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Geology of the South Sepik Region, New Guinea

By

D. B. Dow, J. A. J. Smit, J. H. C. Bain, and R. J. Ryburn

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Mosaic of vertical air-photographs showing the Sepik River immediately downstream of the confluence with the April River (bottom left hand corner).

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SUMMARY

Until 1965 the mountains south of the Sepik River had remained largely unexplored, mainly because of the difficulty of access and the inhospitable nature of the country. It is rugged, wet, and has an unrelieved cover of tropical rain forest: the whole area supports only a few semi-nomadic people, and tracks are almost non-existent.

The Bureau mapped the area using Hamilton jet-boats in 1966 and 1967 for access to the mountains, and a helicopter in 1967 to position field parties within the mountains.

The South Sepik region occupies a small segment of the fundamental break separating the stable Australian continental block from the oceanic crust to the north. This break, which is marked in the South Sepik region by the Lagaip Fault Zone, has had a profound effect on sedimentation in the region throughout the geological record: shelf-type sediments were laid down on the continental block, while geosynclinal sediments were being deposited to the north.

The oldest rocks are Middle and Upper Triassic in age and include a widespread and distinctive volcanic unit called the Kana Volcanics. They are succeeded unconformably by a thick sequence of black pyritic shale (Lagaip Beds), which was laid down south of the Lagaip Fault Zone during the Jurassic and Cretaceous.

North of the fault zone sedimentation started in the Middle Jurassic with the deposition of a great thickness of marine basic volcanics called the Mongum Volcanics. Shale (Maril Shale and Sitipa Shale) was deposited in the Upper Jurassic and the eugeosyncline reached full development during the Cretaceous and Eocene, when the Salumei Formation, consisting of shale, turbidites, basic marine volcanics, and limestone, was laid down.

There was a break in sedimentation on both sides of the fault zone during the Eocene and Oligocene, after which volcanic rocks and volcanically derived sediments (Pundugum Formation) were laid down north of the fault zone in the lower Miocene. To the south the lower Miocene sediments consist of limestone and marl (Yangi Beds and Tibinini limestone member).

The middle Miocene saw a climax to the tectonic and igneous activity throughout the northern part of the region. Large plutons (Maramuni Diorite), andesitic plugs and dykes (Frieda Porphyry), and large bodies of peridotite and dunite (April Ultramafics) were emplaced at this time. Part of the Salumei Formation was metamorphosed to the greenschist facies of regional metamorphism, and locally to glaucophane schist and eclogite (Gufug Gneiss).

This activity was accompanied by island arc volcanism which deposited the volcanic beds of the Burgers Formation, Karawari Conglomerate, and Wogamush Beds. The upper parts of these formations consist of thick sequences of clastic rocks.

The geological history south of the Lagaip Fault Zone was markedly different, for folding and faulting was less intense, and there was almost no volcanic activity. The sediments contrast strongly with those to the north for they consist of limestone and fine-grained calcareous sediments, which constitute the upper part of the Yangi Beds. Volcanic rocks are conspicuously absent, and the only igneous activity recorded at this time was the intrusion of intermediate stocks called the Porgera intrusives.

After the Miocene the only rocks other than alluvium deposited in the map area are the Hagen Volcanics of probable Pliocene and Pleistocene age, which built up the huge volcanic cones of the highlands.

The region north of the Lagaip Fault Zone is part of the New Guinea Mobile Belt, and is broken by a complex series of anastomosing faults, most of which have large vertical throws. It is suspected that they are predominantly transcurrent with large right lateral displacements, but this has not been proved. Folding in the Mobile Belt is subordinate to the

faulting although the rocks are very tightly folded in places. Most of the movement on the faults appears to have taken place in the lower Miocene but many have been active till Recent time. South of the Mobile Belt the rocks are generally only broadly folded and broken by a few large faults.

The South Sepik region, despite its inaccessibility, shows some prospect of economic minerals: the Frieda prospect appears to be a porphyry copper type of deposit, and economic concentrations of nickel may have been developed on some of the April Ultramafics during topical weathering.

Most streams contain some gold, and small quantities of alluvial gold and platinum have been produced from the area, but of the gravels tested during the survey, only those of the upper April River show any promise of containing economic concentrations of gold. The gravels of the Frieda River were not tested.

INTRODUCTION

The northern fall of the Central Range, the largest unexplored area in New Guinea (Fig. 1), separates the swampy Sepik Plain in the north from the high dissected plateau forming the backbone of New Guinea to the south. The whole region is rugged and covered by tropical rain forest; it is almost uninhabited, and as there are few tracks, the long meandering southern tributaries of the Sepik River provide the only practicable access. Travel within the area is slow and laborious.

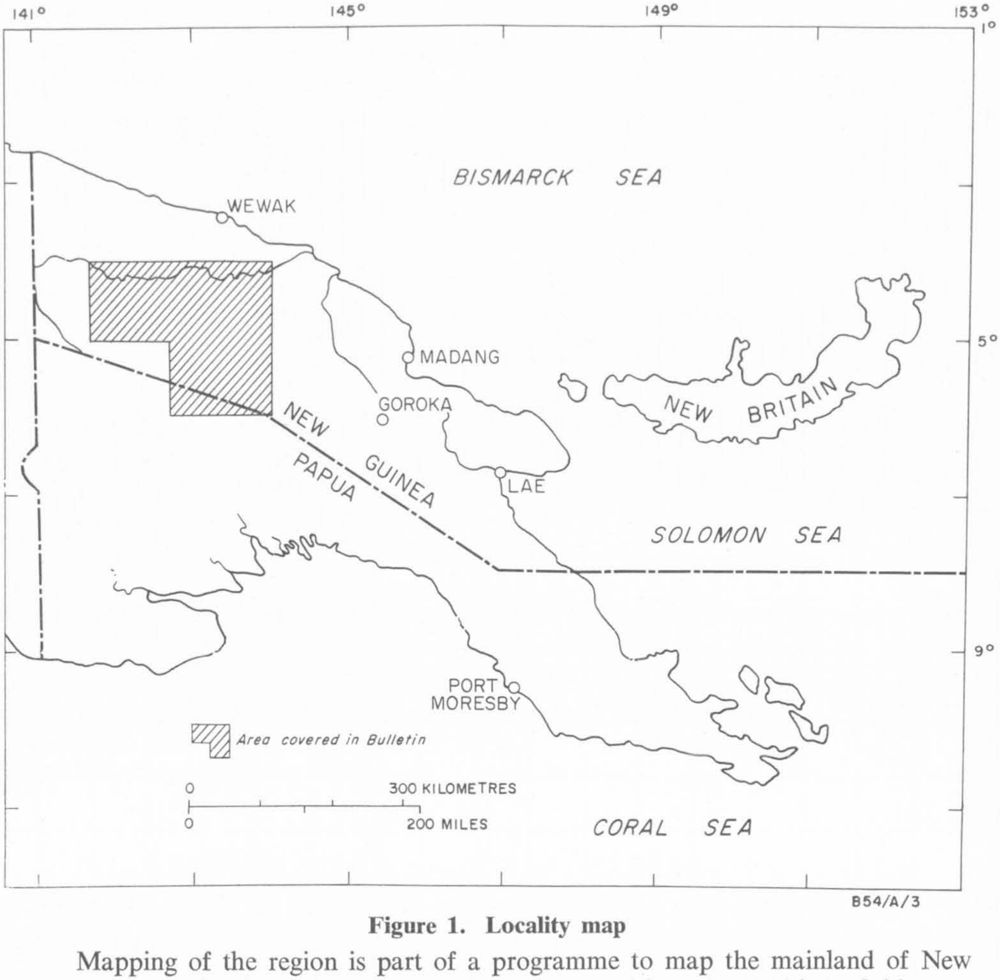

Figure 1. Locality map

Mapping of the region is part of a programme to map the mainland of New Guinea at a scale of 1 : 250 000. Mapping was started in June 1966 by a field party consisting of D. B. Dow, J. A. J. Smit, R. P. Macnab, and J. H. C. Bain, and was continued in 1967 by the same party with the addition of R. J. Ryburn and R. Page.

