, New Ireland, Bougainville, and Manus Island the Foraminifera in the volcanics range up to upper Te, while those in the unconformably overlying limestones range down into the same stage, showing that the hiatus must have occurred within the upper Te.

The evidence for such an abrupt cessation of volcanism is so unequivocal and so consistent throughout the Bismarck Volcanic Province that the complex intertonguing relations between the upper Oligocene and lower Miocene (lower and upper Te) volcanics and the lower and middle Miocene (upper Te to lower Tf) limestone and sediments mapped in the Huon Peninsula (Huon and Markham 1:250 000 Geological Series maps—Robinson, 1974; Tingey & Grainger, 1976) must be regarded as anomalous.

In the Papuan Ophiolite Province the only undoubted Oligocene rocks are basic lavas and minor tuff of the Dabi Volcanics, which are exposed as small inliers on Cape Vogel peninsula; lower Te Foraminifera indicate a late Oligocene age. Though the Dabi Volcanics are not found in contact with metamorphic rocks they are close to the metamorphics on both Mount Suckling and Fergusson Island; that they are unmetamorphosed is strong evidence that they postdate the metamorphism. Such relations are consistent with the early or middle Oligocene age postulated for the metamorphism.

The Iauga Formation, which consists of at least 650 m of basaltic and subordinate andesitic lavas and pyroclastics, is considered to be middle Miocene by some workers (Paterson & Kicinski, 1956; Davies & Smith, 1971). The presence of volcanics of this age in the oceanic crust and island arcs would be notably anomalous because volcanic activity was conspicuously absent elsewhere in this tectonic domain, so a check was made of the one foraminiferal assemblage upon which the age was based. This showed (D. Belford, pers. comm.) that the assemblage ranges from late Te to early Tf (early to middle Miocene). The palaeontological data, therefore, is consistent with the Iauga Formation being the same age as the rest of the volcanics in the oceanic crust and island arcs, i.e., Oligocene to earliest Miocene.

Papuan Ultramafic Belt

Probably the most spectacular feature of the Papuan Ophiolite Province is the Papuan Ultramafic Belt, which consists of several discrete masses—up to 100 km long and 30 km wide—of mafic and ultramafic rocks distributed along the eastern boundary of the mobile belt (Fig. 28). The ultramafic rocks are thought to have been part of the Earth's mantle which has been upfaulted along the Owen Stanley Fault System into its present position against the Owen Stanley Metamorphics (Thompson & Fisher, 1965; Davies, 1971); the mafic plutonics and the oceanic basalts, according to this hypothesis, constitute a section of the overlying oceanic crust. Though it is not part of the Papuan Ophiolite Province, the Marum Basic Belt—the large wedge of layered gabbro and norite, with a core of dunite and serpentinite—which occupies a similar structural position along the Ramu-Markham Fault Zone, by analogy is probably an upfaulted segment of mantle and oceanic crust.

If the hypothesis is correct, then the vertical displacement along the province boundary must have been of the order of tens of thousands of of metres, and emplacement of the Papuan Ultramafic Belt must have been a major tectonic event whose consequences would have been severely felt throughout the mobile belt. The only event of such magnitude recorded in the geological history of the mobile belt was the orogeny which formed the metamorphic rocks, and it is therefore suggested that the emplacement of the Papuan Ultramafic Belt was a consequence, along with the metamorphism of the sediments of the marginal trough, of plate interaction in the Oligocene, and not in the early Eocene as postulated by Davies & Smith (1971). However, the only supporting evidence for this is given by the fact that the metamorphic zones within the Owen Stanley Metamorphics parallel the boundary with the Papuan Ultramafic Belt, indicating that metamorphism and the emplacement of the Papuan Ultramafic Belt were contemporaneous events, probably caused by interaction between the Australian and Pacific Plates.

The only unequivocal upper limit to the age of emplacement of the Papuan Ultramafic Belt is given by the unconformably overlying Quaternary Domara Beds and the volcanics of the Hydrographers Range.

(4) EARLY MIOCENE
(Plate 6)

Sedimentation resumed over the whole of the platform in the early Miocene and continued almost uninterruptedly until the Pliocene. By this time there was a great attenuation in the supply of terrigenous material reaching the platform, so the sediments without exception are limestone or calcareous mudstone and siltstone. Only with the onset of volcanism in the New Guinea Highlands in the Pliocene was there a resumption of arenaceous sedimentation in the platform.

Once again the sediments of the mobile belt offer a complete contrast because a major trough (the Aure Trough) had subsided across the middle of the mobile belt and was receiving great quantities of sediment eroded from the mountains on either side of it. To the northwest an extensive basin—called here the Sepik Embayment—had also developed.

In the oceanic crust and island arcs a fundamental change had taken place in the earliest Miocene (see above), when volcanism ceased throughout the province. Deprived of a source of sediment, the Bismarck Volcanic Province and much of the Papuan Ophiolite Province were the sites of only shelf limestone deposition.

Fig. 21. Slumped polymictic conglomerate in the Aure Beds south-southwest of Kainantu, New Guinea Highlands. The conglomerate is part of the turbidite sequence in the Aure Trough; it attests to rapid erosion of a nearby landmass composed of metamorphic and plutonic rocks, and deposition in an unstable sedimentary environment. (M/825)

The platform

After the break in sedimentation during the Oligocene, the platform was inundated in the early Miocene. Shallow-water shelf limestone was deposited over the whole of the platform throughout the early and middle Miocene, except along a belt 10 km wide on the northeastern margin, where alternating limestone and calcareous mudstone were deposited in a deep shelf environment. This appears to have been a narrow transitional zone between the shallow shelf of the platform and the deep Aure Trough.

Over most of the platform the limestone (as found in exploration wells) is between 500 and 1500 m thick, but it thickens remarkably near the head of the Gulf of Papua, where over 3350 m of limestone was penetrated by the two Omati exploration wells. The limestone is exposed all along the northern margin of the platform, where it is mapped as the Darai Limestone. It is between 500 and 1300 m thick and forms the spectacular limestone cliffs of the western New Guinea Highlands near the Irian Jaya border.

Aure Trough and Sepik Embayment

The early Miocene saw a resumption of sedimentation with the downbuckling of the Aure Trough, which cuts across the mobile belt nearly at right-angles (Plate 6). It was a deep trough developed between two metamorphic landmasses—the Owen Stanley Range to the southeast and the Bismarck and Kubor Ranges to the northwest—which were being rapidly eroded, as shown by the prevalence of coarse

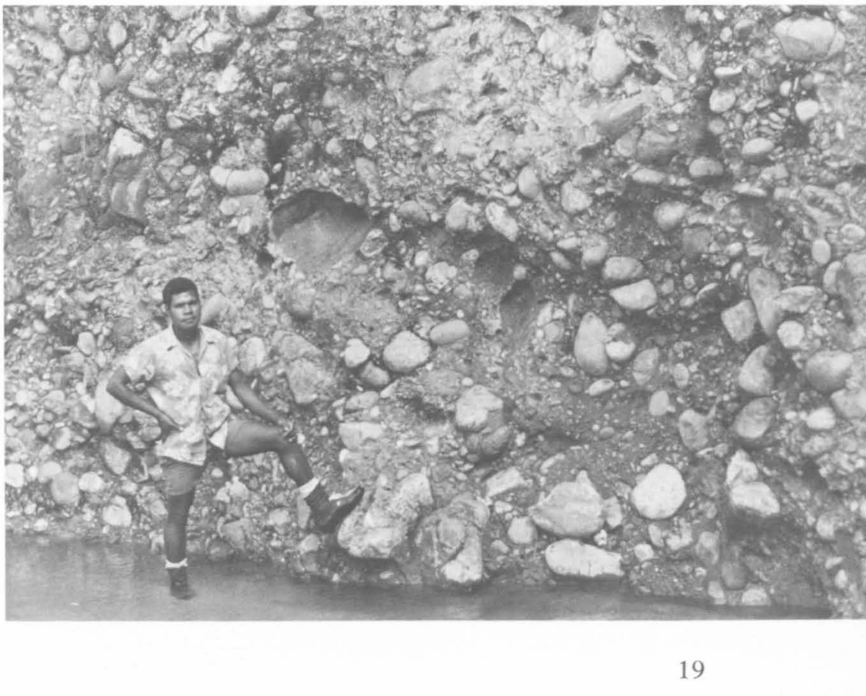


Fig. 22. Amogu Conglomerate in the Amogu River near Maprik, East Sepik Province. The clasts are made up of a wide range of rock types representative of the Lower Tertiary basement rocks of the region. The conglomerate carries traces of gold, apparently derived from the basement nearby. (M/1498/5)

conglomerates composed predominantly of metamorphic clasts along the margins of the trough (Fig. 21).

The early Miocene sediments of the Aure Trough are thick turbidites composed mainly of siltstone and greywacke. They have not been studied in sufficient detail to postulate a provenance, but it seems likely that most of the detritus came from erosion of the metamorphic mountains. The younger middle Miocene turbidites, on the other hand, are made up almost entirely of volcanic detritus.

Sediments of early Miocene age exposed northwest of the Bismarck Range—in the headwaters of the Yuat River and in the mountains north of the Sepik River—show that another, probably separate, downwarped area existed, which I have called the Sepik Embayment. The sediments are thinner than those of the Aure Trough and are composed mainly of terrigenous material derived from land in the areas of the Kubor Anticline and the Bewani-Torricelli Fault System. Thick coarse polymictic conglomerates (Fig. 22) near the margins of the trough attest to rapid erosion of the landmasses. In Plate 6 a landmass is shown in the western part of the south Sepik region: although there is little direct evidence for it in the early Miocene, it is postulated because lower Miocene sediments are absent from this part of the region, and thick coarse conglomerates occur around the southern margin of the Sepik Embayment.

An unconformity separates the lower Miocene sediments from the overlying middle Miocene rocks in both the Sepik Embayment and the Aure Trough, indicating renewed interaction between the Pacific and Australian Plates. On the eastern flank of the Aure Trough, rocks mapped as lower-grade Owen Stanley Metamorphics in the Wau 1:250 000 Sheet area (Dow, Smit, & Page, 1974, fig. 4) are thought to be lower Miocene rocks more highly deformed than elsewhere in the Aure Trough.

The oceanic crust and island arcs

After the volcanic activity in the oceanic crust and island arcs had ceased in the earliest Miocene, limestone was deposited on the eroded volcanics, which formed extensive shoals throughout the Bismarck Volcanic Province. The sedimentary conditions were uniform, and the rocks show little change throughout the province: well bedded to massive coralgal biomicrite predominates, but calcarenite, calcilutite, and other fine-grained calcareous sediments are not uncommon.

The encroachment of the limestone onto the volcanic basement was quite protracted in some areas because the base of the limestone is markedly diachronous; for instance, in western New Britain the basal limestone is of late Te age (early Miocene), whereas to the east the basal beds are of early Tf age (middle Miocene). Though the great influx of sediment derived from volcanics in the Pliocene stopped the growth of coral over much of the province, some areas continued to receive little sediment, and coral reefs continued to grow. Thus in New Britain the Yalam Limestone ranges up into the late Miocene (late Tf) and is overlain in places conformably by the Esis Beds, which comprise mainly calcareous shale and siltstone and interbedded chalky limestone of late Miocene to Pliocene age. Similarly the Gowop Limestone in the Finisterre Range is as young as late Pliocene at the top.

Over most of the Papuan Ophiolite Province there is no record of sedimentation until the middle Miocene Castle Hill Limestone was deposited on the Iauga Formation.

(5) MIDDLE AND LATE MIOCENE (Plate 7)

A dramatic change occurred in the middle Miocene, when marine volcanic activity—accompanied by batholithic intrusion of acidic to basic magma—burst forth along almost the whole length of the mobile belt. I have called this volcanic chain the Maramuni Volcanic Arc.

It is quite remarkable that all this activity in the mobile belt, with its great outpourings of volcanic detritus, is not reflected in the sediments of the platform or the oceanic crust and island arcs, in both of which the pattern of the early Miocene continued with the deposition of shallow-water limestone. It can only be assumed that the then continental slope formed an effective barrier to the southward migration of the volcanic material onto the platform, and that the limestone of the oceanic crust and island arcs was being deposited on shoals isolated from the sedimentary basins.

In the oceanic crust and island arcs the pattern of sedimentation remained the same throughout most of the middle Miocene. The only exception is north of the Bismark Range, where shallow-water clastic sediments were deposited towards the end of the middle Miocene. These sediments grade laterally into the middle Miocene limestone, and there seems little doubt that the detritus was derived from erosion of the Bismarck Range, which was emergent at the time.

Maramuni Volcanic Arc

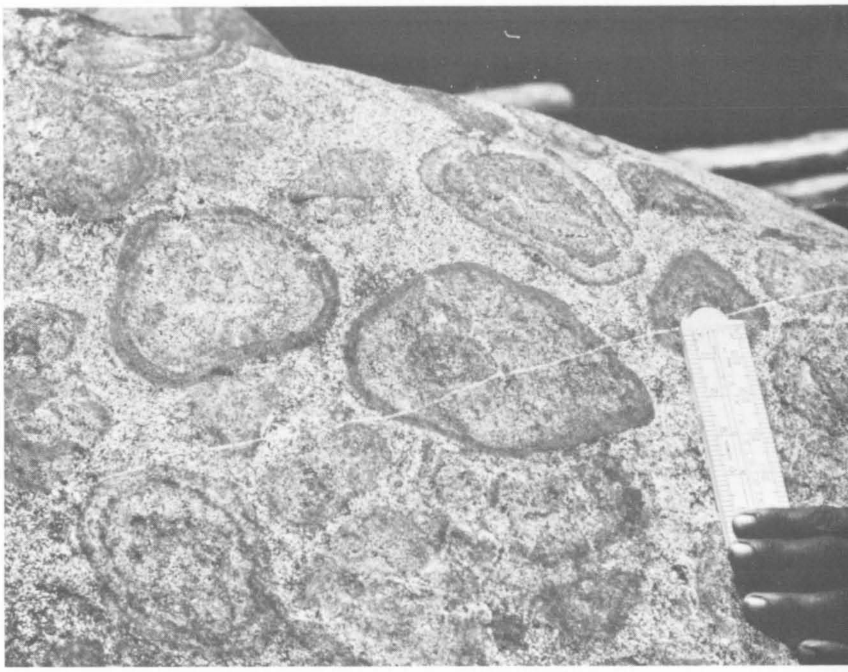
The palaeogeography of the mobile belt in the middle Miocene remained essentially the same as it had been in the early Miocene (cf. Plates 6 and 7), with landmasses along the Owen Stanley, Bismarck, and Kubor Ranges and the Bewani-Torricelli Fault System; there was probably a landmass in the south Sepik region also. The Sepik Embayment and Aure Trough were still subsiding and receiving abundant sediment which was derived almost entirely from the volcanism within the mobile belt.

The volcanoes formed an island chain—the Maramuni Volcanic Arc—extending from the Irian Jaya border to at least the southeastern margin of the Aure Trough, and probably beyond Port Moresby to near the mouth of the Kemp Welch River (Plate 7). The rocks consist of subaerial pyroclastics and lavas and great thicknesses of volcanolithic sediments which comprise the following formations listed from northeast to southwest:

- Wogamush Formation
  - Yapsiei Volcanic Member
  - Aumo Limestone Member
- Karawari Conglomerate
- Burgers Formation
  - Tarua Volcanic Member
- Yaveufa Formation
- Langimar Formation

The volcanolithic sediments in all the formations include, in addition to the predominant tuffaceous sandstone, abundant coarse conglomerate with clasts composed entirely of volcanic rocks, and conglomeratic, algal, and coralline limestone which formed reefs fringing the volcanic islands. All the formations have been reliably dated by Foraminifera, and the volcanic members have been dated by a large number of iso-

Fig. 23. Orbicular granodiorite, Tarua River, south Sepik region. The rocks are part of middle Miocene plutonic rocks intruded along the Maramuni Volcanic Arc. (GA/837)



topic age determinations (Page, 1976) as middle Miocene (early Tf; i.e. 12 to 15 m.y.), so there is no doubt that they were formed by one short-lived volcanic episode.

Southeast of the Aure Trough, the Talama Volcanics, Chiria Formation, and Kore Volcanics are the same age as and so similar to those to the northwest that the Maramuni Volcanic Arc must have extended along the Papuan peninsula at least as far as the Kemp Welch River.

North of the Owen Stanley Range southeast of Morobe, volcanics and volcanolithic sediments of the Iauga Formation were also thought to be middle Miocene, but, as the formation is in the oceanic crust and island arcs, in which middle Miocene volcanic rocks would be highly anomalous, its fauna was re-examined and indicated that the formation might be as old as early Miocene (see p. 18).