An area of about 10 000 km² was mapped in the two field seasons; it covers the northern fall of the Central Range between the Yuat River in the east and the Frieda River in the west. The Sepik Plain to the north was mapped in less detail, because there are few outcrops in the swampy plains .

This report incorporates the results of mapping done by Dow (1962, unpubl.) north of the Lai River, and by Dekker & Faulks (1964, unpubl.) south of the Lagaip and Lai Rivers. Some of this area was re-mapped by the Sepik field party in 1966 and 1967.

Initial planning had shown that if conventional canoes powered by outboard motors were used, the party would have spent an inordinately long time travelling in the unproductive lower reaches of the tributaries; helicopters would have speeded up the work greatly, but to mount a party using helicopters exclusively would have been prohibitively expensive. Thus, it was decided to use boats driven by Hamilton jet units for transport in the lower reaches of the main tributaries. The use of these boats (Pl. 1, fig. 1) in New Guinea has been reported by Dow (1967).

Jet-boats were the only means of transport used in 1966, but the experiences of that year showed that large areas of the hinterland were inaccessible from the lower reaches of the rivers, and the 1967 party used a chartered helicopter for eight weeks to position traverse parties in the more inaccessible localities (Pl. 1, fig. 2). The use of the helicopter has been reported by Dow (1968, unpubl.).

Climate

Most of the region is hot and humid, and has a moderate to high rainfall spread throughout the year. The Sepik Plains have a moderate rainfall, mostly between 1 750 and 2 500 mm per year with a wet season from September to April and a short dry season in June, July, and August (Fig. 2). The annual rainfall at representative centres in the Sepik Plains is:

Place	*No. of Years*	*Average Annual Rainfall (mm)*
Ambunti (central)	12	2 492
Angoram (eastern)	11	2 117
Green River (western)	5	3 430
Maprik (northern)	6	1 863
Marienberg (eastern)	11	1 762

Mornings are generally free of rain, but over most of the plains, helicopter operations can be delayed by ground mist which at times does not rise until 10 a.m. The margins of the plains near the hills are generally less affected by these mists, and during 1967 the Sepik party was seldom delayed from this cause when operating out of the April River camp, and Amboin Patrol Post.

The rainfall in the Central Range is much higher, and though no records are available for any localities on the north side of the range, the totals given below and plotted on Figure 2 for localities south of the range are probably reasonably representative of the map area. The average rainfall is well over 2 500 mm, and there is a dry season during May, June, July, and August, in marked similarity to the Sepik Valley.

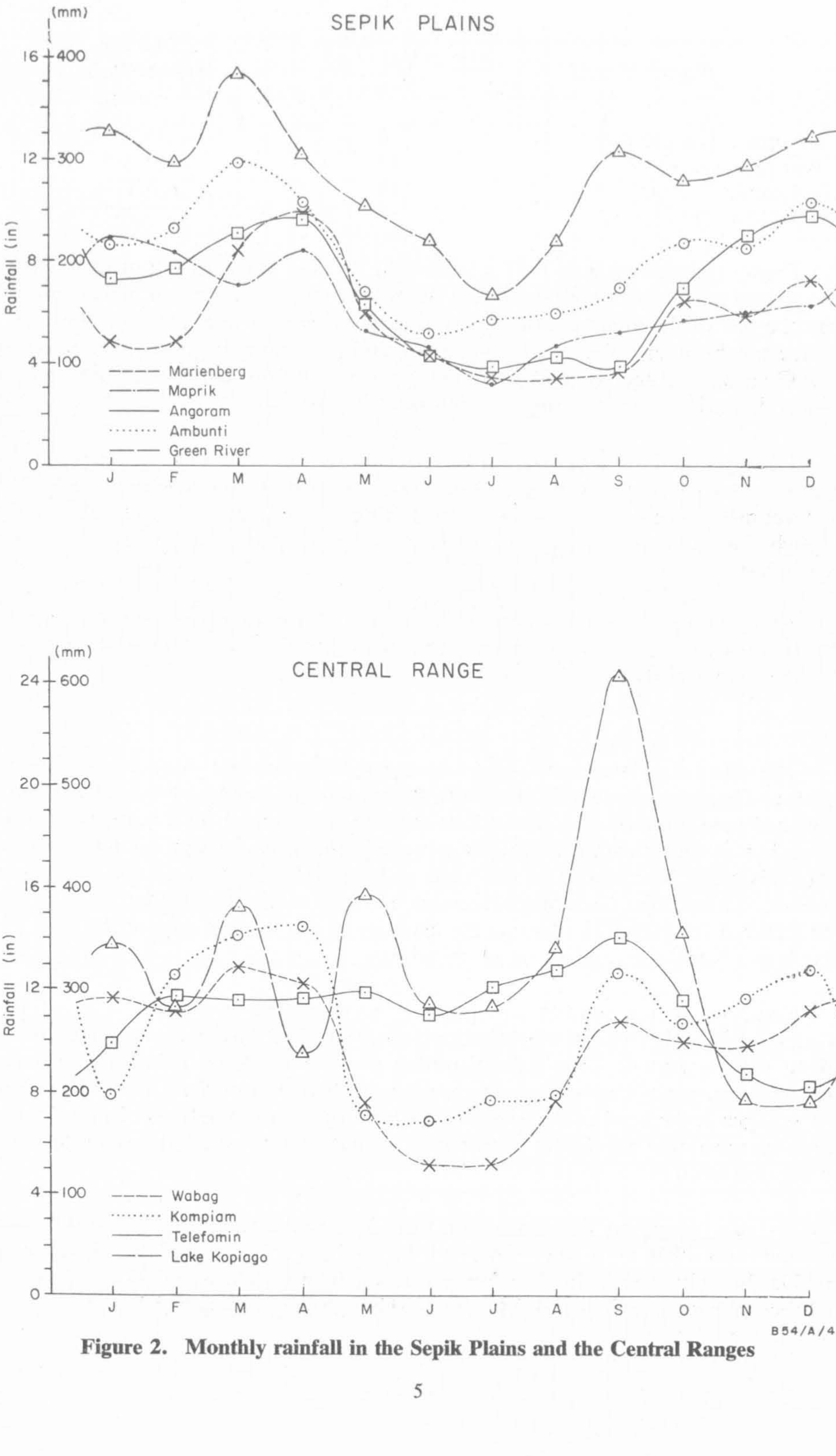

Figure 2. Monthly rainfall in the Sepik Plains and the Central Ranges

Place	*No. of Years*	*Average Annual Rainfall (mm)*
Kompiam (eastern)	6	3 225
Wabag (eastern)	12	2 945
Telefomin (west)	11	3 444
Lake Kopiago (central)	2	3 967

From our experience in 1967 it is thought that the northern fall of the Central Range between Burgers Mountains and the Frieda River has a much higher rainfall than the rest of the area. It rained very heavily on most afternoons, and the rivers carried much larger volumes of water than similar streams in most other parts of New Guinea. Fortunately most mornings were free of rain, but the afternoon rains frequently made setting up camp an unpleasant experience.

The high rainfall makes stream traverses more arduous and much slower than in most other parts of New Guinea, because even short streams can only be forded at favourable localities. It is most frustrating to be forced to cut laboriously through the bush along a cliff on one side of the river while the other side offers easy going.

The regions above 3 000 m are cold, wet, and almost perpetually covered in cloud. Sodden moss covers ground and trees alike, and camping in exposed localities is not pleasant.