The coarse clastics near the volcanic centres throughout the Maramuni Volcanic Arc grade laterally into the middle Miocene turbidites of the Sepik Embayment and the Aure Trough. Those of the Aure Trough have been shown (APC, 1961) to be composed mainly of fresh volcanic detritus which could have come only from the Maramuni Volcanic Arc. As I remarked earlier it seems almost inconceivable that such intense and widespread volcanic activity was not reflected in the shelf limestone accumulating a short distance away in the platform, but very good age control is provided by foraminiferal reef limestones throughout the volcanic arc, and they prove that the volcanics are middle Miocene (early Tf) in age, the same as limestones of the platform and the oceanic crust and island arcs. Additional supporting evidence is given by a very large number of isotopic age determinations made on the volcanics and the associated intrusives, which range between 12 and 15 m.y.

It can only be assumed that the middle Miocene continental slope, which separated the platform from the Aure Trough and Sepik Embayment, formed an effective barrier to the southward migration of the volcanic detritus; however, a close examination of the Tertiary lower Tf limestone of the platform might show some evidence of fine airborne tuffaceous material.

The volcanic activity was accompanied by widespread intrusion of basic to acid plutons, which are now exposed as batholiths and stocks following closely the outcrop of the volcanic rocks (Plate 7). The intrusives have a wide range of composition and texture, but the main rock types are fairly coarsely crystalline gabbro, diorite, and granodiorite (Fig. 23). A large number of isotopic age determinations on the intrusives (Page, 1976) shows quite conclusively that they are of the same age as the volcanics of the Maramuni Volcanic Arc, with which, therefore, they are almost certainly comagmatic.

The areas of land during the middle Miocene are shown (Plate 7) as being much the same as they were in the early Miocene; however, they are not well defined, being based on the absence of middle Miocene sediments. This is in contrast to the early Miocene reconstruction which is based on well documented facies and the presence of coarse nearshore conglomerates close to the margins of the sedimentary basins.

The middle Miocene intrusives are shown as being almost entirely confined to the land areas (Plate 7), and the preserved volcanics are restricted to the sedimentary basins. Though this is a distribution which could be explained by uplift and erosion during the Pliocene-Holocene orogeny (see below), I think it much more likely that the early Miocene palaeogeographic pattern continued into the middle Miocene. If it did, then the volcanics would have formed archipelagos along the Sepik Embayment and Aure Trough, and large stratovolcanoes (similar to the Quaternary volcanoes of the New Guinea Highlands, see p. 24) surmounting the Bismarck and Owen Stanley landmasses.

Erosion of the volcanoes must have been rapid because there are microdiorite pebbles of middle Miocene Marumuni Diorite in the Karawari Conglomerate, which is also of middle Miocene age (Dow et al., 1972).

LATE MIOCENE SEDIMENTATION

The late Miocene pattern of sedimentation followed that of the middle Miocene, except that volcanic activity had ceased and the Aure Trough had contracted southwards, probably far enough for the Bismarck and Owen Stanley landmasses to be joined.

Good palaeontological control shows that clastic sediments were being deposited throughout the restricted Aure Trough and the northern part of the Sepik Embayment, but less is known about the southern part of the Sepik Embayment, where no sediments of late Miocene age are known. However, the Burgers and Wogamush Formations, which are middle Miocene near their bases, consist mainly of thick unfossiliferous clastic sediments which are probably late Miocene towards the top.

Earth movements near the close of the late Miocene, probably heralding the Pliocene-Holocene orogeny (see below), resulted in a fairly widespread angular unconformity in the Aure Trough which is not seen elsewhere. Coarse conglomerates in the northern part of the Sepik Embayment might reflect these earth movements.

In the platform, sedimentation continued unbroken into the late Miocene with the Orubadi Formation—calcareous mudstone and siltstone and minor interbedded limestone—which is about 350 m thick over most of the outcrop area but thickness to over 700 m towards the downwarped Aure Trough. Foraminifera show that the sequence is Tg (late (Miocene) to Th (Pliocene) in age, but it is not known how far up into the Pliocene the formation ranges.

In the oceanic crust and island arcs, sedimentation in the late Miocene followed the same pattern as that of the middle Miocene. Shoal limestone and fine calcareous sediments are predominant, except north of the Bismarck Range and in the Cape Vogel Basin (north of the Owen Stanley Range), where terrigenous sediments predominate.

(6) PLIOCENE TO HOLOCENE

(Plate 8)

Major faulting and subordinate folding accompanied by widespread igneous activity throughout all three geological provinces began in the Pliocene, or possibly latest Miocene, and resulted in the uplift of today's mountains. Many of the tectonic zones still show intense seismicity, and there are active or recently active volcanoes throughout the country, so there seems little doubt that the orogeny continues, probably little abated, to the present day.

The first evidence of the quickening of the tempo of the earth movements is shown by the changed character of the Pliocene sediments. They are in general coarse-grained, and were deposited in shallow water in terrestrial or lacustrine environments, and in many places contain a large component of volcanic detritus. Unfortunately the dating of these sediments, which relies on Foraminifera, is imprecise for such young rocks, and the date of the start of the orogeny is known only within broad limits. Probably the best measure of the start of the orogeny is given by isotopic dating of the older volcanics and associated hypabyssal intrusives, which range from 5 to 1 m.y.; an early Pliocene age for the start of the orogeny is therefore indicated.

By the late Pliocene most of the present highlands were emergent, and most of the sedimentation was restricted to the Sepik Embayment and the platform (Plate 8). The Aure Trough had contracted to a narrow north-south passage connecting the Gulf of Papua with an equally narrow inlet along the Ramu-Markham Fault Zone.

The volcanic and intrusive activity which accompanied the earth movements was widespread, and occurred along the northern margin of the platform, along the southeastern half of the mobile belt, and throughout most of the oceanic crust and island arcs. The only areas without igneous activity were the northwestern end of the mobile belt and the Northern Ranges. Almost all the intrusives are mineralized to some extent, and the Pliocene orogeny constitutes a major metallogenic epoch (see Economic Geology).

The uplift of the mountain areas took place along major faults, some of which have vertical displacements of thousands of metres. Folding was severe only along several well defined zones—the Aure Trough, the Ramu-Markham Fault Zone, and the Bewani Torricelli Fault System—where thick Plio-Pleistocene sequences have been tightly folded and overturned, and in places have suffered multiple overthrusts. The scale of the compressive movements is exemplified along the north flank of the Bewani-Torricelli Fault System, where the entire sequence of over 3000 m of Plio-Pleistocene sediments has been overturned against the basement rocks of the mountain ranges.

SEDIMENTATION

The platform

Most of the platform has a thin cover of Quaternary alluvial and volcanic deposits which mask the underlying sediments. However, oil exploration wells have shown that Pliocene sediments between 100 and 450 m thick are present over most of the platform. They are mainly lacustrine mudstone and siltstone which are commonly carbonaceous and contain many thin lignite seams. Intercalations of marine mudstones show that most of the platform was inundated from time to time by the sea.

Pliocene sediments of the platform are exposed only along the northern, deformed margin of the platform; they are fine and predominantly marine at the base (Orubadi Formation, which ranges in age from latest Miocene to Pliocene and appears to conformably overlie the Miocene Darai Limestone), and grade into lacustrine and terrestrial deposits in the upper part of the sequence. The younger sediments (Wongop Sandstone, Liddle Conglomerate, Birim Formation, and Era Beds) are characterized by a high proportion of volcanic detritus, lignite, and conglomerate, and many disconformities within the succession. The total thickness of these sediments is about 2400 m, much thicker than those of the undeformed part of the platform, to the south.

As the Pliocene sediments are affected by the thrust-faulting which disrupts so spectacularly the competent Darai Limestone, they place a lower limit on the age of the commencement of the thrusting (see p. 35).

Aure Trough

By the latest Miocene the Aure Trough had contracted to a narrow inlet between the Gulf of Papua and the Ramu-Markham Fault Zone. The rapidly eroding mountains to the northeast and southwest were supplying large quantities of coarse sediment, which forms the only formally named Pliocene unit in the Aure Trough—the Babwaf Conglomerate. The conglomerate occurs mainly as elevated synclinal remnants capping the mountain ranges; it is up to 2000 m thick, is resistant to

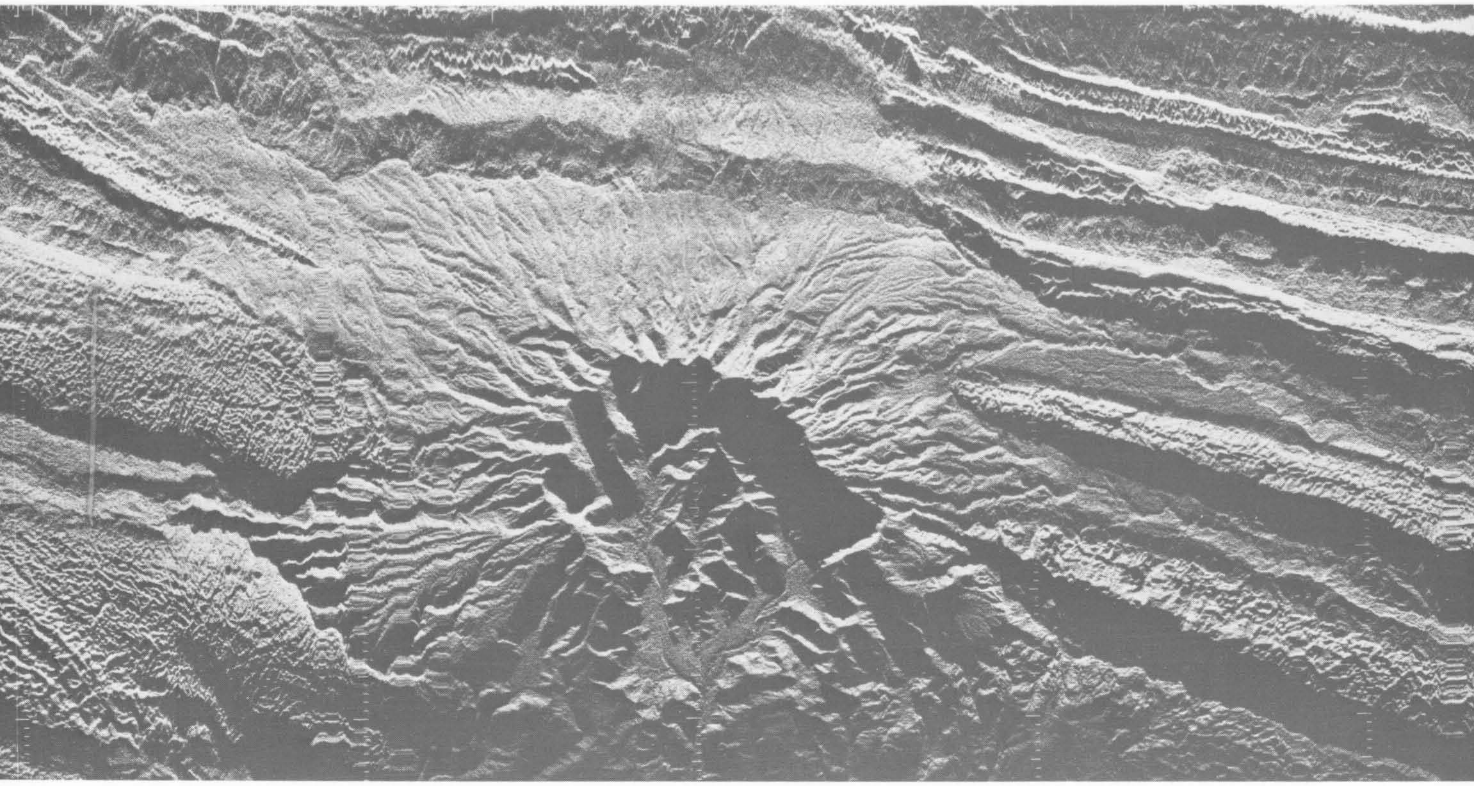


Fig. 24. Radar image of Mount Murray stratovolcano (lat. 6°45′S, long. 144°00′E)—of late Pliocene or Quaternary age—surmounting the prominent strike ridges of folded Miocene Darai Limestone. Deep erosion of the crater has exposed the intrusive core of the volcano. (Scale about 1:250 000.)

Reproduced with the permission of the Australian Department of Defence and the Papua New Guinea Department of Natural Resources.

erosion, and forms imposing cliffs hundreds of metres high. To the north the conglomerate has been downfolded in a very tight syncline, on whose eastern limb the 2000 m of sediments are overturned by as much as 30°.

To the south the inlet opened out into the Gulf of Papua, where latest Miocene and Pliocene sediments rest unconformably on middle and upper Miocene sediments. The Pliocene sediments—coarse detritus supplied by erosion of the surrounding metamorphic landmasses, and large quantities of volcanic detritus from the stratovolcanoes to the east—are a complex mixture of fluviatile, lacustrine, and marine sediments, which are over 2000 m thick in places.

Ramu-Markham Fault Zone

Between the rising New Guinea Highlands to the south, and the Finisterre and Saruwaged Ranges to the north, the Ramu-Markham Fault Zone was a narrow arm of the sea in which was deposited up to 2000 m of sandstone and conglomerate—the Leron Formation. Though some of the sediments are marine, most are lacustrine and fluviatile. As expected in such a fundamental fault zone, the Leron Formation is highly deformed, and dips of 40-60° are common.

Sepik Embayment

The sedimentary environment in the Sepik Embayment was very complex during the Pliocene, and the task of unravelling the sedimentary history is hampered by the lack of diagnostic Foraminifera. However, the rocks in the western part of the embayment have been mapped by oil exploration companies and BMR in much more detail than in any other area of similar size in Papua New Guinea, and the development of the sedimentary basins is now well documented.

In the western half of the embayment, most of the Sepik Plains were either emergent or covered by shallow seas, and sedimentation was restricted to three narrow troughs adjacent to the Bewani-Torricelli Fault System, which was a narrow, rising, and rapidly eroding mountain range. The three troughs are the Aitape trough to the north, the Lumi trough to the south, and the Wewak trough to the east.

Sedimentation in these troughs was extremely variable, and a complex stratigraphic nomenclature has been found necessary to describe the rocks, which range from thick pelagic marls deposited in the deeper parts of the troughs to massive polymict conglomerates deposited near the margins. The Plio-Pleistocene sequences are over 3000 m thick in the deepest parts of the troughs, but the sediments thin rapidly away from the mountains, as shown by the recently completed Bongos No. 1 well (Plate 8), which penetrated only about 300 m of Pliocene sediments before reaching deformed Miocene rocks.

The Pliocene sediments have been intensively faulted by movements in the Bewani-Torricelli Fault System, and along the northern front of the mountains they are tightly folded. At the western end of the mountains, near the Irian Jaya border, over 3000 m of Plio-Pleistocene sediments overturned against the basement rocks of the Bewani Mountains attest to the extraordinary scale and intensity of the recent earth movements in this region.

The eastern half of the Sepik Embayment has not been mapped in as much detail, and the Miocene, Pliocene, and Pleistocene sediments have been mapped as the one formation—the Kabenau Beds. However, the sedimentary environment was much the same as in the western part of the embayment. Sandstone, mudstone, and conglomerate derived from the Bismarck Range to the south, and the Adelbert Range to the north, are the main rock types, and are probably several thousand metres thick.

The oceanic crust and island arcs

Clastic sediments were also deposited during the Pliocene in the Cape Vogel Basin, at the southeastern end of the Papuan mainland. The sediments, which range in age from latest Miocene to Pliocene, are similar to those of the Sepik Embayment and consist of about 4200 m of lithic sandstone and siltstone, polymict conglomerate, and some intercalated tuff.

Similar volcanolithic sediments are widespread throughout the islands of the Bismarck Volcanic Province, and were probably deposited in similar restricted basins.

Raised coral reefs of Plio-Pleistocene age fringe much of the coastline of Papua New Guinea, particularly in the outlying islands and New Britain.

IGNEOUS ACTIVITY

The Pliocene and Quaternary volcanics and associated hypabyssal intrusives can be conveniently subdivided for the purposes of description into three groups: those of (a) the New Guinea Highlands, (b) southeast Papua, and (c) the Bismarck Volcanic Province.

New Guinea Highlands

The skyline of the New Guinea Highlands is dominated by stratovolcanoes of andesitic and basaltic composition. The highest is Mount Giluwe (lat. 6°05′S, long. 143°50′E), 4370 m above sea level, but it is rivalled by Mount Hagen (3780 m), Mount Ialibu (3467 m), and Doma Peaks (3568 m). The largest is Mount Bosavi (2389 m) for, though it is not as high, it rises not from the New Guinea Highlands at over 2000 m, but from the Fly-Strickland Lowlands only a few hundred metres above sea level.