Access

The party used the Subdistrict Offices at Angoram and Ambunti as supply centres. These are situated on the Sepik River, and are supplied by coastal trading ships and light aircraft. The Patrol Post at Amboin was used for an advanced base camp, but as this is supplied only by powered canoes, equipment for this and the other advanced base camps in the Yuat and April Rivers was carried by a 6-m jet-boat. These three Government centres are part of the Sepik District, and are administered from Wewak. During the mapping of the western part of the area the May River Patrol was used as the advanced base.

Kompiam in the southeastern part of the map area is a Patrol Post of the Western Highlands District, administered from Wabag; it has an airstrip capable of taking Piaggio aircraft. The Administration posts at Laiagam and Wapenamanda also have airstrips. The only airstrip on the northern fall of the Central Range is at Pasalagus in the head of the Maramuni River, but safety standards of this airstrip are so marginal that air-charter firms refuse to land, and it is used almost exclusively by Mission aircraft.

To gain access to the mountains from the Sepik River centres, 80 km of swampy Sepik Plain must be crossed, and the southern tributaries of the Sepik River provide the only routes. In their lower reaches these are deep and slowly flowing, and they provide excellent travel for boats although they generally follow extremely meandering courses.

Stranded logs and shoals are the only obstructions, but even in times of low water they are generally not troublesome. The levels of the rivers fluctuate greatly, and during the wet season they are at or above plain level.

Within a few miles of the mountains the gradients of the streams are steeper, and gravel banks make their appearance. Log jams are common in these reaches and may provide serious obstacles, especially in times of low water. These gravel reaches generally persist for several kilometres into the mountains, and though they are impassable to canoes, they are generally navigable by jet-boats. Within the mountains the stream gradients increase and the streams are obstructed by gorges and rapids, so that the limit of jet-boat navigability is soon reached.

The Yuat River is an exception, for though it flows through a long steep-sided gorge, it proved navigable for about 55 km into the mountains. The gorge contains many rapids, but only three were cause for great anxiety when they were being negotiated (Pl. 1, fig. 1). Another was impassable, but one boat was hauled around by means of a wooden track built over the river boulders and this enabled a further 16 km of river to be traversed.

Access within the mountains proved much more difficult than expected. In New Guinea most travel is done on foot using local people as carriers; in populated areas carriers are generally readily available and there is a network of foot-tracks, the worst of which provide much quicker access than breaking virgin forest. In the South Sepik region, however, there are only small groups of semi-nomads, many of whom have had no contact with white people. Thus there are large areas with no tracks, and while tracks are known to link the scattered groups of population, it is generally impossible to get the local populace to co-operate to the extent of acting as guides. Each group of people speaks a different language and has no knowledge of either pidgin English or English, and communication was often possible only by sign language.

The densely populated southeastern part of the map area is well endowed with walking tracks and roads.

Carriers

Previous Bureau parties in New Guinea used 12 to 14 carriers per geologist, but it was realized early in the 1966 season that the logistics of keeping such large parties in the field were beyond the resources of the party. It was also realized that such large traverse parties would be prohibitively costly the following year when most of the parties would be positioned by helicopter. The number of carriers was therefore reduced to five per geologist towards the end of the season, giving a party capable of travelling up to seven days away from a source of supplies.

The success of a geological survey in New Guinea depends to a large extent on the calibre of the carriers used. The Sepik Plains support a large number of people who live in villages of the main waterways: as they prefer travelling by canoe, they seldom penetrate the mountains and are of no use as guides in the mountains. They are generally poor carriers, but most speak the lingua franca, pidgin English; a few of those near the mountains can act as interpreters for some of the mountain people.

Most of the carriers used during the 1966 survey were recruited from Asangmut in the Yuat River, but they proved unsatisfactory.

In the South Sepik region the mountain people do not live in villages, but congregate in small groups of several families each living in huts sited near the family gardens. The soil in the mountains is poor, and new gardens have to be established every year, and it is quite common for a group to move up to 15 km between seasons. They are generally stronger and healthier than the plains people, and the few recruited from the Pundugum and Bisorio groups in 1966 and 1967 proved excellent carriers. Unfortunately only a few people are available from these groups, and even in favourable times when the gardens are established, no more than 15 men can be recruited from this source.

No doubt the other mountain people living between the Karawari and the Frieda Rivers would have made good carriers had not communication been such a problem.

It appears that if a party is to work efficiently in the South Sepik region it is necessary to recruit labour from outside despite the cost of recruiting and repatriation. In 1967 the Sepik party recruited carriers from the Simbai and Asai Valleys over 150 km to the east, and though of small stature, these men proved excellent carriers.

Air-photographs and base maps

Lack of air-photographs and reliable base maps was a continual handicap from the start, and only irregular sporadic coverage, taken at heights ranging from 2 100 to 7 500 m, was available. When it was decided in 1965 to map the area, air-photographs of the eastern part only were available, but as these had been very recently taken (December, 1964), and the area was one of top priority, it was thought that photographs of the rest of the area would be available shortly afterwards.

The latest topographic maps of the area were published in 1966 on a scale of 1 : 250 000 by the Royal Australian Survey Corps, but over large areas the only topographic information incorporated is that gained by Behrmann's expedition of 1912 to 1913, and it is not surprising that there are many inaccuracies and omissions.

The topographic base for the accompanying geological map was compiled from all available air-photographs, which were reduced to give the best fit with the more reliable parts of the published maps. The villages shown were located as accurately as possible from the latest Administration patrol maps.

History of exploration

Discoloured water indicating a large river off the north coast of New Guinea was known to mariners as early as the beginning of the 17th century, but it was not until 250 years later that the river, the Sepik, was explored by Europeans. The German zoologist Dr Otto Finsch was the first white man to venture inland, when in 1885 he followed the river for 48 km in an open whaleboat. He showed that the river was large enough to take ocean-going ships, and in the following year von Schleinitz penetrated by steamer for about 320 km until stopped by sand bars. The party then proceeded by whaleboat a further 65 km to the Yamben Gate above the present Ambunti (Souter, 1963).

In 1887 the Sepik River was carrying a greater volume of water, and Dr C. Schrader navigated upstream a total distance of 600 km in the steamer *Samoa.*

No more exploration of the waterways of the Sepik River was done until 1910, when a joint Dutch-German expedition led by Dr Leonhard Schultze mapped the boundary with Netherlands New Guinea, and penetrated 960 km up the Sepik River, reaching nearly to the Zweifel Gorge through which the river debouches from the mountains (Schultze, 1914).

None of these expeditions moved far from the main river, and it was left to the expedition of Dr Walter Behrmann in 1912 and 1913 to explore the hinterland. The expedition followed most of the lower reaches of the southern tributaries, where they flow over the Sepik Plain, and during three epic ground traverses penetrated almost to the main divide. The country was inhospitable and peopled in places by large populations of warlike natives (Behrmann, 1923), and the journeys rank with the greatest explorations in New Guinea.

On the first and easternmost traverse, the party followed the lower part of the Keram River to its confluence with the Clay River, which they then followed to its source in the Schrader Range. They completed a memorable journey by crossing the range and descending to the Yuat River at a point not reached again from the Sepik River until 1966, when the Sepik party explored the Yuat River by jet-boat.

The April River was the waterway used for the next deep penetration south: the party walked from the limit of canoe travel, following the Bamali tributary, which was the most direct route to the mountains. They reached the crest of the Central Range, but as they were at the limit of their resources they returned quickly by the same route.

The third great journey was made by Dr Thurnwald, who in 1913 traversed the Sepik River almost to its source, reaching a point very close to what is now Telefomin. The party must have made friendly contact with the natives, for the next explorers through the area, Karius and Champion (Champion, 1931) were not troubled when they retraced the German's route in 1927.