A range of erosional forms can be seen—for example: completely eroded stocks near the Irian Jaya border; deeply dissected volcanoes such as Mount Murray (Fig. 24), in which most of the original form of the volcano has been destroyed; and well preserved volcanoes with fresh summit craters such as Mount Bosavi. Mount Yelia and Doma Peaks are the most recent, and still exhibit solfataric activity.

The summits of the higher volcanoes have been glaciated, so must have reached their present altitudes at least as long ago as the late Pleistocene. This is confirmed by the oldest isotopically dated lava, which is 0.85 m.y. old (Mackenzie, 1973), but most of the volcanoes are much older and probably commenced activity in the Pliocene when the influx of volcanic detritus into the sediments of the platform started. Isotopic ages of 5 m.y. on porphyry stocks at Mount Fubilan copper prospect (lat. 5°08′S, long. 144°08′E) show that igneous activity commenced in some places in the earliest Pliocene.

The volcanics range in composition from basic to intermediate and rarely acidic, and most are shoshonitic (high potash). The stratovolcanics are composed of ash, agglomerate, and lava flows surrounded by large aprons of outwash deposits. Lahar deposits are common and extensive; thick chaotic deposits containing huge boulders have been found in the Yuat River 130 km downstream from their origin, Mount Hagen volcano (Dow et al., 1972).

Erosion has exposed the intrusive cores of Mount Hagen and Mount Murray volcanoes, and many stocks which are part of the same igneous epoch are exposed throughout the New Guinea Highlands. They are mostly porphyritic, intermediate or acidic in composition, and all are hydrothermally altered to some extent. Some, such as Mount Michael and Mount Elandora (lat. 6°30′30″S, long. 146°01′E) do not have associated volcanic rocks, and it is believed that they may never have had a volcanic edifice.

Southeast Papua

The southeastern part of the Papuan mainland and the outlying islands are notable for widespread Quaternary volcanoes, some of which have erupted in historic time. Those of the mainland are mostly large, predominantly andesitic stratovolcanoes similar to the volcanoes of the New Guinea Highlands, whereas the volcanoes of the islands are small basaltic cones and cumulodomes.

Volcanoes of the Papuan mainland

The volcanoes form two separate complexes: one is dominated by Mount Lamington (1576 m; Fig. 25), and includes the dissected Hydrographers Range and the Managalase Plateau; the other is formed by the coalescing stratovolcanoes of Mount Victory (1930 m) and Mount Trafalgar (1720 m), southwest of Tufi.

The oldest and most dissected volcano is that of the Hydrographers Range, whose estimated Pleistocene age has been confirmed by K/Ar isotopic ages in the 1.5 to 0.5 m.y. range (Ruxton, 1966). However, the volcanic activity commenced considerably earlier, for isotopic ages of 5.4 to 5.7 m.y. (latest Miocene) have been determined from the Sesara Volcanics, which are part of the Managalase Plateau.

The Managalase Plateau consists of the gently sloping dissected slopes of the Hydrographers Range volcano, upon which younger volcanic landforms have been built. Very recent volcanic features abound, and it is not surprising that a small basaltic cone and explosion crater are reported to have been active in village memory (Ruxton, 1966).

Mount Lamington is the most recently active volcano in the more-westerly complex, and, though it dominates the surrounding region and exhibits many youthful volcanic features, it had not been active within historic times and was not recognized as a volcano until the catastrophic eruption in 1951 (Fig. 26), in which nearly 3000 people died. A superb description of the eruption is given by Taylor (1958) in his monograph, to which the reader is referred.

Of the more-easterly complex, Mount Victory is less dissected than Mount Trafalgar, and was active between 1890 and the early 1930s but is now quiescent. A small volcano to the south, Waiowa volcano, which is not connected to the Mount Victory complex is another recently active mainland volcano; it erupted in 1943 and 1944.

Both volcanic complexes are predominantly andesitic, though basalt, dacite, and rhyodacite are common throughout, and, based on the small number of samples chemically analysed, both appear to be composed of high-potash calc-alkaline rocks, similar in composition to those of the New Guinea Highlands.

Volcanoes of the Papuan islands

The volcanoes of the Papuan islands are characteristically small, and most were therefore probably short-lived. Volcanic activity has been spasmodic since the early Pliocene (K-Ar isotopic dates range from 4 to 0.5 m.y.) and may even date back to the late Miocene, as indicated by a K-Ar isotopic date of 11.4 m.y. from the Calvados Chain (Smith, 1973). Consequently, the amount of dissection of individual volcanoes ranges from small isolated volcanic remnants without any trace of original volcanic landforms, to extremely youthful volcanoes exhibiting very little erosion. Though no eruptions have been recorded, several thermal areas are known on Goodenough and Fergusson Islands, and volcanic activity is clearly by no means extinct.

A wide range of rock types occurs throughout the islands, and though it is difficult to generalize, intermediate and acidic rocks predominate over basic rocks. Thus, though volcanic landforms typical of fluid basalt lava (extensive lava flows and scoria cones) are common, most of the volcanoes were produced by more explosive activity typical of the more viscous acidic lavas. The only reliable analyses available from the Papuan islands (Morgan, 1966) are for rocks from Fergusson and Dobu Islands, which proved to be peralkaline and point to the possibility that the islands constitute a peralkaline province.

Bismarck Volcanic Province

Present-day volcanic activity in the Bismarck Volcanic Province appears to be at a level as high as at any time since the start of the Pliocene-Holocene orogeny. Active and recently active volcanoes form a belt nearly 1000 km long from the Schouten Islands in the northwest, to the Gazelle Peninsula of New Britain in the east. Though the belt is probably made up of several distinct structural elements, for the purposes of description it is referred to here as the Bismarck Volcanic Arc.

A second belt comprises the extinct volcanic islands off the northeast coast of New Ireland, and the active and recently active volcanoes of Bougainville. Quaternary volcanic activity also took place on Manus Island, and in the Witu Islands, north of New Britain, and volcanoes in St Andrew Strait, southeast of Manus Island, are still active.

The 1:2 500 000 geological map shows major volcanic centres which have erupted in historic times, or which exhibit thermal activity, but as most of the volcanoes in the Bismarck Volcanic Province show youth-

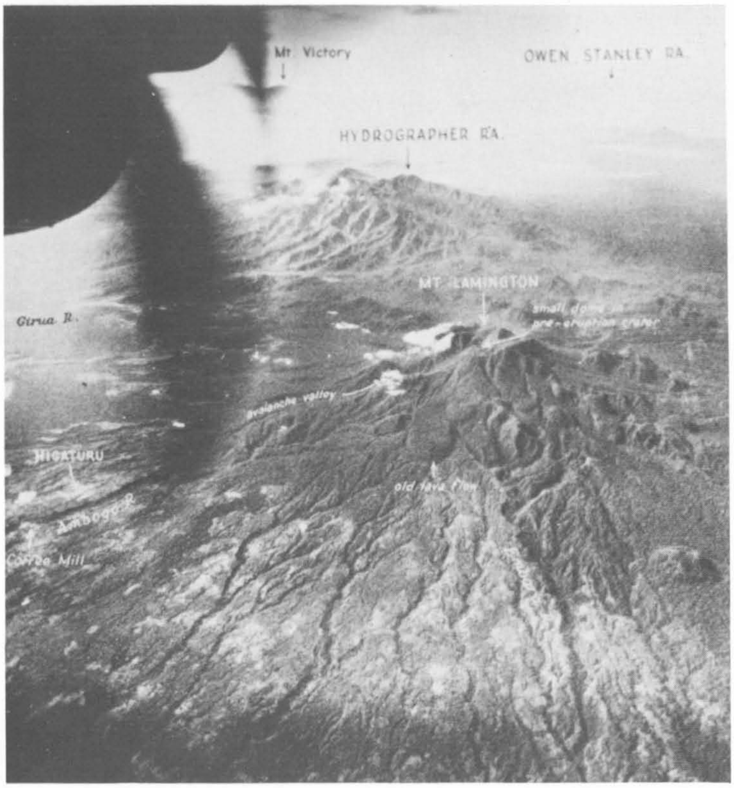


Fig. 25. Mount Lamington in 1947—looking eastward. The dissected volcanics of the Hydrographers Range are in the distance. (GB/208)

Fig. 26. Mount Lamington volcano erupting in 1951. (GB/207)

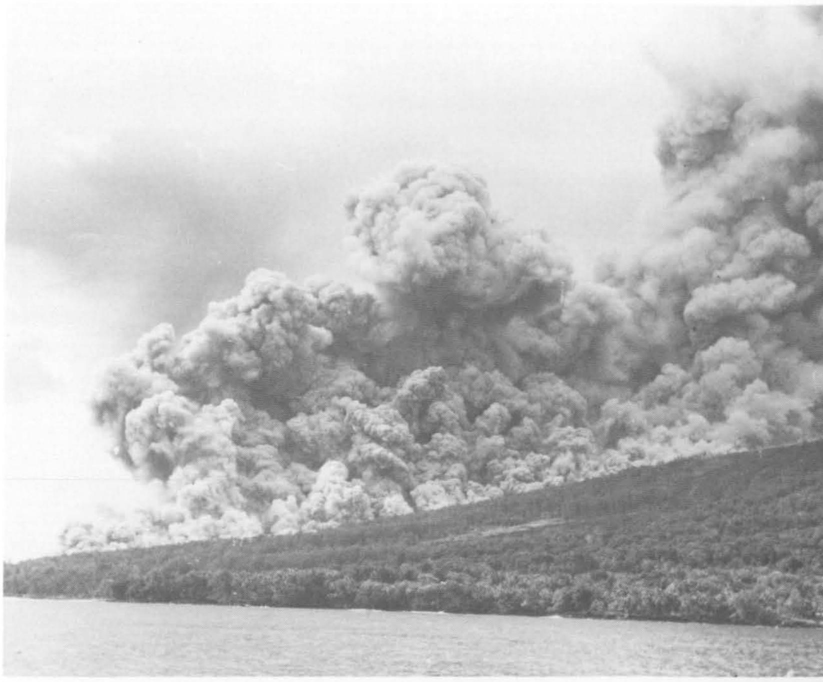


Fig. 27. Glowing cloud descending the north-east flank of Manam volcano, March 1960. (M/2044)

ful volcanic features it would be unwise to classify more than a few as extinct—especially as the recorded history of the region barely exceeds 100 years.

The historic eruptions cover almost the whole range of volcanic activity: from quiet effusion of basaltic lava with mildly explosive fountaining of incandescent lava, to catastrophic events such as the one that destroyed the cone of Ritter Island (between Umboi Island and New Britain) in 1888 and generated tidal waves which caused large loss of life on neighbouring islands and the mainland. Also represented among the active volcanoes is Pelean-type activity, which is exhibited by probably the most active volcano in Papua New Guinea —Manam volcano, off the north New Guinea coast, which in historic times has produced several glowing clouds (Fig. 27) that have devastated the surrounding countryside (Palfreyman & Cooke, 1976).

Many of the volcanoes in the Bismarck Volcanic Arc have calderas. The Blanche Bay caldera, for example, within which stands the town of Rabaul, was formed about 1100 years ago and still shows a considerable level of residual activity, exemplified by the 1937 eruption during which Vulcan was built up from the sea floor to a height of 226 m above sea level within 4 days.

The eastern end of the Bismarck Volcanic Arc parallels the New Britain Trench and its associated seismic zone, and has many of the characteristics of an island arc. Thus the earthquake epicentres beneath New Britain form a steep seismic zone dipping to the northwest (Denham, 1969), and eleven focal mechanism solutions by Johnson & Molnar (1972) indicate that the Solomon Sea floor is underthrusting New Britain. Also, the potash content of the volcanic rocks tends to increase with distance from the trench (Johnson, Taylor, & Davies, 1972), a characteristic of other volcanic arcs (Hatherton & Dickinson, 1969).

However, the volcanoes of the western end of the arc, along the north coast of the mainland, do not have an associated oceanic trench, nor a well defined seismic zone, and therefore do not fit the pattern of a simple island arc.

The volcanoes of Bougainville Island also parallel the New Britain Trench and the steeply-dipping seismic zone associated with it. Ten focal mechanism solutions suggest that the Solomon Sea floor is underthrusting Bougainville Island (Johnson & Molnar, 1972); this may provide a mechanism for the generation of the magma forming the volcanoes. However, the volcanoes off the northeast coast of New Ireland, which are thought to be part of the same belt, are extinct and not related to the New Britain Trench and its associated seismic zone.

STRUCTURE

The fundamental differences in the geology of the three provinces emphasized earlier is also strikingly shown by the structure. The province boundaries are the sites of fundamental crustal dislocations which have dominated the geology of the region since at least as long ago as the Cretaceous.

Between these fundamental structures is the mobile belt, which has reacted to stress by extraordinarily intense faulting—so intense that the whole belt is best described as a fault zone. Folding is subordinate to the faulting, and over most of the belt is comparatively simple, consisting of broad folds which are generally broken into moderately to steeply dipping fault blocks. However, the thick sedimentary rocks along the outer margin of the belt have reacted much less competently, and in places are very tightly folded and metamorphosed.

The continental block underlying the platform has reacted to stress competently by broad folding and some faulting; the very complex folding and thrust-faulting of the Papuan Fold Belt (Figs. 28, 32) are thought to affect only the sedimentary cover and not the basement rocks.

The structures in the oceanic crust and island arcs, where seen, are also mainly broad open folds broken in places by a few major fault zones, and are explained

Fig. 28. Major structural elements of Papua New Guinea.

by the competent nature of the plates making up the leading edge of the Pacific Plate.

Thus, the structure of Papua New Guinea falls naturally into four categories: fundamental province boundary structures, and structures of the mobile belt, the platform, and the oceanic crust and island arcs.

The effects of the Pliocene-Holocene orogeny were so intense that they largely obliterated evidence of earlier earth movements. In the following account most of the structures described, especially the dominant faulting, are post-Miocene, but evidence of earlier movements has been deciphered in many of them.

FUNDAMENTAL PROVINCE BOUNDARY STRUCTURES

Most of the great crustal dislocations forming the boundaries between the geological provinces are expressed as major physiographic features which are due to recent movements. However, there is considerable evidence of earlier movements, some of which occurred as long ago as the Cretaceous.

The boundary of the platform consists of two structures: the Lagaip Fault Zone to the north, and the Aure Tectonic Belt to the east. The boundary between the mobile belt and the oceanic crust and island arcs comprises three major fault zones: the Bewani-Torricelli Fault System to the north, the Ramu-Markham Fault Zone to the northeast, and the Owen Stanley Fault System to the southeast (Fig. 28).

Lagaip Fault Zone

The Lagaip Fault Zone apparently forms the northern boundary of the Palaeozoic crystalline basement block for 350 km southeastwards from the Irian Jaya border. Unlike the other major fault zones it has no marked physiographic expression, but can generally be traced on aerial photographs by features such as linear stream courses, and landslides which mark shear zones. In common with all the major faults of the mobile belt, the faults constituting the Lagaip Fault Zone have straight or gently curved fault traces, and consist of zones of cataclasite and mylonite up to several hundred metres wide; almost invariably the zones dip steeply. As a fundamental crustal fracture, the Lagaip Fault Zone has had a long history of movement, during which it controlled the sedimentary environment. This is seen first during the Cretaceous and Eocene, when the zone marked the limits of a shallow shelf sea to the south and a marine trough in which turbidites were being deposited immediately to the north. The change in sedimentary environment across the Lagaip Fault Zone was even more marked in the early and middle Miocene, especially in the headwaters of the Lagaip River, where middle Miocene shelf limestone occurs south of the fault zone only 15 km away from the volcanics and volcanolithic sediments of the same age which make up the Burgers Mountains to the north.

It might be argued that these relatively abrupt changes in sedimentary environment have been caused by later strike-slip displacement along the Lagaip Fault Zone bringing contrasting lithologies into juxtaposition. This, however, is an unlikely explanation, because the Lagaip Fault Zone forms the boundary between the different sedimentary environments for 350 km; consequently a lateral displacement of over 175 km would have to be invoked to explain the contrasting sedimentary facies. For the Miocene rocks, of course, a much greater displacement has to be invoked because no shelf limestone of that age is known anywhere in the mobile belt.

Unlike the other boundary faults the Lagaip Fault Zone appears to have only a small vertical component (rarely exceeding 600 m according to Dow et al., 1972), and could be a predominantly strike-slip zone. As the youngest strata that the fault zone displaces are of Miocene age the precise age of the dislocation is not known, but as major movements on the faults in the mobile belt took place in the Pliocene and Quaternary, most of the movement along the Lagaip Fault Zone is assumed to have taken place at that time.

Apart from warping which has formed Lake Iviva (25 km northwest of Wabag), recent activity in the fault zone appears to have been negligible.