During the years following World War I, the Sepik Valley was opened up by the Administration patrols, but none penetrated into the southern mountains. However, prospectors were active in the region and some undoubtedly penetrated the northern fringes of the southern mountains, but there is no record of their travels. A gold strike is known to have been made in the Yuat River near its junction with the Maramuni River, but no mining was done. It is reported that Bulolo Gold Dredging Pty Ltd drilled the lower Maramuni flats with a light percussion drill some time in the 1930s, but the gold values were not economic (L. Schmidt Jnr, pers. comm.).

In marked contrast to these peaceful expeditions was the next exploration into the South Sepik area, which was made in 1934 by a prospecting party led by Ludwig Schmidt. The party set out from Mount Hagen and prospected north-westwards to the junction of the Maramuni and Yuat Rivers, where they ran into serious trouble with the natives.

Ludwig's son was speared while attempting to swim the Yuat River, and was lucky to survive the journey to Angoram for aid. The rest of the party continued the expedition, returning some months later to the highlands, apparently by way of the Karawari and Maramuni Rivers. Ludwig senior was later tried and hanged in Rabaul for the indiscriminate shooting of natives during the expedition.

The following years saw most of the Sepik Plains explored and brought under administration control, but it was not until the 1960s that the southern mountains were again penetrated: the Gadio and Pundugum groups in the watershed of the Karawari River were contacted from Amboin, and the Wapi people on the Yuat-Maramuni divide from Kompiam. The latest exploration was in 1965, when an expedition led by R. Barclay explored the Leonhard Schultze headwaters and the Bamali tributary of the April River.

In 1966, when the geological mapping began, large areas of the South Sepik region remained virtually unexplored.

Previous geological investigations. Although there was no geologist with Behrmann's expedition, rock samples were collected, and examined petrographically when the party returned to Germany (Behrmann, 1923). No further geological work was done in the South Sepik mountains until the present expedition.

The first geological investigations of the Wabag area were made in 1948 by H. Ward (1949, unpubl.), who inspected the gold discoveries at Timun and Porgera Rivers, and F. D. Rickwood (1955), who mapped the Lai River. D. B. Dow (1961, unpubl.) made a reconnaissance of the Sau River, and the whole region was mapped by a Bureau of Mineral Resources team in 1963 (Dekker & Faulks, 1964, unpubl.).

Acknowledgements

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We are grateful to Dr Atkinson of C.R.A. Exploration Pty Ltd for making available to us the results of their geochemical survey in the eastern part of the region. We have quoted freely from this report.

The geology of the Frieda River prospect area has been revised from information supplied by geologists of Carpentaria Exploration Pty Ltd, to whom we are indebted.

We gratefully acknowledge the important part played by S. K. Skwarko, D. J. Belford, G. Terpstra, R. P. Macnab, R. W. Page, and D. E. Mackenzie. Macnab participated in both seasons of field work; Page in the second field season and in part of the writing; and Mackenzie in part of the petrography and together with one of us (D.B.D.) re-interpreted the air-photographs of the Western Highlands (mapped by Dekker and Faulks); Belford, Terpstra, and Skwarko made all the palaeontological determinations.

Our appreciation and thanks to Drs D. H. Green and E. J. Essene of the Australian National University for valuable discussions on the glaucophanitic and eclogitic rocks.

PHYSIOGRAPHY

The South Sepik region falls naturally into two simple physiographic divisions: the Sepik Plains in the north and the Central Range to the south.

Sepik Plains

The Sepik Plains cover an area of about 25 000 km². They are flat and low-lying — the rivers draining them have remarkably low gradients, and even 500 km from the sea, they are generally only 30 m above sea level. The area has a high rainfall and much of the low-lying country consists of lakes and swamps or is perennially inundated (Pl. 2, figs 1 & 2). Dry land is generally found along the banks of the larger streams, which form levees slightly above the level of the swamps, and on isolated hills which are remnants of a drowned topography.

The plains are drained by the Sepik River, which flows along the north side of the map area, following a convolute course which is about three times the straight-line distance. The river is constantly changing course by eroding the convex outer banks and depositing alluvium on the inside bends; swampy cut-off meanders and oxbow lakes are common (see Frontispiece).

The levee banks of the Sepik River impound much of the drainage from the plains into shallow lakes, such as Chambri Lake to the east of Ambunti, and the Amer and Wasui Lagoons to the south.

Most of the plains are covered in sago forest, which is swampy underfoot and virtually impenetrable. The more deeply inundated areas are covered by swamp grasses and other water plants, which commonly form floating grass islands (Pl. 2, fig. 1). These consist of tangled masses of vegetation floating on the lakes at the mercy of the prevailing winds.

The levels of the lakes fluctuate greatly, and at times of low water the streams draining into the lakes build levee banks extending into the lakes (see Pl. 2, figs 1 & 2).

A common feature of the Sepik Plains is the jungle-covered hills which rise out of the swamps (Pl. 2, fig. 2); they are remnants of a drowned topography, and over most of the area only isolated hills or the tops of ridges now emerge. The streams draining them are generally small and completely covered by the forest canopy; few of the openings in the canopy are large enough for a helicopter to land. The hills in the Sepik Plains could be mapped in more detail by traversing on foot, but this would be time-consuming.

Though most of the population of the Sepik Plains is concentrated along the major waterways, the swamps support a large scattered population, most of whom live in villages situated on the margins of the hills. These people have hunting tracks in the hills and sparse tracks joining the main centres of population, but travelling is generally by canoe on the lakes, and along narrow waterways which are kept open in the grassy swamps.

The people of the Sepik Plains grow subsistence crops, but sago, which is easily won from the ubiquitous sago palms, and fish, which abound in the rivers, are their staple diet. Some villages are built on stilts in the middle of large swamps with no dry ground for kilometres around; most of their gardens are visited by canoes. Some of the people live by foraging and trading.

The area north of the Sepik River, between Angoram and Pagwi, slopes gently southwards from the Prince Alexander Mountains, and hence is better drained. Impermanent streams follow shallow channels separated by broad and almost flat interfluves clothed in tall kunai grass in contrast with the dense forest filling the stream channels.

The large tributaries of the Sepik River which drain the Central Range, flow northwards across the Sepik Plains. They are slow-flowing and provide good, if somewhat indirect, access to the mountains; some of the rivers, like the Sepik itself, follow extremely convolute courses.

Most of the villages in the region are built on the levee banks of the rivers, which in the wet season are only about a metre above river level and are occasionally inundated (Pl. 3, figs 1 & 2). After prolonged dry weather in the headwaters, the rivers drop dramatically, and flow between steep muddy banks which are sometimes as much as 4.5 m above water level.

It is not uncommon for these tributaries to change course drastically when the levee banks have been built too high above the surrounding swamps. An old course of the Yuat River, which was abandoned before the time of the Berhmann's expedition in 1912, can be seen as a chain of swampy oxbow lakes still with villages lining the banks.

The Hunstein Range is an isolated mountain block rising out of the Sepik Plains south of Ambunti, and on the few occasions when it is free of cloud, it dominates the Sepik Plains. It culminates in a broad peak nearly 1 500 m high, and is drained by the Hunstein River, which flows northwards to the Sepik River near Ambunti. The whole range is clothed in dense forest, and clearings suitable for landing a helicopter are rare; it has a higher rainfall than the surrounding Sepik Plains.

The Sepik Plains offer little by way of exploitable natural resources. Some timber is cut by local people and rafted down the major tributaries to saw mills at Angoram, but because most of the logs have to be hauled long distances through swamps, it seems unlikely that timber milling will develop into a major industry.

Crocodile skins bring a high price, but as a consequence hunters are so active that the whole area is in danger of being shot out.

The Sepik people are well known for their expressive wood carvings, and they make a small income from their export.

Bird life abounds in the Sepik Plains and wild ducks are a reliable source of food in the lake country. Other native game such as cassowaries, wild pigs, and small wallabies are common, and it is an advantage to have carriers experienced in hunting with a shot gun.

Insects are troublesome over much of the Sepik Plains, and the plagues of mosquitoes in some areas defy description. Stops in the swamp country are made a misery, even in daylight, by clouds of biting mosquitoes, but fortunately in the better-drained country near the southern mountains there are far fewer mosquitoes and they are generally troublesome only at night. Another biting insect which causes much discomfort is the bush mite, which causes angry red lumps which itch for several days. Some members of the party were particularly troubled by this pest and often much of their bodies was covered by bites. As the mite is a carrier of scrub typhus it is a worthwhile precaution to apply mite repellant (dibutyl phthalate) when walking in infested areas. Leeches and sand-flies also cause much discomfort.

Central Range

The second physiographic division is the Central Range, which occupies the southern half of the map area. It forms the main New Guinea watershed between the Sepik River in the north and rivers flowing southwards to Papua. The whole of the range is over 2 000 m above sea level and is extremely rugged and covered with rain forest. The region is one of extreme relief: the Central Range culminates in the Burgers Mountains (3 900 m), which drop precipitously to the Sepik Plains in a distance of a few kilometres.

The section of the Central Range between the Burgers Mountains and the May River is one of the most isolated areas in Papua and New Guinea, and is one of the largest areas of unrelieved rain forest. It is deeply dissected and is drained by tributaries of the Sepik River, which follow steep courses to the Sepik Plains. Most of the major tributaries are widely spaced and carry large volumes of water; they all are obstructed by deep boulder-choked gorges for much of their length, and most are virtually continuous cascades. They are therefore impossible to traverse, and the only accessible outcrops are provided by the small side streams; but even these are difficult and at times dangerous to traverse. Only the lower reaches of the major tributaries (e.g. the Karawari River, Pl. 4, fig. 1) are navigable by jet-boat for some distance into the mountains.

Small groups of semi-nomadic people eke out a precarious existence in this area. Disease, the wet climate, and possibly the depredations of tribal warfare, appear to be the main reasons for the limited population, as there is no shortage of land for gardens.

In 1967 the Sepik party made several first contacts with people who live in the more remote parts of the region, among whom the people from the headwaters of the April River are typical. They live in huts built on stilts for defence (Pl. 1, fig. 2) and are untouched by European culture, except that they no longer use stone axes, which have been a rarity for many years. The region is crossed by several tracks, which have served as trade routes between the Sepik Plains and the Highlands to the south for many generations, and steel axes were probably introduced into the region before World War II.

Small pockets of similar people are found in the headwaters of all the major tributaries, living at altitudes between 900 and 2 400 m. Almost all were friendly when contacted, but were generally unco-operative, especially when we managed to convey a desire to follow their tracks.

The people living at the head of the Frieda River at the Wabia hamlets are a very different people, who apparently have no communication with the people to the east. They are true Highland people with close affinities with the Telefomin population to the south, and have had contact with Administration patrols for several years. They were friendly and acted as carriers for one traverse party in 1967. Several youths had a smattering of pidgin, so communications were above the level of sign language.

Between the Maramuni and Karawari Rivers the country is quite different and is drained by large rivers flowing in wide valleys flanked by spectacular vertical cliffs of conglomerate up to 900 m high (Pl. 5, fig. 1). The valleys generally provide reasonable travelling, but the intervening areas are virtually impassable.

The only people in the area are the Meakambuts, a very small semi-nomadic group who range between the Maramuni and the lower Arafundi Rivers, and the Pundugums who live at the head of the Arafundi River.

The Meakambuts probably number less than 150 people (M. O'Reagan, Patrol Officer, Amboin, 1967, pers. comm.), and are very shy and elusive. Despite many attempts made by Administration patrols, these people had not been contacted by 1966, and the Sepik party made the first contact while traversing the area in July 1966.

The Pundugums had been contacted by Administration patrols before 1966, and proved to be co-operative. They were recruited by the party as permanent carriers in 1966 and 1967 and proved invaluable, for not only were they our best carriers, but they also had a smattering of the languages of the surrounding groups.

The southeastern part of the map area is the only part to have a substantial population, and much of the area consists of garden clearings or is clothed in kunai grass (Pl. 4, fig. 2). The forest is prevented from encroaching on the clearings by regular burning off by the local people during hunting forays.

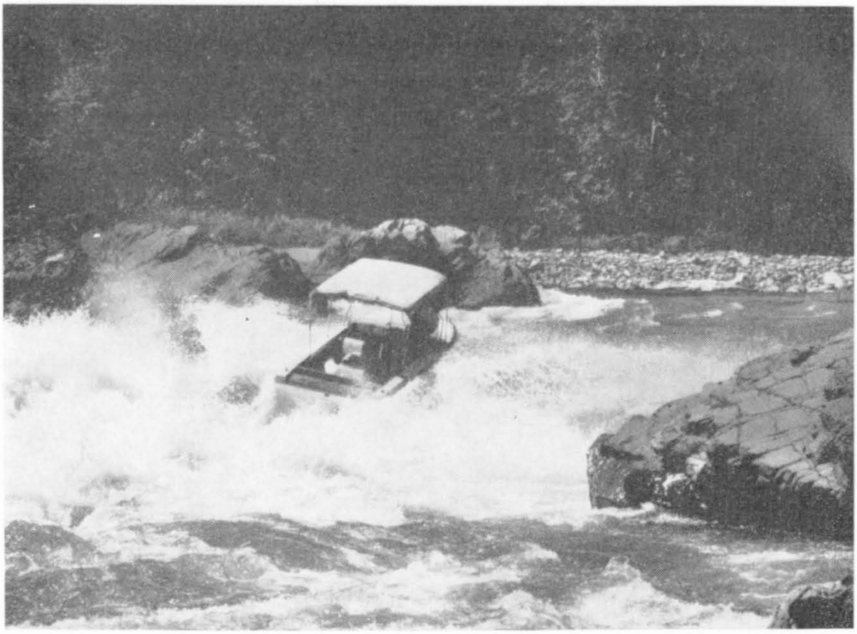

Plate 1, Figure 1. Jet-boat negotiating a rapid in the Yuat River.

Plate 1, Figure 2. Helicopter pad constructed near the head of the Salumei River. The houses along the Central Range, between the Korosameri and Frieda Rivers, are built on stakes up to 10 m high for defence purposes.

Plate 2, Figure 1. Lakes south of Ambunti showing floating grass islands on the lower right. The stream entering the lake is defined by levee banks deposited at times of low water.

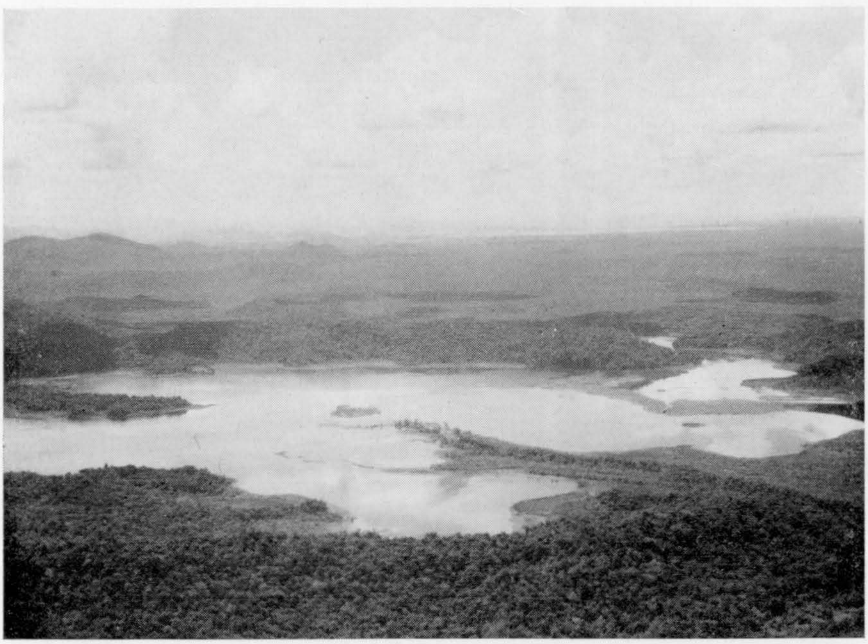

Plate 2, Figure 2. Lake south of Ambunti showing the levee banks built out into the lake by the small stream entering from the bottom right. The hills rising from the swamps are remnants of a drowned topography (see also Fig. 1).