Aure Tectonic Belt

The eastern margin of the Palaeozoic crystalline basement block is marked not by a fault zone, but by a narrow downfolded belt in which were deposited the sediments of the Aure Trough.

The sediments are folded into a remarkable series of parallel folds with horizontal axes which can be traced on the aerial photographs for up to 100 km (Fig. 29). The fold axes are gently curving and trend roughly north-south; the folds are generally tight, with the western limbs of the anticlines being more steeply dipping—many of them overturned. As the western flanks of the anticlines are commonly ruptured by easterly dipping thrust-faults the whole structure appears to have been formed by compression from the east against a buttress formed by the Palaeozoic basement block. Offshore seismic surveys by oil exploration companies show that similar structures continue southwards for at least 100 km under the Gulf of Papua.

The downbuckling and folding commenced in the early Miocene and has continued almost uninterruptedly until the present day. A progression from very tightly folded and faulted lower Miocene sediments, to less tightly folded upper Miocene sediments, to broadly folded Pliocene and Quaternary sediments, can be seen in the Tauri and Lakekamu Rivers at the head of the Gulf of Papua. However, this is not so throughout the Aure Tectonic Belt, for some zones of quite tightly folded upper Miocene and Pliocene sediments have been mapped along the eastern margin of the shelf limestone, which is regarded as the eastern margin of the Palaeozoic basement block.

The remarkable parallelism between the structural trends of the Aure Trough and the trend of the northern end of the Owen Stanley Fault System cannot be coincidental, and they must be related in some way. The most likely explanation is that the downbuckling of the Aure Trough is a result of sustained compression caused by the movement of the Pacific Plate against the Australian Plate since at least the early Miocene. Le Pichon (1970) has calculated that the Pacific Plate has been moving southwestwards (255°) relative to the Australian Plate at about 10 cm per year since the Eocene, a movement which would result in sustained compression along the northeastern edge of the Australian Plate, and would be consistent with the known geology.

Bewani-Torricelli Fault System

The northern boundary of the mobile belt consists of an east-west-trending zone of markedly intense faulting which I have called the Bewani-Torricelli Fault System. It is over 250 km long and about 20 km wide, and separates gently dipping Oligocene and early Miocene volcanic rocks and overlying sediments to the north from metamorphic rocks of the mobile belt.

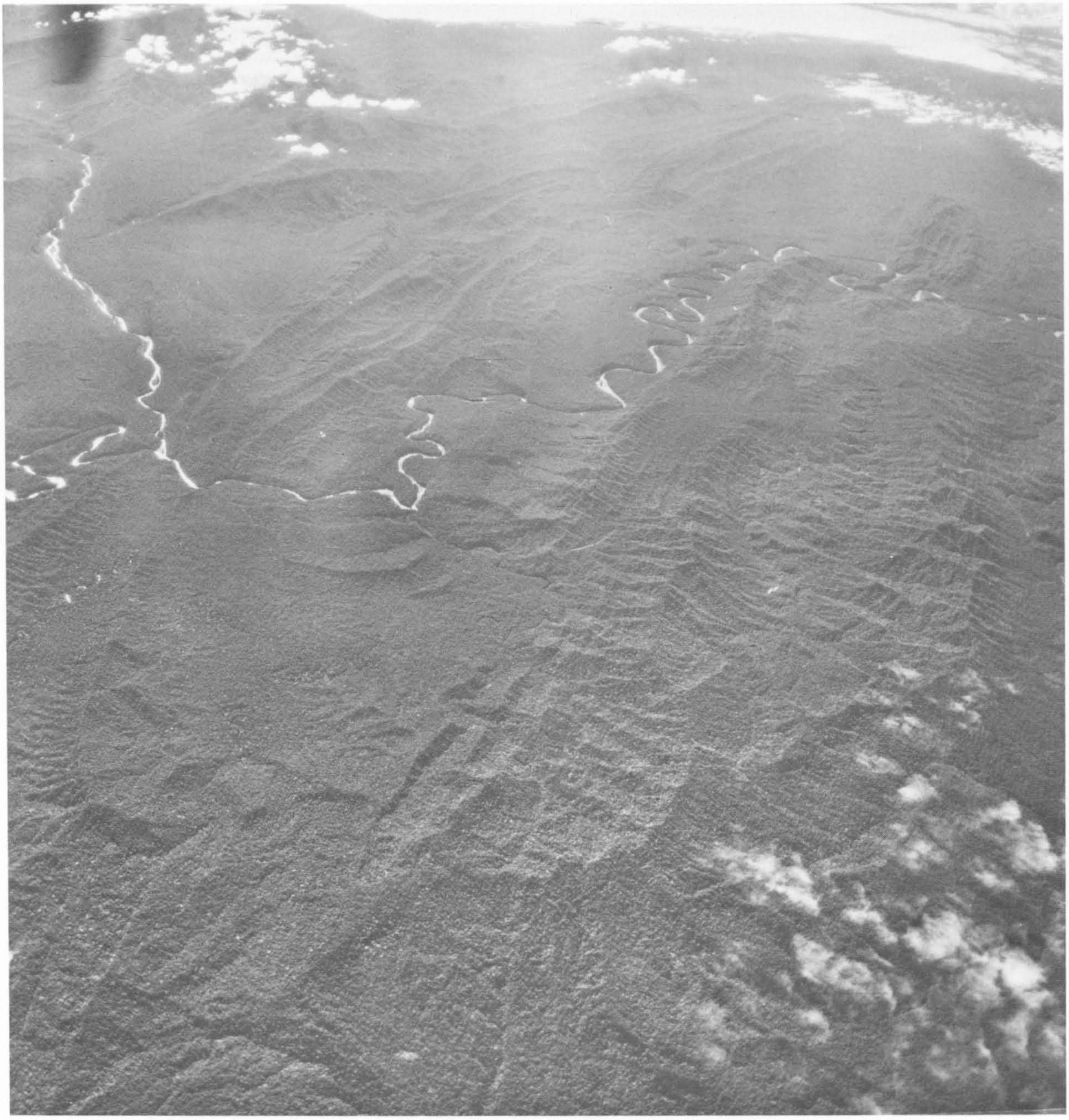


Fig. 29. Tightly folded sediments of the Aure Tectonic Belt in the headwaters of the Vailala River—looking southeastwards.

The faults are so closely spaced that in many places the fault system is an imbricate belt consisting of thin fault slices of many contrasting rock units. The faults are invariably steeply dipping and consist of zones of mylonite, cataclasite, and rare crush breccia up to 100 m wide. Pods of serpentinite and other ultramafic rocks crop out along some of the fault zones and probably attest to the deep-seated nature of the faults. Most of the faults exhibit vertical displacements of several hundreds of metres, and, along at least one fault, thousands of metres, but there is no measure of any horizontal displacements. Slickensides within the fault zones are almost invariably within 30° of horizontal, indicating that the main component of the displacements might be strike-slip.

Many of the larger faults dislocating the Oligocene and early Miocene basement volcanics do not affect the overlying early Miocene sediments, whereas others dislocate the sediments by small amounts. Clearly, therefore, the faults have a long history of movement, going back at least to the early Miocene. Some of the larger faults, however, involve Pliocene sediments in vertical displacements, some of which are more than 1000 m. The area is being so rapidly eroded that any evidence of recent faulting would have been quickly removed, but the faulting is thought to have continued unabated to the present day.

The fault system occupies a belt of earthquakes; dammed lakes and large landslips are a prominent legacy of the 1935 Wewak earthquake, which resulted from movement in the fault system. This earthquake belt continues eastwards across the Bismarck Sea to near the northern end of New Britain and defines a plate boundary (Johnson & Molnar, 1972), part of which, therefore, has as its surface expression the Bewani-Torricelli Fault System. Focal mechanism solutions for three recent earthquakes on the plate boundary indicate left-lateral movement (Johnson & Molnar, op. cit.), which is consistent with the geological evidence along the fault system.

Ramu-Markham Fault Zone

The Ramu-Markham Fault Zone is marked by a narrow alluvium-floored trench (Fig. 12), which, though flanked by mountains mostly over 2000 m high on both sides, does not rise above 300 m above sea level for the whole of its 350-km length. It is nearly straight and trends southeastwards from the lower reaches of the Ramu River to the Huon Gulf. It separates volcanics, volcanolithic sediments, and shelf limestone of the oceanic crust and island arcs from the Oligocene metamorphics and younger plutonic rocks of the mobile belt, but unfortunately, though it is obviously a crustal dislocation of great magnitude, nothing is known of the nature of the fault zone because it is completely covered by recent alluvium. The only exposure—a narrow sheared lens of limestone about 100 m long that has resisted erosion—is in a floodplain of the Ramu River. The displacement along the Ramu-Markham Fault Zone is not known either, though most of the uplift of about 4000 m of the Finisterre and Saruwaged Ranges, which has taken place since the late Miocene, has occurred along the fault zone.

The large wedge of ultramafic and mafic plutonic rocks (Marum Basic Belt) along the southern margin of the Ramu-Markham Fault Zone (Fig. 28) is, by analogy with the Papuan Ultramafic Belt, probably an upfaulted segment of oceanic crust and mantle, and therefore attests to earlier vertical displacements of very great magnitude.

The displacement along the Ramu-Markham Fault Zone may have a major strike-slip component, although there is no unequivocal evidence for one. The only indication of horizontal displacement is given by the splay faults which trend westwards from the fault zone into the mobile belt around the Marum Basic Belt: offset river valleys along the traces of these faults suggest several kilometres of right-lateral movement in Quaternary times (Dow & Dekker, 1964). On this slender evidence, the Ramu-Markham Fault Zone is thought to have a right-lateral horizontal component, possibly of many kilometres; evolving from this thought is the speculation that the 100 km by which the Huon Peninsula protrudes into the Solomon Sea might conceivably have resulted from right-lateral movement. However, right-lateral movement of the oceanic crust and island arcs relative to the Australian Plate might at first seem counter to that expected from a westward movement of the Pacific Plate relative to the Australian Plate; nevertheless, a reconstruction of recent plate movements with right-lateral movement along the Ramu-Markham Fault Zone is consistent with the geological evidence.

A broad diffuse zone of earthquake epicentres along the fault zone testifies to its persistent activity. In 1973, BMR in conjunction with the Division of National Mapping set up permanent survey stations (which were accurately surveyed by a laser-beam geodimeter) on either side of the Ramu-Markham Fault Zone in the Markham valley, to detect any present-day movement.

Owen Stanley Fault System

One of the most important crustal dislocations in Papua New Guinea is a complex fault zone which extends the length of the Papuan peninsula, for about 400 km from Salamaua (lat. 7°05′S, long. 147°00′E) in the north to Mount Suckling in the southeast. It forms the boundary between the Papuan Ultramafic Belt to the east and the Owen Stanley Metamorphics to the west, and I have named it here the Owen Stanley Fault System.

Dow & Davies (1964) and Thompson & Fisher (1965) used the name Owen Stanley Fault for the zone forming the boundary between the Papuan Ultramafic Belt and the Owen Stanley Metamorphics as far south as the Sibium Mountains (lat. 9°20′S, long. 148°20′E), but Davies (1971) restricted the name to the single fault which forms the eastern boundary of the metamorphics, and named the other faults of the zone the Timeno Fault system. However, though very complex, the zone constitutes a single fault system in which I have also included the Keveri Fault Zone (Smith & Davies, 1976), the southeasterly extension of it.

The Owen Stanley Fault System has a prominent physiographic expression which for most of its length consists of a series of narrow intermontane valleys flanked by high mountains, the Owen Stanley Range to the southwest (Fig. 15) and massive ranges formed by the Papuan Ultramafic Belt to the northeast. The fault system is broadly sinuous over most of its length, and consists of several anastomosing faults forming a zone 5 to 10 km wide. The individual faults are seldom well exposed, but where seen consist of zones of mylonite and sheared serpentinite between 20 and 500 m wide, which are almost invariably steeply dipping.

The northern half of the Owen Stanley Fault System forms the boundary between the mobile belt and the oceanic crust and island arcs, but south of Kokoda the boundary between the provinces apparently swings southwards away from the fault system (Fig. 28).

If the Papuan Ultramafic Belt is an upfaulted wedge of oceanic crust and mantle, as postulated by Thompson & Fisher (1965) and Davies (1971), then an enormous vertical displacement must have taken place along the fault system. At least 8-km thickness of oceanic crust is thought to be represented by the basalt and gabbro, and 4 to 8 km thickness of mantle by the ultramafic rocks, leading to the inescapable conclusion that the vertical displacement is at least 12 km and possibly as much as 16 km.

The nature of the Owen Stanley Fault System at depth is not known, and the present surface expression has probably resulted from recent movements which have greatly modified the original crustal break along which the Papuan Ultramafic Belt was emplaced. Adding to the difficulties of interpretation is the lack of evidence for the time of emplacement of the ultramafic belt; Davies & Smith (1971) suggested an early Eocene age, while Davies (1971) gave an age range of late Eocene or Oligocene, but it could conceivably be much younger.

Early Tertiary displacement along the Owen Stanley Fault System

The greatest displacements along the Owen Stanley Fault System were those during which the Papuan Ultramafic Belt was emplaced, any discussion of which must depend entirely on the origin of the Papuan Ultramafic Belt. I favour the hypothesis originally proposed by Thompson & Fisher (1965), and elaborated by Davies (1971), which interprets the belt as being a segment of oceanic crust and mantle.

Because of the recent advances in the study of the Earth's crust and mantle, it is difficult to ascribe any other than a mantle origin to the ultramafic rocks of the

Papuan Ultramafic Belt, and uplift of at least 12 km must have taken place. Davies (1971) postulated a low-angle thrust dipping to the east or northeast as the means of emplacement, and in the absence of contrary evidence this must be accepted as the most likely explanation, especially as low-angle thrusting at the base of the Papuan Ultramafic Belt has been convincingly demonstrated in the Mount Suckling region (Smith & Davies, 1976).

As mentioned earlier (p. 18), there is no evidence for the age of emplacement of the Papuan Ultramafic Belt, other than an upper limit given by unconformably overlying Quaternary sediments and volcanics, and a lower limit given by the Eocene age of the Kutu Volcanics. If the Oligocene age for the Owen Stanley Metamorphics proposed earlier (p. 17) is accepted, then the possible age range for the emplacement of the Papuan Ultramafic Belt is Oligocene to Pliocene, but, as reasoned previously (p. 18), an Oligocene age is most likely.

Late Tertiary and Quaternary displacement along the Owen Stanley Fault System

The present-day surface expression is the result of later movements on the fault system during the Pliocene-Holocene orogeny. The low elevation of the intermontane valleys results from a combination of downfaulting, and erosion of the less resistant rocks in the shear zones, whereas most of the great elevation of the Owen Stanley Range, which is over 3500 m for most of its length, was caused by vertical displacement on the Owen Stanley Fault System. The total recent vertical movement across the whole fault system, or even the direction of movement, is not known, but the vertical movement is probably only a minor component of the total Pliocene to Quaternary displacement, which appears to have been predominantly strike-slip. Dow & Davies (1964) cite evidence for left-lateral displacement of about 4 km along the fault system near Lake Trist, and Davies (1971) postulates that the Papuan Ultramafic Belt has been displaced 90 km to the northwest by left-lateral movement on the Timeno Fault (Fig. 28). The marked sinuosity of the fault system might well be due to similar left-lateral displacements on other major easterly splay faults.

Therefore the evidence for the later movement along the Owen Stanley Fault System indicates a displacement of the Papuan Ultramafic Belt (and by inference the Pacific Plate) slightly north of west relative to the mobile belt. The movement that caused this left-lateral displacement along the Owen Stanley Fault System had a compressive component which caused the buckling of the Aure Trough and the overthrusting so obvious in the Aure Tectonic Belt.

Earthquake epicentres are sparsely distributed along the Owen Stanley Fault System and provide evidence that movement continues to the present day. This is confirmed in the Lake Trist area, where a large number of fault scarps disrupt the present land surface and have caused the ponding of small lakes and formed small swampy areas. These are regarded as the consequence of a compressive component to the stress which has caused the recent strike-slip displacement in the region.

STRUCTURES OF THE MOBILE BELT

Faulting

Faulting completely dominates the structure in the mobile belt, especially in the New Guinea Highlands, where the whole belt is broken into long narrow fault wedges by sinuous anastomosing faults, most of which have large vertical displacements and can be traced for hundreds of kilometres. All are marked by zones of cataclasite and mylonite, some of which are several hundred metres wide, and which, almost without exception, dip within a few degrees of vertical.