Plate 3, Figure 1. BMR camp on the bank of the April River, showing the helicopter pad in the foreground and the sleeping and messing quarters on the edge of the bush. The river is running at a high level (see also Fig. 2).

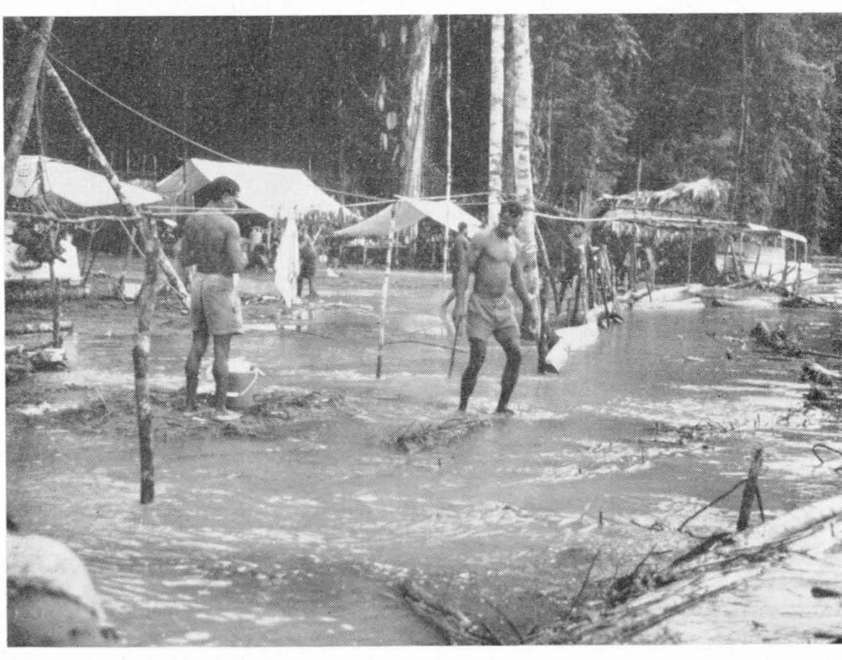

Plate 3, Figure 2. The April River camp was flooded on several occasions, so all equipment was stored on benches about a metre above the ground.

Plate 4, Figure 1. The middle reaches of the Karawari River. The river flows along a flat-floored valley flanked by vertical cliffs of Karawari Conglomerate up to 900 m high. The river provided excellent jet-boat travel as it consists of long placid pools separated by shallow gravel bars.

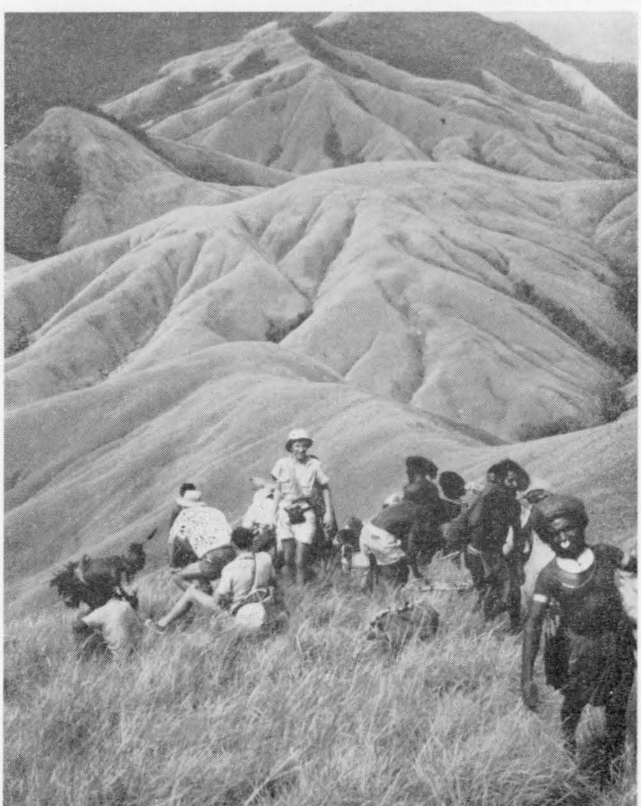

Plate 4, Figure 2. Grass-covered hills above the Yuat Gorge. The hills are burnt off periodically during hunting forays. The local Wapi people are seen carrying traverse equipment.

The people living between the Yuat and Maramuni Rivers are called the Wapi and were first contacted by the Administration in 1955. They have been spasmodically patrolled since 1958, but their culture has been little altered. The latest census figures (taken in 1966) give the population as almost 2 000 people. They proved helpful to the Sepik party and were keen to carry cargo and act as guides. People from the northernmost village, which overlooks the upper part of the Yuat Gorge, provided great service when they built a wooden railway 100 m long across large river boulders, over which one of the jet-boats was pulled to bypass a difficult rapid in the Yuat River.

Farther south, in the headwaters of the Maramuni and Lagaip Rivers and in the watershed of the upper Lagaip River, there is a large population, and almost the whole area is covered by gardens or kunai grass. The region has been regularly patrolled since before World War II, and is now well served by roads and graded walking tracks. Government stations are situated at Wabag, Laiagam, Wapenamanda, and Kompiam, and there are many mission stations throughout the area.

The Burgers Mountains are the highest mountains of the Central Range and their crest at over 3 900 m above sea level is above the forest line. Most of the tops are covered with mountain grasses and clumps of stunted shrubs. Some of the small streams draining the tops begin in cirque-like hollows, and it seems almost certain that the mountains were capped by permanent ice fields during the Pleistocene.

OUTLINE OF GEOLOGY

The South Sepik region lies mainly within the *New Guinea Mobile Belt* (Fig. 7), an unstable orogenic zone which includes much of the axial ranges and northern fall of New Guinea. The zone has had a profound effect on sedimentation in the region throughout the geological record, and while shelf-type sediments were laid down on the continental block geosynclinal sediments were deposited to the north.

The break between the two environments is remarkably sharp, and in the map area is marked by the Lagaip Fault Zone, which is rarely more than 12½ km wide.

There is also a great contrast in the structure of the two environments: the shelf sediments are relatively undeformed and are broken by only a few major faults (APC, 1961), but the oceanic sediments are intensely faulted along the major tectonic zone known as the New Guinea Mobile Belt.

Only small remnants of the oldest rocks, extensive unmetamorphosed shelf sediments of Triassic age, are now preserved in the South Sepik region. They are exposed along a narrow horst between the Yuat and Maramuni Rivers as the *Yuat Formation* (black well bedded shale and siltstone of Middle Triassic age), and the *Kana Volcanics* (thick dacitic volcanics, and volcanolithic* sediments). The Kana Volcanics are widespread and distinctive, and form a valuable stratigraphic marker where exposed.

* The term 'volcanolithic' refers to the following categories of rocks:
1. Rudite and arenite of sedimentary origin, which are composed of volcanic material;
2. rudite, agglomerate, and tuffaceous arenite of volcanic or sedimentary origin, which are composed of volcanic material. These rocks are commonly interbedded with lavas and other volcanic rocks.

Though there is no evidence in the South Sepik region, it is known (Dow & Dekker, 1964) that the Triassic sedimentation was followed by intense folding and faulting, and a period of erosion.

The Sepik Valley is underlain by large areas of metamorphosed sediments called the *Ambunti Metamorphics*, which range from slate and sericite schist to muscovite gneiss and amphibolite. Complex intrusive bodies, ranging from gabbro to quartz diorite, have been converted into amphibolite and orthogneiss. The age of the metamorphics is not known, but they may have been formed during the orogeny that deformed the Yuat Formation and Kana Volcanics.

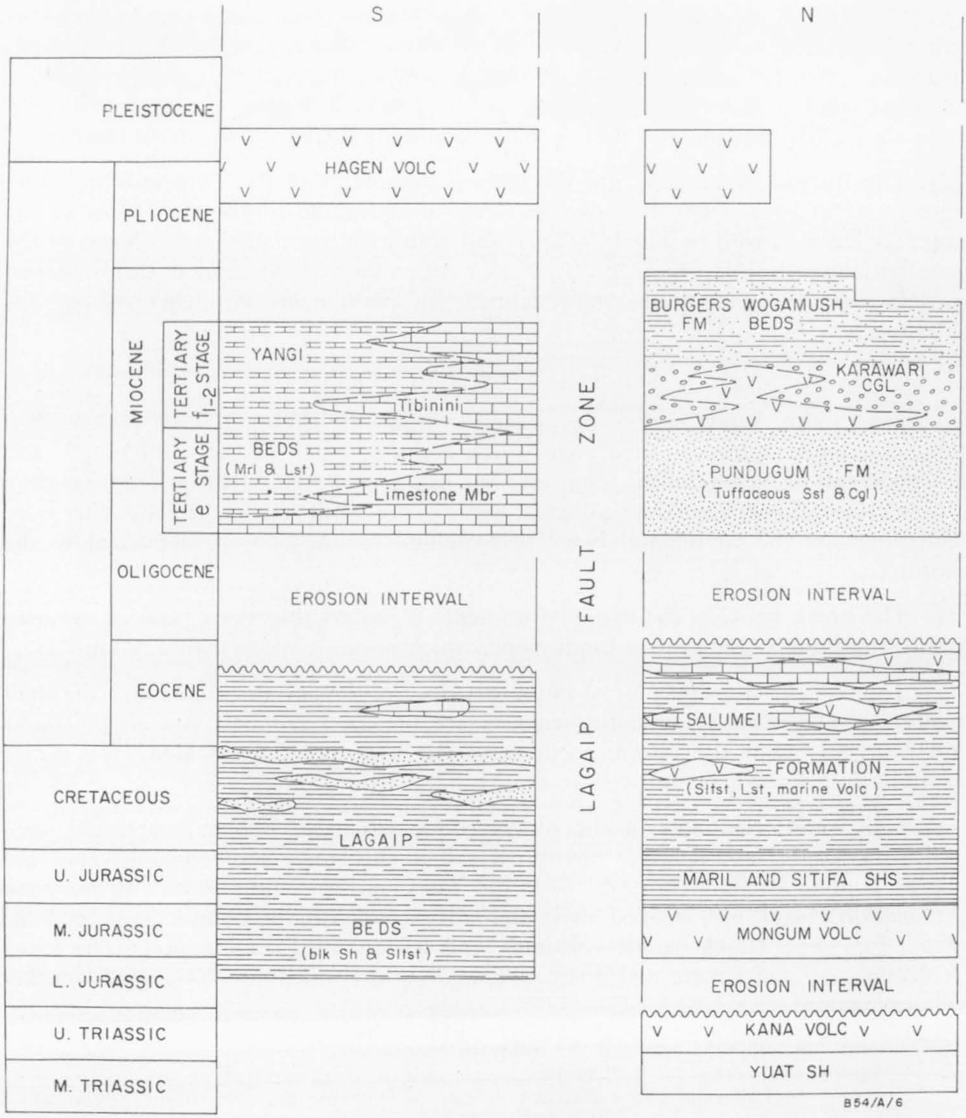

Figure 3. Stratigraphic correlation chart

Sedimentation began again about the Middle Jurassic and continued without a break until Tertiary time (Fig. 3). South of the Lagaip Fault Zone a thick sequence of black pyritic shale and siltstone (the *Lagaip Beds*) was laid down. The sediments were deposited in a typical euxinic environment (Pettijohn, 1949), probably in a narrow trench where the circulation of water was very restricted. The trench extended southeastwards to Papua where it has been called the Kutubu Trough (APC, 1961). Towards the top of the formation there are thick beds of pure quartz sandstone which testify to a shallowing of the trough in Cretaceous time, although sedimentation continued at least until middle Eocene time.

Eugeosynclinal sediments were laid down north of the Lagaip Fault Zone over most of the area that is now the north face of the Central Range. Sedimentation started in the Middle Jurassic with the deposition of a great thickness (over 2 400 m in places) of basic marine volcanics called the *Mongum Volcanics*. Grey shale was then deposited in the Upper Jurassic in extensive shallow seas which extended well beyond the map area to the southeast. These rocks are called the *Maril Shale* in the eastern part of the map area, and the *Sitipa Shale* near the April River.

The eugeosyncline reached full development during Cretaceous and Eocene times when the *Salumei Formation*, consisting of siltstone and fine-grained greywacke, foraminiferal limestone, tuffaceous sandstone, and sporadic basic marine volcanics, was laid down.

Volcanic rocks are more common and more widespread in the Eocene, and the increase in volcanism was a forerunner of the greatly intensified tectonic activity in the lower Miocene.

Uplift was widespread in the Oligocene, and the areas north and south of the Lagaip Fault were exposed to erosion until the lower Miocene.

Tectonic activity reached a climax in the lower Miocene, but the contrasting environments of deposition north and south of the Lagaip Fault Zone continued: during the Tertiary e Stage tuffaceous sediments derived from basic volcanism (the *Pundugum Formation*) were deposited in the north while the lower part of the *Yangi Beds* was laid down to the south. The Yangi Beds consist of marl and thin-bedded limestone containing the *Tibinini limestone member* which formed a large barrier reef on the northern edge of the continental shelf.

The extrusion of the volcanic rocks during the Tertiary e Stage and f_{1-2} Stage was accompanied by major earth movements, mostly faulting of great magnitude, and widespread plutonic activity. Batholiths ranging in composition from gabbro to granodiorite were intruded at this time; they are now exposed to erosion, and there is good evidence that they were exposed as early as the Tertiary f_{1-2} Stage. The large plutons are confined to the eastern part of the area, where they are called the *Maramuni Diorite*.

Stocks and dykes of andesite porphyry found to the south (*Porgera intrusives*) and to the west (*Frieda Porphyry*) are possibly apophyses of similar batholiths not yet exposed.

Large irregular bodies of dunite and peridotite (*April Ultramafics*) are exposed over an area of about 1 000 km^2. They were emplaced along the imbricate fault zones forming the northern front of the Central Range, at the same time as the main instrusions.

During this igneous activity much of the Salumei Formation was metamorphosed to give a great variety of rocks ranging from slate and sericite schist to biotite and muscovite schist and some glaucophane-bearing schist.

A spectacular suite of glaucophane gneiss and eclogite (the *Gufug Gneiss*) was also formed at this time. It may have been formed from the Salumei Formation by high-pressure/low-temperature metamorphism, or it may consist of older metamorphic rocks upfaulted from depth into their present position.