Because of their steep dip and relatively straight traces the faults are thought to have a large strike-slip component, which might be predominant. To prove such displacements in regions of rapid erosion, such as Papua New Guinea, is notoriously difficult, and the only evidence seen to date is given by the Bundi Fault Zone in the Bismarck Range, which appears to have displaced rivers right-laterally by about 3 km (Dow & Dekker, 1964), and by the Wampit Fault, west of Lae, movement upon which has displaced a recent alluvial fan horizontally by about 400 m (Fig. 30). Elsewhere, strike-slip movement is suspected where rivers change direction as they cross some faults (e.g., the Frieda Fault, Fig. 31) and flow along them for several kilometres; however, seldom can a consistent pattern be seen, probably because of subsequent river capture. Along some other faults (e.g., the Simbai Fault), vertical movement has been proved to be small, yet large displacements are indicated by mylonite zones up to 500 m wide; such faults must be predominantly strike-slip in character.

Many of the faults along which the New Guinea Highlands were uplifted have quite marked physiographic expressions, such as the dissected scarp of the Bismarck Fault Zone, which forms the northern wall of the Wahgi valley. Faults which are thought to be predominantly strike-slip, such as the Simbai, Frieda (Fig. 31), and Bundi Faults, do not have prominent fault scarps, but can generally be traced on aerial photographs as straight river valleys, ridge notches, and linear belts of subdued relief caused by rapid erosion of the zones of shearing.

Ultramafic rocks have been emplaced along many of the major faults in the mobile belt, notably in the mountains south of the Sepik River, where large bodies of dunite and serpentinite up to 25 km long by 10 km wide intrude the Salumei Formation along the major faults of the region. Similar, but much smaller, bodies of eclogitic rock have also been emplaced along the faults in this region, and there can be little doubt that the faults are very deep-seated, fundamental fractures in the Earth's crust. Many of the ultramafic bodies have complex intrusive boundaries, and the mechanism by which they have been emplaced in the upper levels of the crust is not known. Many of the characteristics of the mobile belt in this region—blueschist facies and eclogitic rocks, and ultramafics, which form a melange with metamorphosed and unmetamorphosed geosynclinal sediments—are similar to those of the Franciscan tectonic belt of southern California, which is thought to have been formed in a subduction zone. The complex structures of the south Sepik region may have been formed in a similar manner during the Oligocene, by the incorporation of the sediments of the marginal trough in a subduction zone.

Age of faulting

Pliocene and Quaternary

The fault features of the mobile belt described above have resulted from earth movements which began in the late Miocene and culminated in the late Pliocene and Quaternary. Some of the vertical movements on the faults during this time were very great, as exemplified by the middle and late Miocene rocks of the Burgers

Fig. 30. Stereoscopic pair of aerial photographs showing a faulted alluvial fan at Zenag Gap (lat. 6°57′S, long. 146° 37′E) on the road from Lae to Wau—one of the few places in Papua New Guinea where evidence of recent fault displacements is preserved.
The Wampit Fault zone trends north as a linear trend partly filled by an alluvial fan of the Zenag Creek, which debouches from the mountains on the left. Recent movement along the fault on the western (left) boundary of the fault zone has displaced the alluvial fan northwards by about 400 m and Zenag Creek by about 300 m. (Scale of photograph about 1:42 000.)

Mountains (south Sepik region), which have been upthrown about 4500 m by the Karawari Fault.

If the hypothesis that the mobile belt was formed as a result of interaction between the Australian Plate and the Pacific Plate is correct, then the major faults must have had a long history of movement dating back to at least the Eocene. Evidence of such early movements has largely been obliterated by the Pliocene-Holocene orogeny, but nevertheless there is considerable evidence to suggest that faulting, particularly in the middle Miocene and Oligocene, was of considerable magnitude.

Middle Miocene

Unequivocal evidence of faulting in the middle Miocene is understandably rare, but in the Maramuni River (south Sepik region) pebbles of the middle Miocene Maramuni Diorite are plentiful in the upper parts of the middle Miocene Karawari Conglomerate, testifying to rapid uplift along the major faults of the region.

Other faults in the mobile belt have had a marked effect on the sedimentary environment in the middle Miocene—for example, the Lagaip Fault Zone in the Wabag area separated the shelf environment to the south (in which shallow-water limestone was being laid down) from the trough in which the volcanics and volcanolithic sediments of the Burgers Formation were being deposited. The boundary between the two environments is so sharp and persisted for such a long time that it can be explained only by faulting during sedimentation.

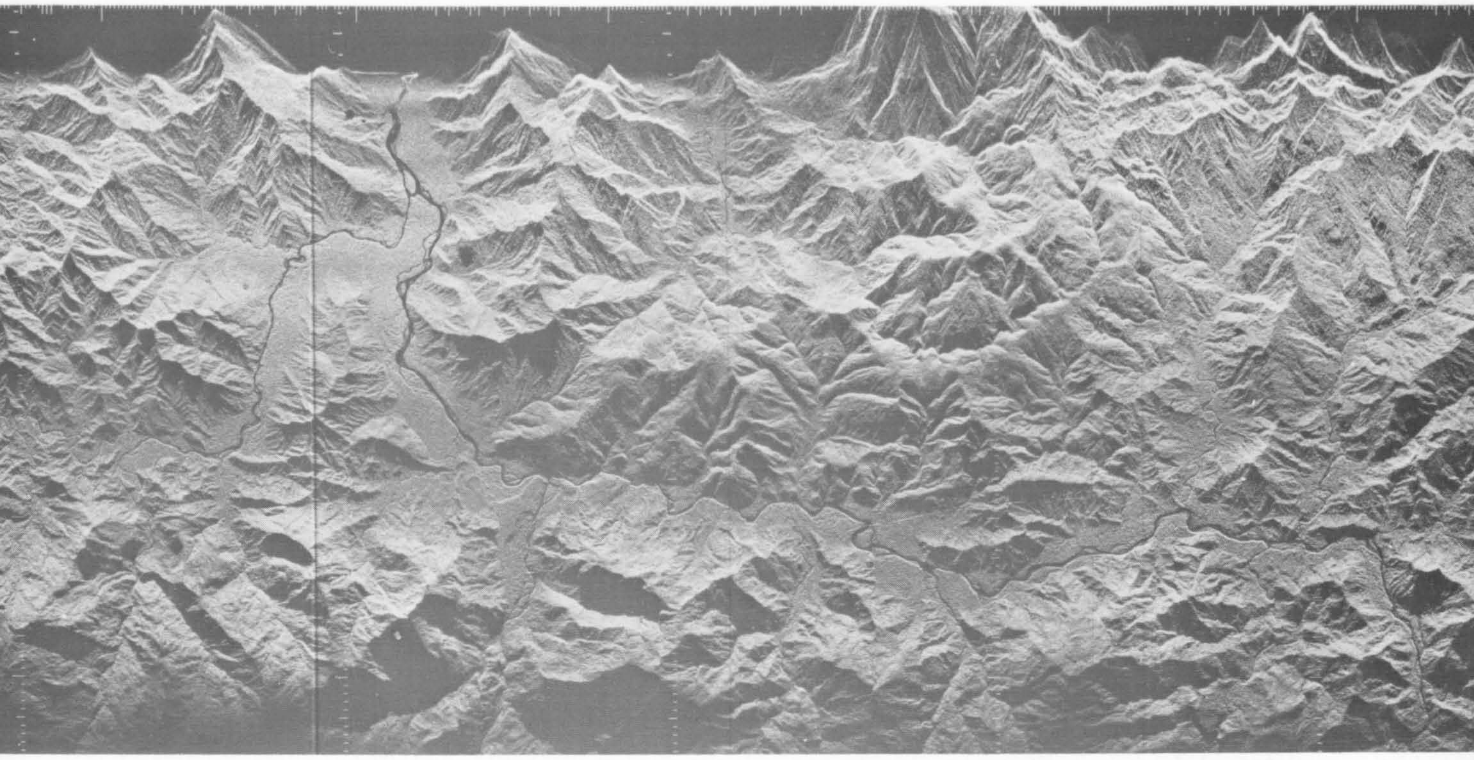


Fig. 31. Radar image of the Frieda Fault (south Sepik region), which displays many of the physiographic features of the major faults of the mobile belt.
The main shear zone of the fault in this region is expressed as an east-west-trending valley along which flows the Leonard Schultze River from the east and Milali River from the west. North and south of the main shear zone subsidiary faults are expressed as linear V-shaped notches cutting across ridges.
Reproduced with the permission of the Australian Department of Defence and the Papua New Guinea Department of Natural Resources.

Pre-middle Miocene

Though the most obvious effect of the Oligocene orogeny was to tightly fold and metamorphose the sediments of the marginal trough, faulting may have been important, especially along the major faults of the region. Certainly the northern margin of the Palaeozoic crystalline basement block, at present delineated by the Lagaip Fault Zone, formed a fairly sharp boundary between shelf sediments to the south and trough-type sediments to the north, and was probably even then an active fault zone.

Unequivocal evidence of faulting before the middle Miocene is seen in the Maramuni River north of Mount Hagen where the Salumei Formation has been downthrown at least 1000 m against Upper Jurassic rocks along the Maramuni Fault, which hardly affects the middle Miocene Maramuni Diorite. Similar evidence is seen 100 km to the southeast where the Jimi Fault, which consists of a zone of mylonite, cataclasite, and sheared gabbro 200 m wide, has juxtaposed the Upper Jurassic Maril Shale against the Jimi Greywacke—a vertical displacement of at least 1000 m—without affecting the middle Miocene Bismarck Intrusive Complex; this faulting probably took place during the later stages of the Oligocene orogeny.

Fault wedges of the Bismarck Range

Fault wedges account for most of the width of the mobile belt in the Bismarck Range; they are made up of Mesozoic rocks, which together with the rocks in the Kubor Anticline and in two smaller fault wedges farther west are the oldest known in the mobile belt. They offer a marked contrast to the rest of the mobile belt, for their constituent rocks are generally only broadly folded and consist of shelf-type sediments. Because of these characteristics, the fault wedges are assumed to be underlain by crystalline basement, unlike the Tertiary trough sediments, which were probably laid down on oceanic crust.

The anomalous position of such continental crustal rocks can be explained in two ways:

(a) They were originally part of a prominent lobe of the Palaeozoic basement block which was broken into a large number of thin fault slices during the earth movements of the Oligocene, the middle Miocene, and the Pliocene and Quaternary. On this hypothesis the faulting would have been mainly vertical and the fault slices remained essentially in their original position.

(b) They represent fault wedges which were detached from the Palaeozoic basement block and carried to their present position, probably by strike-slip displacement from the southeast. The anomalous presence of the two other fragments of assumed Palaeozoic crystalline rocks in the Sepik region (see p. 8) would be explained by similar displacement of detached continental fragments.

FOLDING

The sediments of the marginal trough reacted to stress during the Oligocene orogeny mainly by tight folding and metamorphism.

The metamorphics form some of the most rugged inaccessible country in Papua New Guinea, and even in the more accessible terrain, such as in the Wau area near the northern end of the Owen Stanley Range, good exposures are rare, and structural interpretation is of

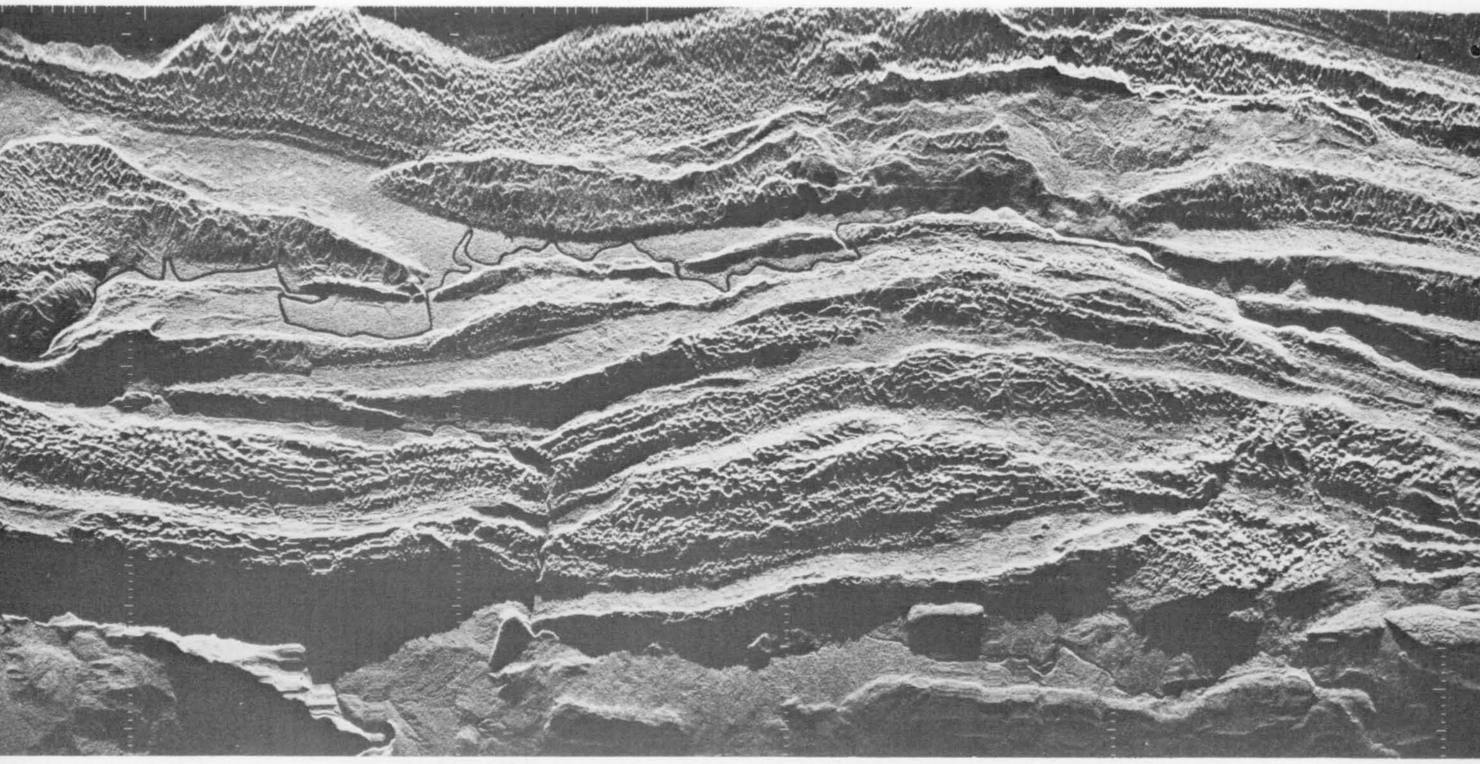


Fig. 32. Side-looking radar image of the eastern end of the Papuan Fold Belt between Mount Murray and Mount Karimui.
The prominent ridges are steeply dipping Darai Limestone which has been repeated by folding and thrust-faulting. The karst surface developed on the limestone is evident despite the very heavy jungle cover.
This image was obtained with the radar looking from the south, so the image is oriented with north to the bottom of the page to prevent the viewer seeing inverted topography. (Scale about 1:250 000.)
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necessity largely speculative. However, mapping in this area shows that the main foliation is parallel to the axial plane of small-scale isoclinal folds (Dow & Davies, 1964). The foliation has since been folded, but away from the Owen Stanley Fault System it dips only gently over large areas, which is difficult to explain unless it was subhorizontal when formed. The few known facts, therefore, do not conflict with a picture of large recumbent folds being formed in the Owen Stanley Metamorphics by the impact of the Papuan Ultramafic Belt in Oligocene time.

Elsewhere in the mobile belt the structure of the metamorphic rocks is not known, mainly because of the lack of exposure and the broad reconnaissance nature of all the geological mapping. However, in most places two periods of folding can be distinguished: the first formed an axial-plane cleavage; the second deformed the cleavage, and generally resulted in crenulation cleavage and other small-scale folds.

Kubor Anticline

The Kubor Anticline is a broad fold near the northeastern edge of the platform, a region susceptible to the effects of the interaction between the Australian and Pacific Plates. In this synthesis the Kubor Anticline is interpreted as a detached fragment of crystalline basement, and has therefore been included in the mobile belt, but there are equally persuasive arguments for regarding it as a part of the platform which acted as a buttress when the plates interacted (cf. the Muller Anticline, see p. 35). Not surprisingly then, the Kubor Anticline has had a long history of movement. It was a broad arch during the Late Jurassic, when the Maril Shale was deposited on a crystalline basement, and was folded into its present form, probably after the Eocene Chimbu Limestone was deposited. It formed a landmass during the rest of the Tertiary, probably as a result of continued up-arching. The present great elevation of the Kubor Range (over 4200 m) is a consequence of regional uplift during the Pliocene-Holocene orogeny.

STRUCTURES OF THE PLATFORM

Quite the most outstanding feature of the structure of the platform is the Papuan Fold Belt, a zone of spectacular overfolding and thrusting which extends along the southern flank of the New Guinea Highlands from the Aure Trough to the Irian Jaya border. Though the folding and faulting is very intense it does not appear to affect rocks older than Cretaceous; the underlying Mesozoic sediments and crystalline basement are only broadly arched.

Farther south, over the major part of the platform, the Mesozoic and Tertiary sediments are almost completely undeformed.

Papuan Fold Belt

The Papuan Fold Belt, over 400 km long by 50 km wide, is located along the southern flank of the New Guinea Highlands. It consists of parallel subhorizontal folds over 60 km long (Fig. 32); they are markedly asymmetrical with steeper southwestern limbs which are generally overturned and broken by northeasterly dipping thrust-faults.

In the western half of the Papuan Fold Belt the direction of overfolding and overthrusting shows conclusively that the sedimentary cover over the whole of the fold belt has been subjected to southerly or south-southwesterly movement, which may have been largely the result of gravity-sliding off the southern flank of the rising New Guinea Highlands. The folding and thrust-faulting are probably confined to the upper part of the succession, decollement having taken place in the thick Cretaceous siltstone underlying the Tertiary limestone. Upper Miocene and Pliocene sediments are included in the folding, which was probably of middle or late Pliocene age; undeformed Quaternary sediments impose an upper time limit on the folding.

Muller Anticline

The Mesozoic sediments and crystalline basement have been broadly arched and faulted by major west to west-northwest-trending faults within 100 km of the edge of the platform. The folding is exemplified near the Irian Jaya border by the Muller Anticline, a broad arch over 100 km long by about 50 km wide which contains the Tertiary Darai Limestone as well as the older rocks. Clearly, the anticline existed when the Papuan Fold Belt was formed because it acted as a buttress against which overthrust Tertiary sediments piled up.

STRUCTURES OF THE OCEANIC CRUST AND ISLAND ARCS

Pre-middle Miocene

Little is known of the pre-middle Miocene structure of the oceanic crust and island arcs because bedding can seldom be distinguished in the volcanics which constitute the bulk of the rocks of this age. However, where the structure can be deciphered the rocks are gently or moderately dipping over large areas; for example, north of the Bewani-Torricelli Fault System and at the northern end of the Papuan Ultramafic Belt.

Surprisingly, even the structures in the metamorphic rocks of southern Papua follow this pattern; even though the rocks are high grade, bedding is well preserved and shows that the rocks are only broadly folded. This is so in the D'Entrecasteaux Islands, where the D'Entrecasteaux Metamorphics are folded into broad domes with flanks generally dipping between 20° and 40°, and at Mount Dayman, on the southeast Papuan mainland, where the Gorupu Metabasalt is folded into a similar broad dome.

Post-middle Miocene

Only broad arching consequent upon regional uplift has taken place throughout the oceanic crust and island arcs since the middle Miocene. The middle Miocene limestones, which unconformably overlie the Lower Tertiary volcanics, form broad gently dipping platforms wherever they are preserved. The limestone forming the northern flank of the Finisterre and Saruwaged Ranges is a huge slab, over 200 km long and 20 to 30 km wide, which dips consistently to the north-northeast as a result of uplift along the Ramu-Markham Fault Zone. Similar though smaller and more gently dipping slabs cap the volcanics of New Britain, New Ireland, and Bougainville.

Apart from minor faults with small throws, which attest to minor block-faulting readjustment, large areas of the oceanic crust and island arcs are essentially unfaulted. The only exceptions are west of Madang, where the northwest-trending Gogol Fault is an active major structure, and at the northeastern end of New Britain and the southeastern end of New Ireland, which are broken by several major northwest-trending faults—the surface expressions of an active major tectonic zone trending southeastwards along the Solomon Islands chain; the major fault forming the southwest flank of Bougainville is probably part of this zone.

These faults might be predominantly strike-slip, for the Weitin Fault, on New Ireland, has displaced a Quaternary coral terrace left-laterally by several kilometres (French, 1966). Focal mechanism solutions for earthquakes in the region are consistent with such left-lateral movement (Johnson & Molnar, 1972).

The structure outlined above suggests that since the Early Tertiary most of the oceanic crust and island arcs has reacted competently to stress; most of the stress has apparently been released along the major faults, which delineate the boundaries of subplates within the region.

ECONOMIC GEOLOGY

For details of mineral production, locations of mineral deposits, and a short history of the mining industry, the reader is referred to the 1:2 500 000 Mineral Deposits map of Papua New Guinea and its explanatory notes (Grainger & Grainger, 1974). The main mineral occurrences are shown in Figure 33.

Until mining started on the huge porphyry copper-gold deposit at Panguna on Bougainville Island in 1972, the only significant mineral production had been gold and silver, and this had been steadily declining since World War II. The discovery of Panguna showed that Papua New Guinea was a major porphyry copper province, and the greatest potential for further production lies in this type of deposit. Promising nickel values have been found in weathering profiles overlying ultramafic rocks, but as yet no commercially viable deposit has been proved.

The search for hydrocarbons has been going on in Papua New Guinea since 1912, but with the exception of some large gas flows the results have been disappointing.

Copper

Until the opening in 1972 of Panguna copper mine on Bougainville Island, only a few small parcels of copper ore had been produced—from Woodlark Island, the Astrolabe Mineral Field (near Port Moresby), and the Kainantu area—but now Papua New Guinea is a major copper producer. The upsurge of mineral exploration, stimulated by the realization that Papua New Guinea is a porphyry copper province, has led to the discovery of several porphyry copper prospects and a large number of smaller occurrences. The major prospects include Mount Fubilan and Tifalmin, in the western New Guinea Highlands; Frieda River, south of the Sepik River; Yandera, in the Bismarck Range; Plesyumi, on New Britain; and Mount Kren, on Manus Island; and it seems certain that copper mining will play an even more important role in Papua New Guinea's development in the future.

Gold and silver

Gold (and alloyed silver) has been mined in Papua New Guinea since its discovery in Papua in 1888. Until the opening of the Panguna mine, almost all the gold had been won from alluvial deposits; primary lodes had been worked in most of the goldfields, but had contributed only a small proportion of the gold produced. The total recorded gold production (in kg) to June

Fig. 33. Main mineral occurrences of Papua New Guinea. (Note that a symbol for lode mine in the Morobe Goldfield has been omitted in error.)

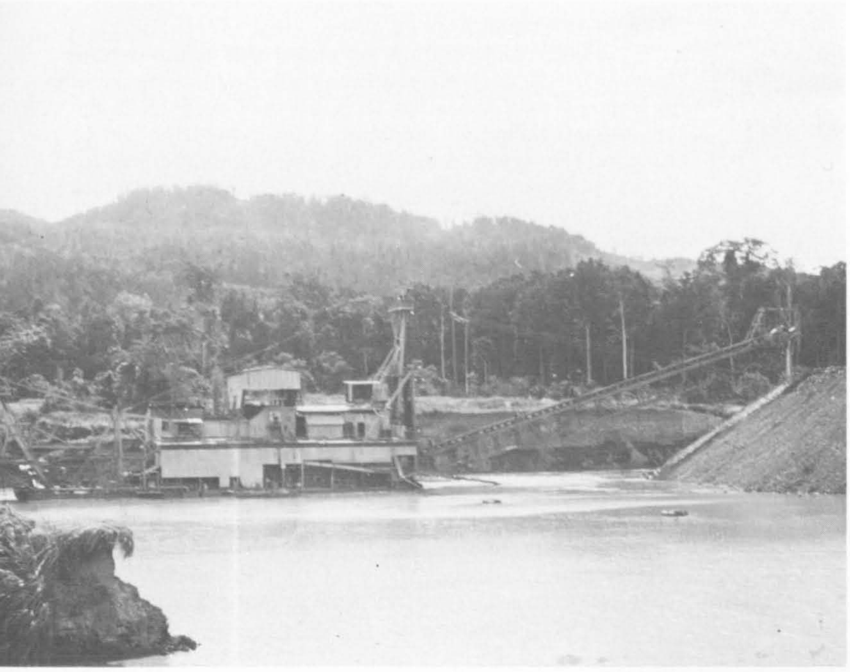

Fig. 34. Last gold dredge working in the Bulolo valley near Bulolo township, 1959. (GA/8205)

Fig. 35. Villagers groundsluicing in Namba Wan Gold Creek (at the head of Parchee Creek), East Sepik Province, in 1973. River gravels, originally mined before World War II, are being reworked for small returns. (M/1485/13)

Fig. 36. Groundsluicing eluvial gold deposit at Kumbruf, Simbai River, in 1960. The gold has weathered from ancient gravels capping the ridge—the large boulders are Kumbruf Volcanics weathering out of the hillside. (GA/8209)

1975 for each of the major goldfields in Papua New Guinea is tabulated below:

MOROBE	115455
PANGUNA	60700
LOUISIADE (including Misima and Sudest Islands)	7460
WOODLARK ISLAND (mostly lode gold)	6200
YODDA (Papua)	2500
GIRA RIVER (Papua)	2110
EAST AND WEST SEPIK (north of the Sepik River)	1675
LAKEKAMU RIVER (Papua)	1150
EASTERN HIGHLANDS (Goroka and Kainantu)	805
MILNE BAY (Papua)	470
KEVERI RIVER (Papua)	155
MOUNT HAGEN-PORGERA (since July 1972)	155
MADANG	110

Alluvial deposits

Gold was first worked in 1888 at Sudest and Misima Islands, and by World War I most of the Papuan deposits had been virtually worked out. Total production until then had been small; gold was not produced in large quantities until the discovery of the Morobe Goldfield in 1922 by J. M. 'Sharkeye' Park, who panned gold near the mouth of the Koranga Creek in the headwaters of the Bulolo River. The field was gradually extended and worked for moderate returns until 1926, when a small prospecting party climbed around a 250-m obstructing waterfall in Edie Creek to discover the phenomenally rich gravels of upper Edie Creek. The extensive alluvial flats of the Bulolo and upper Watut Rivers were then found to contain economic values, and in 1932 dredging operations commenced using bucket-line dredges (Fig. 34). At this time the only ground access was by walking track, so all the dredging machinery had to be transported by air, a pioneering achievement in air transport at that time (Idriess, 1933). At the peak, eight dredges were working, but all dredging and most mechanized sluicing operations had ceased by 1966.

Papua New Guinea now produces only small quantities of alluvial gold (total annual production about 740 kg) mainly from small ground sluicing operations (Figs. 35 and 36), and, despite recent increases in the price of gold, a substantial increase in production is unlikely because the gold sheds are well known, and any large gravel deposits likely to have received substantial amounts of gold have been tested.

Primary lodes

Apart from gold produced from Panguna copper mine, gold has been mined from small primary lodes in Woodlark, Misima, and Sudest Islands, Milne Bay, the Kainantu area, and Bougainville Island. The only substantial production was from mines in the Wau/Edie Creek area of the Morobe Goldfield, where 12 650 kg of gold was produced up to the end of 1968.

The present high price of gold has stimulated exploration for lode gold, and there is some prospect of finding economic lodes in areas where rich gold is being shed, such as the Amanab and Garamambu areas in the Sepik valley. However, as the many gold lodes found to date have been small, so any new discovery is not likely to be large.

Gold production has risen markedly since the Panguna mine, Bougainville, was opened in 1972; up to mid-1975 the mine had produced 60 700 kg of gold.

NICKEL AND COBALT

Economic concentrations of nickel and cobalt can be formed by the deep weathering of ultramafic rocks, and as Papua New Guinea has large areas of such rocks the chances of finding an economic deposit were thought to be good. However, most of the areas containing ultramafic rocks are of high relief, and the consequent rapid erosion prevents the accumulation of a deep-weathering profile.

The search for nickel/cobalt concentrations has therefore been confined to areas of low relief. Samples from hand auger holes have been examined: at Lake Trist, Waria valley, and Kokoda in the Papuan Ultramafic Belt; near Bundi in the Marum Basic Belt; and at several localities south of the Sepik River. Though no economic deposit has been found, large tonnages of low-grade ore are known, and could be worked in the future.

Nickeliferous sulphides have been found in boulders from streams draining the Papuan Ultramafic Belt and the Marum Basic Belt, but the only occurrence known in situ is a small pod of nickel sulphide in the Adau River, east Papua. This has been drilled but was of no commercial significance.

PLATINUM

Platinum occurs as traces in most streams draining ultramafic rocks in Papua New Guinea, but has been mined only as a byproduct along with alluvial gold. The main localities were the Gira River and Yodda goldfields, Timun River (near Wabag), and near Kilifas (in the ranges north of the Sepik River); there seems little prospect of platinum being mined for its own sake.

* * * * * *

Chromite, asbestos, olivine sand, rutile, cinnabar, sphalerite, galena, and molybdenite have all been found in Papua New Guinea, but only in small quantities, and no deposits of likely commercial significance are known.

METALLOGENESIS

It has so far not proved possible to relate occurrences of metals to any particular geological environment, except for the obvious relation of platinum and nickel with ultramafic rocks. However, one factor shared by nearly all the copper, gold, and silver deposits mined to date is the same age: an overwhelming proportion of the ores mined, whether from primary lodes or from alluvial deposits, owe their origin to hypabyssal stocks and dykes intruded during the Pliocene-Holocene orogeny.

The only known pre-Pliocene primary lodes that have been mined are those on Woodlark Island, from which the gold and minor copper produced are associated with intrusives of undoubted Oligocene age, and those in the Astrolabe Mineral Field, from which the small amount of copper mined is thought to have been syngenetic and therefore of Eocene age. One other major occurrence thought until recently to be pre-Pliocene is on Misima Island, where the primary gold was introduced by porphyritic intrusives dated originally as Miocene by Foraminifera contained in the overlying tuffaceous sediments (de Keyser, 1961); however, a re-examination of the faunal list (D. Belford, pers. comm.) has shown that the sediments are Pliocene and that the intrusives might be the same age.

Where alluvial gold has been traced to its source, most of it has been found to have been derived from Pliocene hypabyssal intrusives. The only known exceptions are in the Maprik area north of the Sepik River, where a small proportion of the gold was introduced by the middle Miocene Morobe Granodiorite. Also, the alluvial gold in the Keveri River and Milne Bay Goldfields appears to have originated in stocks of middle Miocene age.

The reason for the association of economic mineralization with Pliocene and younger igneous activity is probably two-fold:

(a) The Pliocene igneous activity is the first which has affected all three geological provinces. It is such major widespread plutonic activity at depth which has apparently provided a greater opportunity than in the past for the concentration of metals.

(b) The most important factor, however, is thought to be depth of erosion. Of the Pliocene and younger intrusives, erosion has had time to expose only the near-surface hypabyssal intrusives, in which concentrations of epithermal minerals are to be found. Of the earlier igneous rocks, erosion has generally removed the upper parts of the plutons, and consequently most epithermal mineral deposits have long since been removed.

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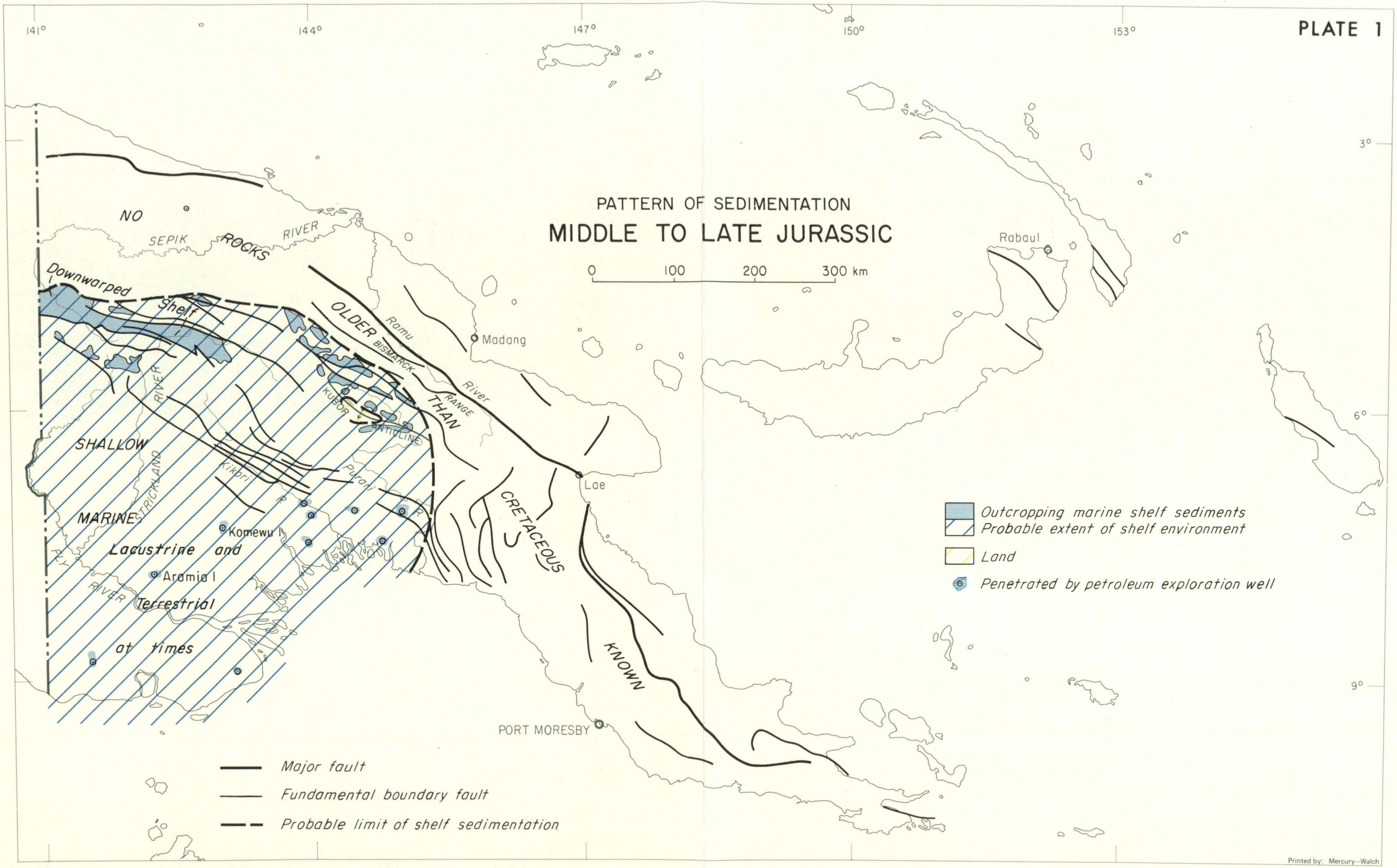
PLATE 1



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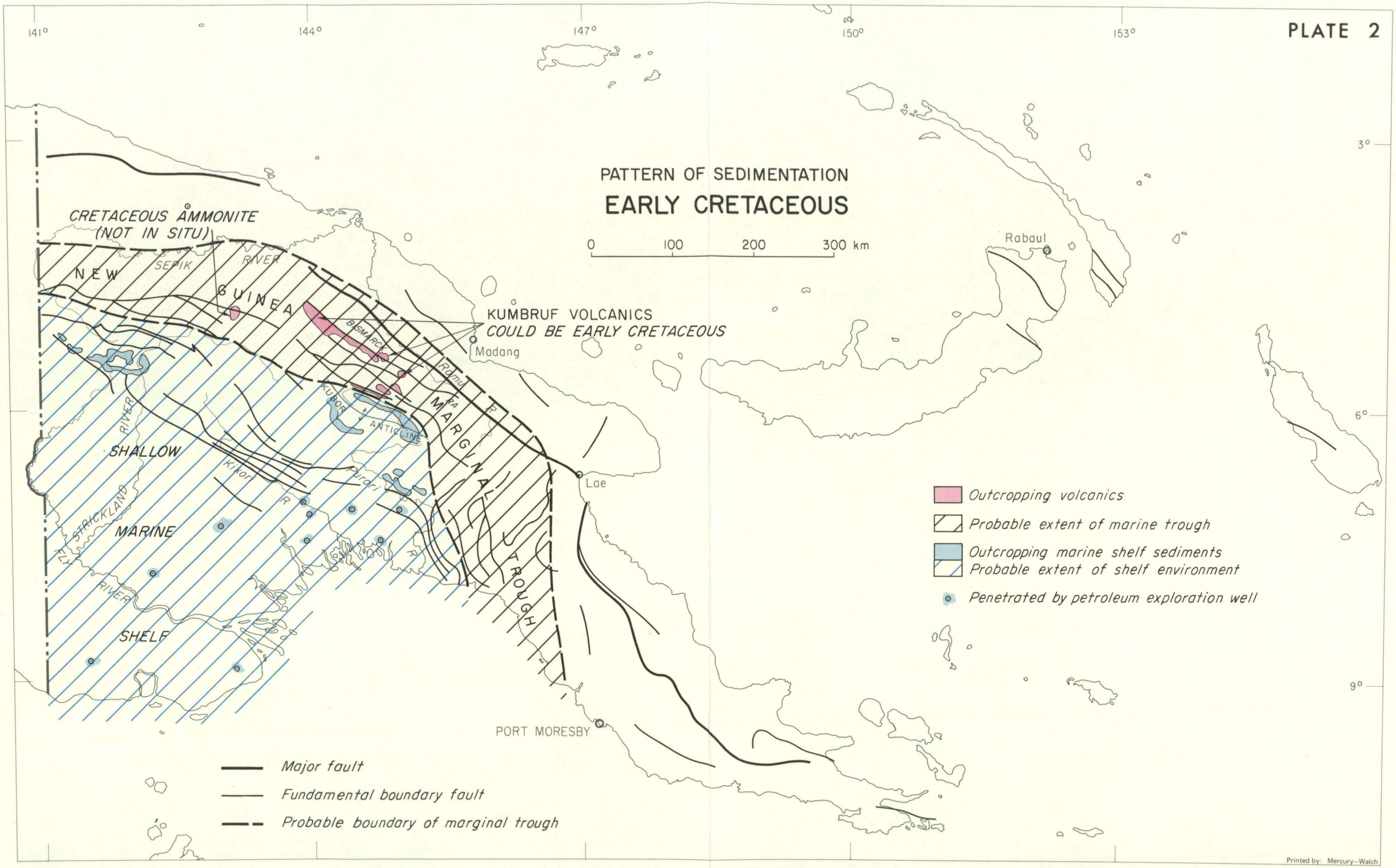


PLATE 2
PATTERN OF SEDIMENTATION
EARLY CRETACEOUS
0 100 200 300 km
141°
144°
147°
150°
153°
3°
6°
9°
CRETACEOUS AMMONITE (NOT IN SITU)
NEW GUINEA
SEPIK RIVER
KUMBRUF VOLCANICS COULD BE EARLY CRETACEOUS
Madang
Rabaul
Lae
PORT MORESBY
MARGINAL TROUGH
SHALLOW MARINE SHELF
KUBOR ANTICLINE
Kikori R
Purari R
STRICKLAND RIVER
FLY RIVER
Ramu R
Outcropping volcanics
Probable extent of marine trough
Outcropping marine shelf sediments
Probable extent of shelf environment
Penetrated by petroleum exploration well
Major fault
Fundamental boundary fault
Probable boundary of marginal trough
Printed by: Mercury-Walch

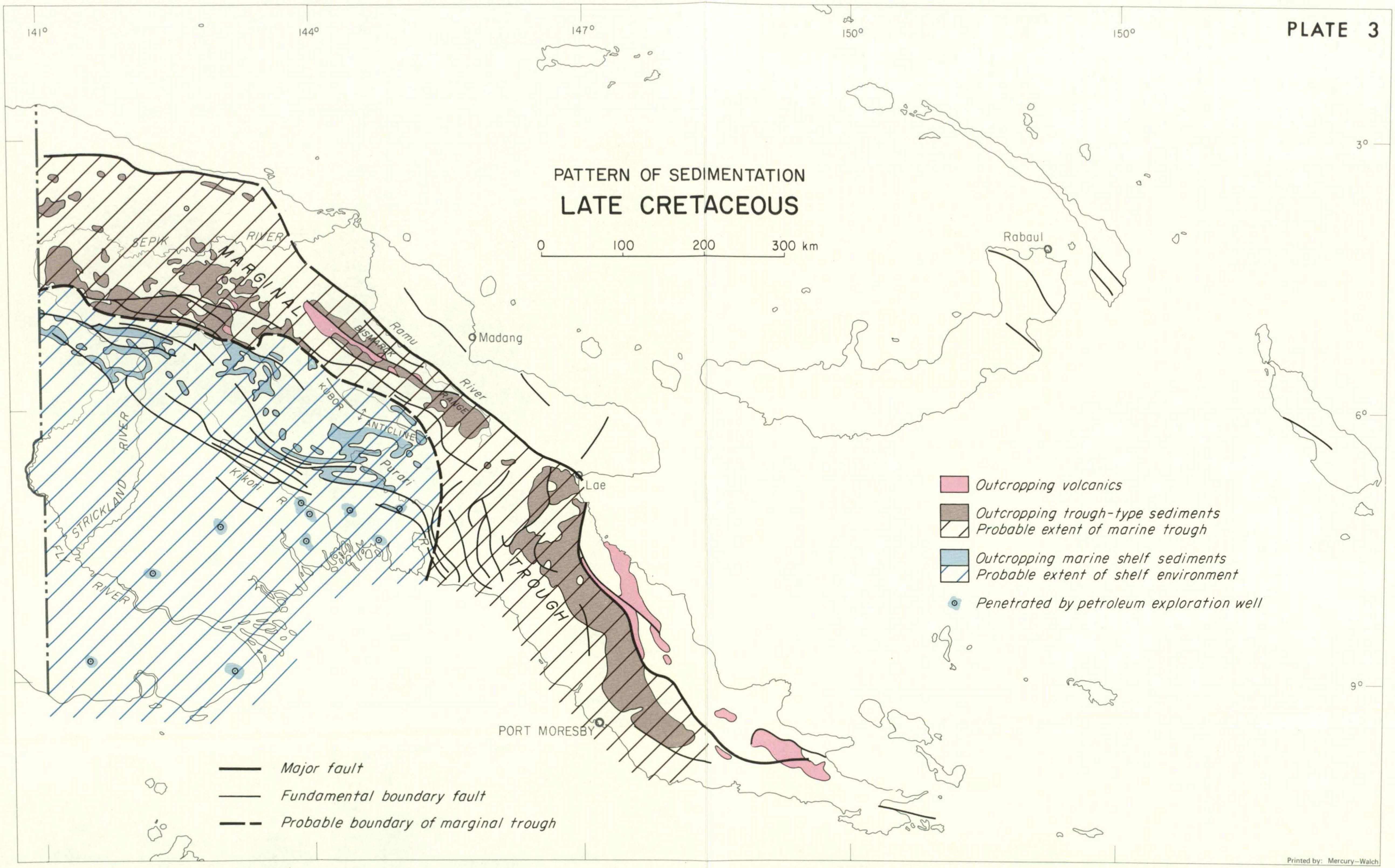
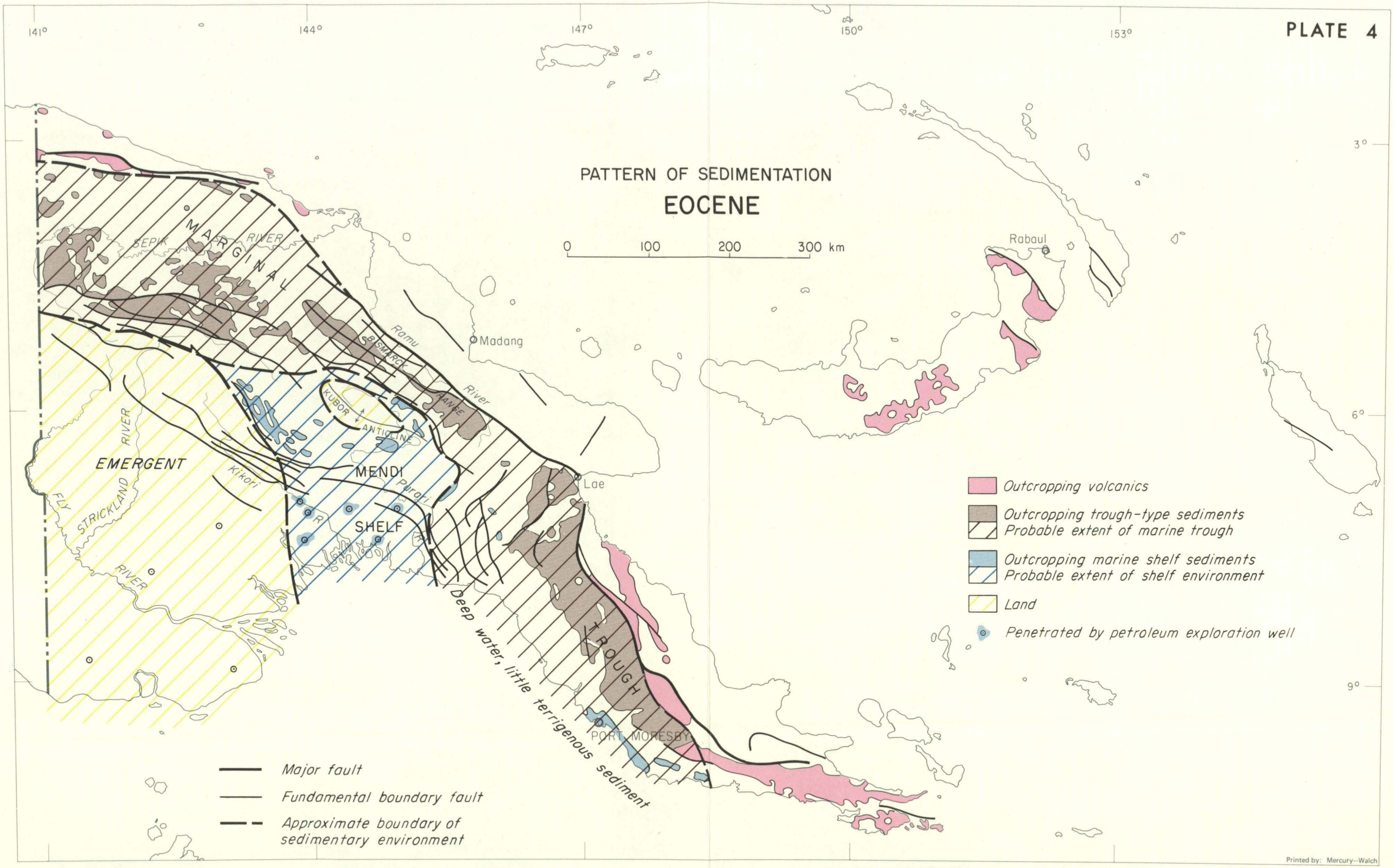


PLATE 3
PATTERN OF SEDIMENTATION
LATE CRETACEOUS
0 100 200 300 km
141°
144°
147°
150°
150°
3°
6°
9°
SEPIK RIVER
MARGINAL
TROUGH
Ramu River
BISMARCK RANGE
KUBOR ANTICLINE
Purari R
Kikori R
STRICKLAND RIVER
FLY RIVER
Madang
Rabaul
Lae
PORT MORESBY
Outcropping volcanics
Outcropping trough-type sediments
Probable extent of marine trough
Outcropping marine shelf sediments
Probable extent of shelf environment
Penetrated by petroleum exploration well
Major fault
Fundamental boundary fault
Probable boundary of marginal trough
Printed by: Mercury-Walch

PLATE 4



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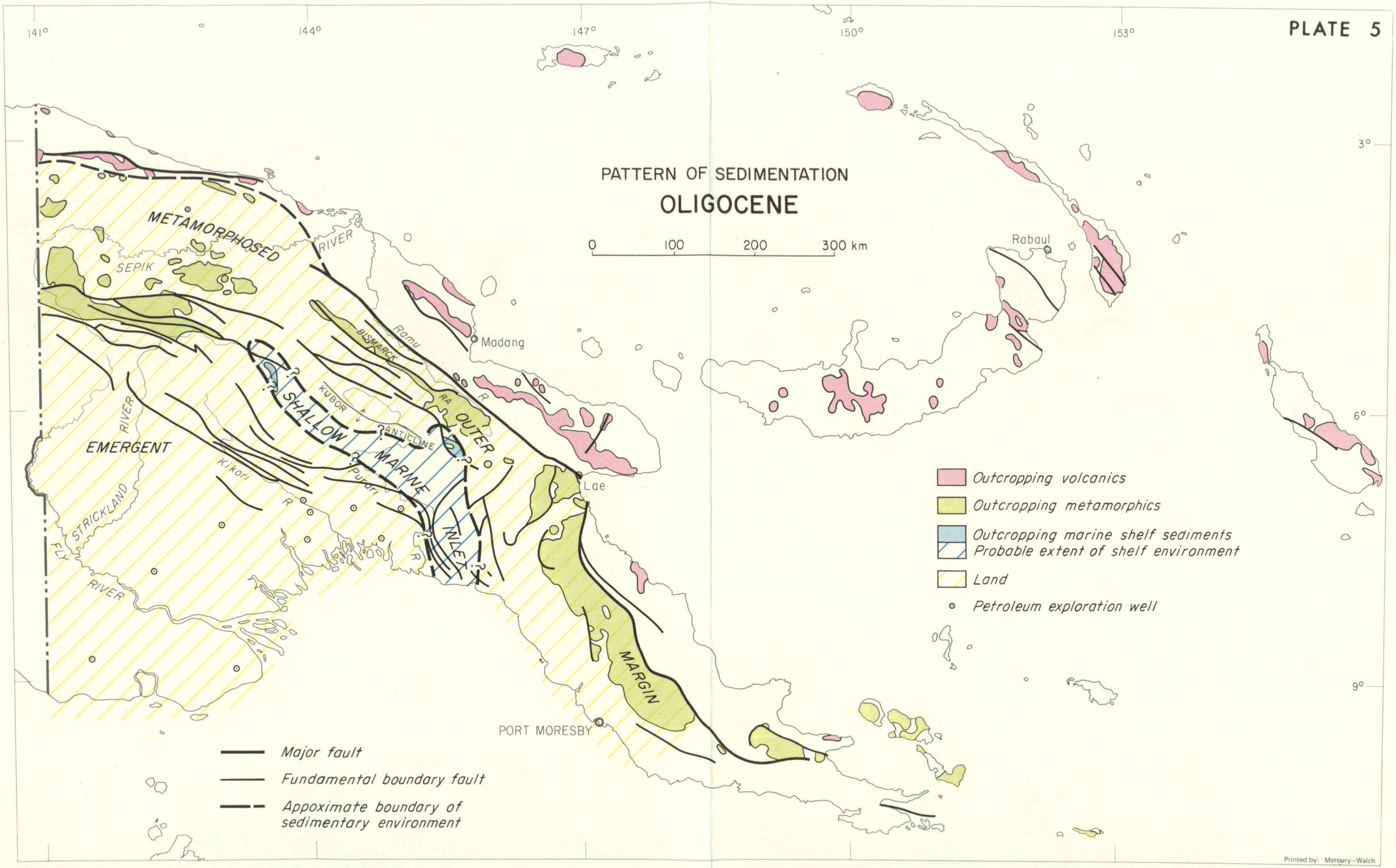


PLATE 5
PATTERN OF SEDIMENTATION
OLIGOCENE
0 100 200 300 km
141°
144°
147°
150°
153°
3°
6°
9°
METAMORPHOSED
SEPIK
RIVER
EMERGENT
RIVER
STRICKLAND
FLY
RIVER
Kikori
R
Purari
R
KUBOR
ANTICLINE
SHALLOW
MARINE
INLET
OUTER
MARGIN
BISMARCK
RA
Ramu
R
Madang
Lae
PORT MORESBY
Rabaul
Outcropping volcanics
Outcropping metamorphics
Outcropping marine shelf sediments
Probable extent of shelf environment
Land
Petroleum exploration well
Major fault
Fundamental boundary fault
Appoximate boundary of sedimentary environment
Printed by: Mercury-Walch

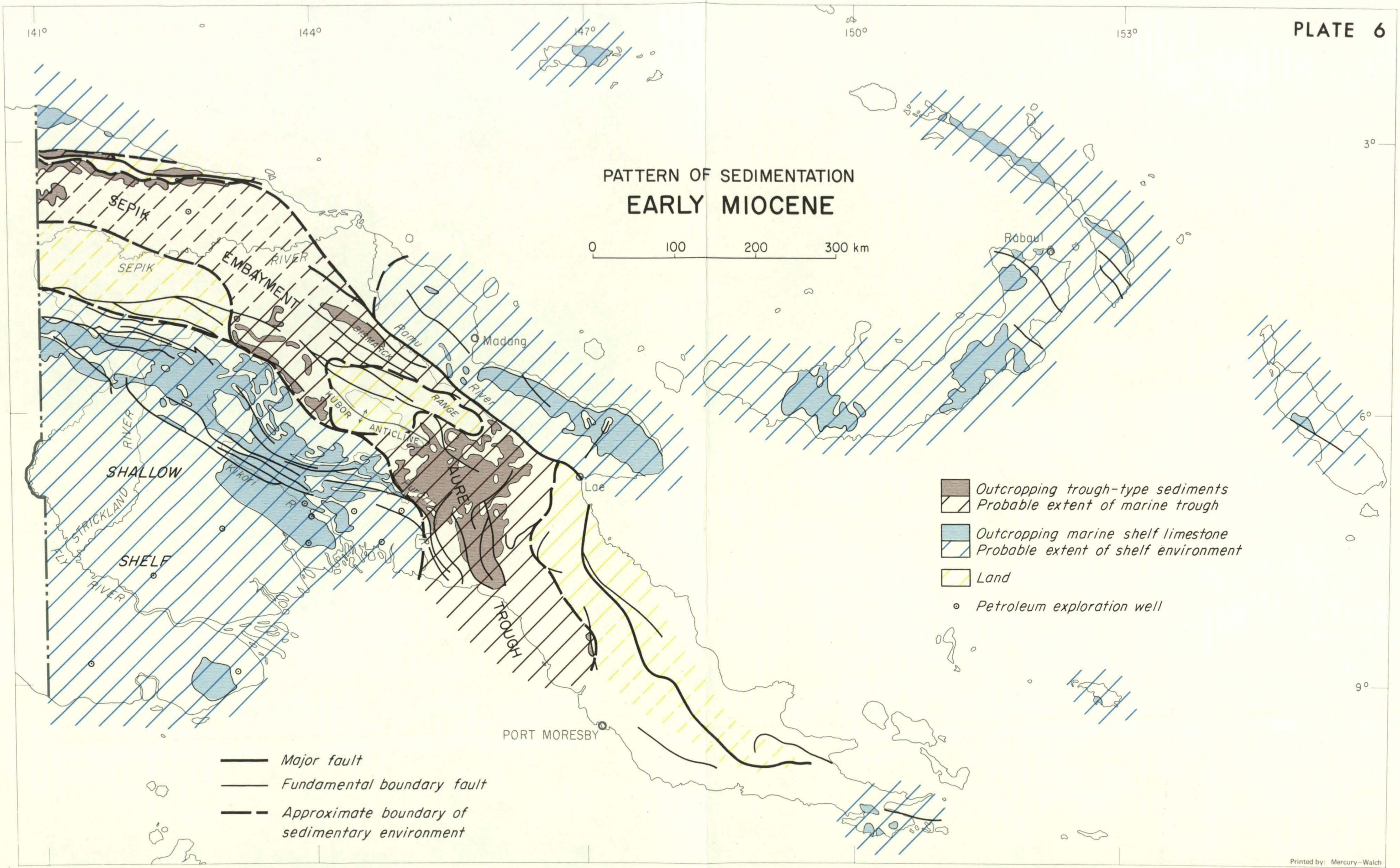
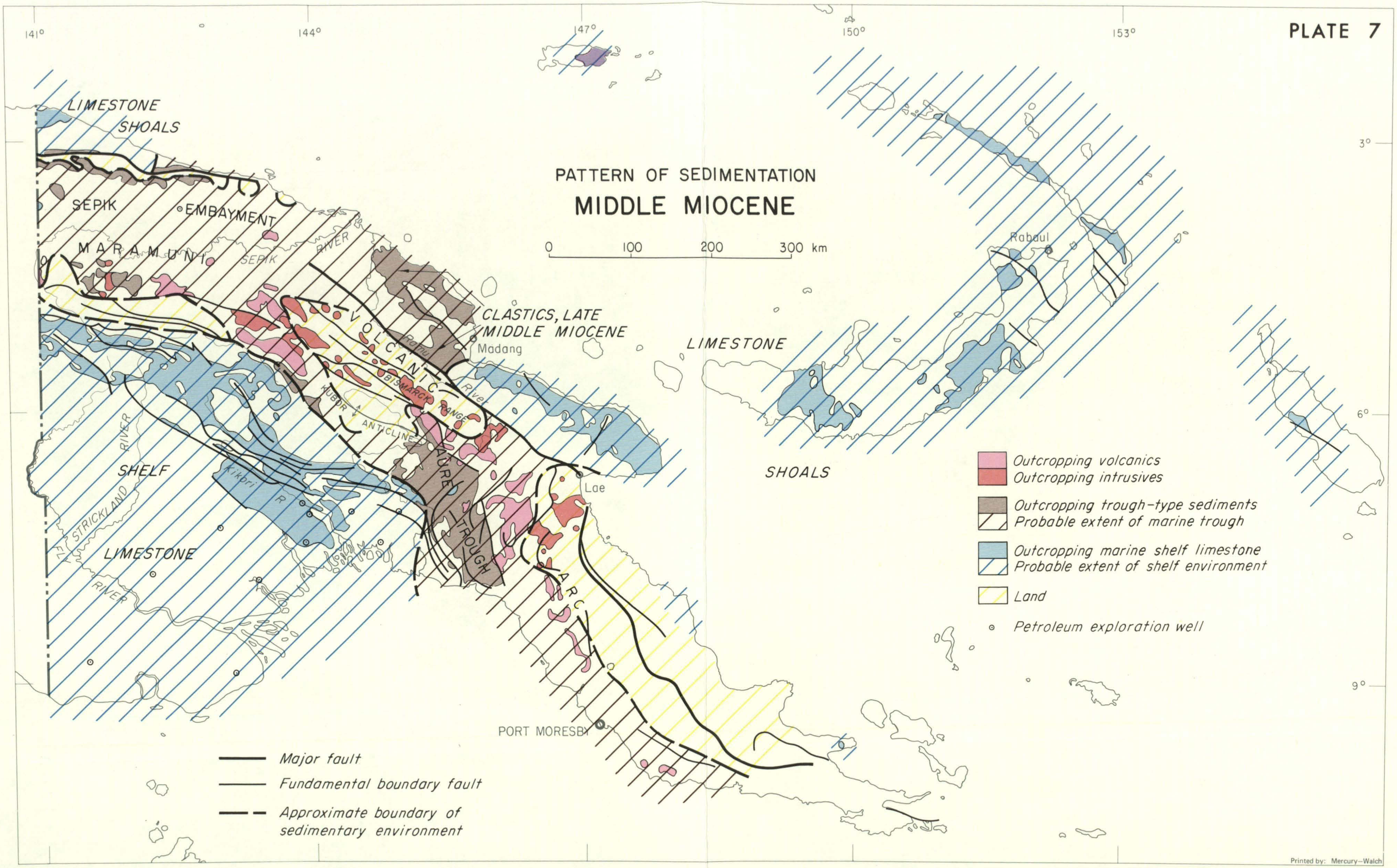


PLATE 6
PATTERN OF SEDIMENTATION
EARLY MIOCENE
0
100
200
300 km
141°
144°
147°
150°
153°
3°
6°
9°
SEPIK
EMBAYMENT
SEPIK
RIVER
Ramu
River
Madang
BISMARCK
RANGE
KUBOR
ANTICLINE
AURE
TROUGH
SHALLOW
SHELF
STRICKLAND
RIVER
Kikori
R
FLY
RIVER
Lae
Rabaul
PORT MORESBY
Outcropping trough-type sediments
Probable extent of marine trough
Outcropping marine shelf limestone
Probable extent of shelf environment
Land
Petroleum exploration well
Major fault
Fundamental boundary fault
Approximate boundary of
sedimentary environment
Printed by: Mercury-Walch


PATTERN OF SEDIMENTATION
MIDDLE MIOCENE
0 100 200 300 km
141°
144°
147°
150°
153°
3°
6°
9°
LIMESTONE
SHOALS
SEPIK
EMBAYMENT
MARAMUNI
SEPIK
RIVER
CLASTICS, LATE
MIDDLE MIOCENE
Madang
VOLCANIC
Ramu
River
BISMARCK
RANGE
KUBOR
ANTICLINE
AURE
TROUGH
ARC
Lae
SHELF
Kikori
R
STRICKLAND
RIVER
FLY
RIVER
LIMESTONE
LIMESTONE
SHOALS
Rabaul
PORT MORESBY
Outcropping volcanics
Outcropping intrusives
Outcropping trough-type sediments
Probable extent of marine trough
Outcropping marine shelf limestone
Probable extent of shelf environment
Land
Petroleum exploration well
Major fault
Fundamental boundary fault
Approximate boundary of
sedimentary environment
Printed by: Mercury-Walch

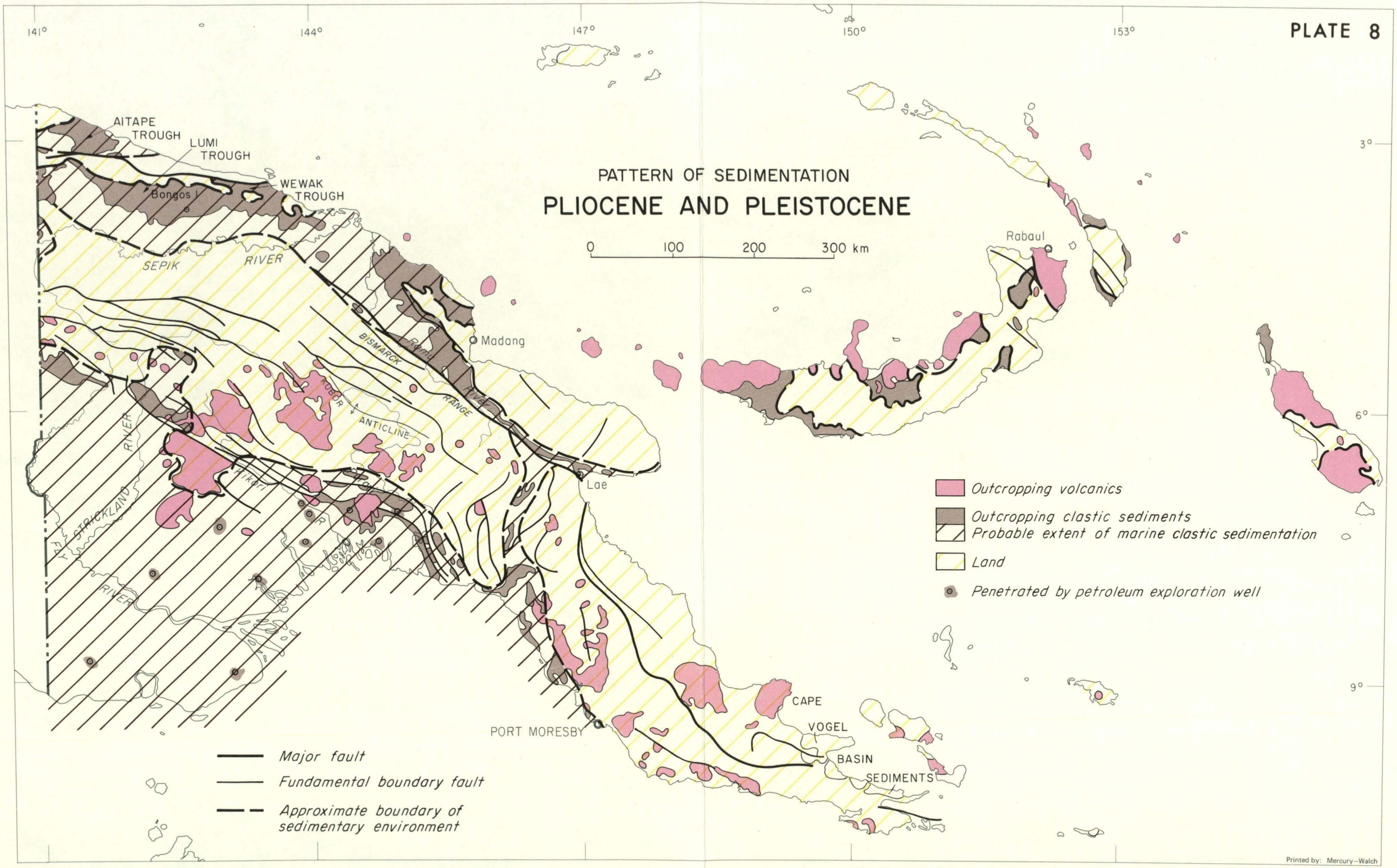


PLATE 8
PATTERN OF SEDIMENTATION
PLIOCENE AND PLEISTOCENE
0 100 200 300 km
141°
144°
147°
150°
153°
3°
6°
9°
AITAPE TROUGH
LUMI TROUGH
WEWAK TROUGH
Bongos I.
SEPIK RIVER
BISMARCK RANGE
Ramu River
KUBOR ANTICLINE
Madang
Lae
Rabaul
STRICKLAND RIVER
FLY RIVER
Kikori R.
PORT MORESBY
CAPE VOGEL BASIN SEDIMENTS
Outcropping volcanics
Outcropping clastic sediments
Probable extent of marine clastic sedimentation
Land
Penetrated by petroleum exploration well
Major fault
Fundamental boundary fault
Approximate boundary of sedimentary environment
Printed by: Mercury-Walch