The end of the lower Miocene (Tertiary f_{1-2} Stage) saw a climax in volcanic activity throughout the New Guinea Mobile Belt. In the map area basic and andesitic island arc volcanic rocks and a great thickness of volcanolithic cobble conglomerate and tuffaceous sediments were laid down. These rocks have been divided into three formations, the Burgers Formation, Karawari Conglomerate, and Wogamush Beds, which were laid down simultaneously, possibly in separate troughs.

It is quite remarkable that such widespread volcanic activity did not affect the sediments south of the Lagaip Fault Zone, but there is no sign of volcanic detritus in the upper part of the Yangi Beds which was laid down at this time, even though the volcanic rocks to the north of the fault occur within 12½ km of the Yangi Beds in the upper Lagaip River. The continental slope to the south was capped by a fringing barrier reef and appears to have been an effective barrier to southward migration of volcanic detritus.

There is no reliable palaeontological dating of the upper part of the Miocene successions, but it seems unlikely that sedimentation continued beyond the middle Miocene.

The only post-Miocene rocks, other than recent alluvium, deposited in the map area are the Plio-Pleistocene *Hagen Volcanics* (Mt Hagen Volcano) and the Recent Sugarloaf Volcanics (Mt Sugarloaf area). Lahars from Mount Hagen filled the Yuat Valley to a depth of about 100 m as far as the Sepik Plains during the height of the late Pliocene/early Pleistocene eruptions.

TRIASSIC

The oldest rocks known in the South Sepik region are shelf-type sediments and acid volcanics of Triassic age. They show affinities with later rocks laid down in the stable environment of the Australian continental block to the south, and it is thought that they represent wedges of the continental margin faulted into their present position in the New Guinea Mobile Belt.

Yuat Formation
(new name)

Lithology. Dark grey shale, greywacke, feldspathic sandstone.
Distribution. Confined to Yuat Gorge and lower Maramuni River.
Derivation of name. Yuat River.
Type section. Yuat Gorge; no section measured.
Stratigraphic relationships. Base not exposed; overlain, probably conformably, by Kana Volcanics.
Thickness. Not measured; at least 600 m.
Fossils and age. Ammonites, nautiloids, bivalves, and crinoid stems: Middle to Upper Triassic.

The formation is well exposed only along the Yuat River where massive black shale predominates; the shale is overlain by poorly exposed tuffaceous greywacke which forms the steep western wall of the Yuat Valley. The formation is about 600 m thick, but the base of the sequence was not seen.

The black shale is at least 90 m thick, generally massive, indurated, and well jointed: it crops out well in the Yuat River, and fine silty bands can generally be distinguished on close examination. The shale is richly fossiliferous and contains well preserved ammonites (Pl. 5, fig. 1), nautiloids, and bivalves, abundant crinoid stems, and some rare bone fragments (Skwarko, in press). Rare beds of feldspathic sandstone up to 1 m thick are interbedded with the shale. The sandstone is brown to grey, fine to medium-grained, and well sorted, and consists of grains of sub-rounded quartz and kaolinized feldspar in about equal proportions. Fragments of ferromagnesian minerals are common and there is a small amount of sericitic matrix. The sandstone appears to be derived from an acid volcanic source, and is similar to the tuffaceous sandstone of the overlying Kana Formation.

The shale passes upwards rather abruptly into a predominantly arenaceous sequence. The transition is about 15 m thick, and consists of light grey to brown feldspathic sandstone and calcareous sandstone beds, $7\frac{1}{2}$ cm to 1 m thick, inter-bedded with subordinate thinly bedded black and grey shale and siltstone. Thick beds of poorly sorted quartz sandstone are found here, some crowded with well rounded pebbles of black indurated shale. The presence of coaly fragments, carbonaceous lenses, and small pieces of bone in many of the beds, and the absence of graded bedding indicate a shallow-water environment.

The shale member is overlain by a sequence 450 to 600 m thick, which, although it forms the steep western slopes of the Yuat Valley, is poorly exposed. The only exposures seen were massive to thick-bedded tuffaceous greywacke, which is green and highly indurated when fresh. Though the beds have been included in the Yuat shale, it seems likely that they are the northwestern extension of the Jimi Greywacke, which crops out widely at the head of the Jimi River (Dow & Decker, 1964).

Skwarko (in press) has described and dated fossils collected from the black shale. There are two distinct faunas, the older being of Anisian (Middle Triassic) age, and the younger — previously described by Skwarko (1967) from outcrops in the Jimi River area — of Carnian-Norian (Upper Triassic) age. The Anisian fossils are mainly ammonites with some nautiloids, crinoid stems, bryozoans, and gastro-pods, while the younger fauna consists predominantly of bivalves with some gastropods and problematical fossils.

Kana Volcanics
(name amended)*

Lithology. Dacitic, rhyolitic, and andesitic tuffs and lavas; tuffaceous sandstone, volcanolithic pebble conglomerate, red tuffaceous siltstone.
Distribution. Crops out in belt between lower Maramuni River and Chimbu River 160 km to southeast.
Derivation of name. Kana River, tributary of Jimi River draining western flank of Mount Herbert in Bismarck Mountains.
Type section. Chimbu River (145°04′, 5°53′).
Stratigraphic relationships. Overlies Jimi Greywacke, probably unconformably; overlain unconformably by Lower Jurassic Balimbu Greywacke.
Thickness. About 600 m exposed in map area.
Fossils and age. Fairly widespread Upper Triassic macrofauna, possibly ranging into Lower Jurassic.

* See Appendix.

In the map area, the Kana Volcanics crop out along the divide between the Yuat and Maramuni Rivers, and in the Yuat Gorge farther east.

The lower half of the formation is poorly exposed in slopes west of the Yuat River, and is almost identical with the lower part of the Kana Volcanics in the headwaters of the Jimi River. It consists mainly of tuffaceous sandstone derived from acid volcanics, dacite-pebble conglomerate, and some interbedded red siltstone. The upper part of the unit along the crest of the divide and for some distance down the Maramuni fall is poorly exposed, but appears to be finer in grainsize. The sequence contains less conglomerate and more red and grey siltstone than the lower part.

The sandstone in the Maramuni River/Yuat River divide area is fine to coarse-grained, and grades into pebble conglomerate. It is characteristically light green or grey, and feldspar commonly forms over half of the rock by volume. It is a clean well sorted tuffaceous sandstone composed of angular to rounded fragments of volcanic rocks, quartz, and sodic plagioclase (An_{30}), with a few fragments of sedimentary rocks and detrital biotite, and small patches of carbonate matrix. Some of the weathered beds contain poorly preserved shells from which the carbonate in the matrix may have been derived.

The conglomerate consists of well rounded pebbles and cobbles of dacite, fine-grained acid intrusives, and quartz, set in a matrix of coarse tuffaceous sandstone. Another characteristic component is a massive maroon tuffaceous siltstone, which is generally indurated and commonly contains small scattered fragments of feldspar and quartz. Some of the beds are probably water-laid tuffs, but all traces of their origin has been obliterated by subsequent alteration.

In the lower part of the Yuat Gorge the Kana Volcanics consist of strongly sheared green and purple dacite and quartz-feldspar porphyry. The sequence appears to be bedded, but it is possible that the banding is foliation caused by movement on the Jimi Fault. Small lenses of strongly sheared and indurated conglomerate, similar to conglomerates found in the formation to the southwest, were also seen in the Yuat Gorge.

Most of the rocks are acid volcanics composed of phenocrysts of quartz and feldspar and fragments of microdiorite set in a very fine-grained recrystallized groundmass of quartz, feldspar, sericite, and some epidote. The groundmass is strongly foliated owing to shearing associated with movement on the Jimi Fault.

Fossils have not been found in the Kana Volcanics in the map area, but in the headwaters of the Jimi River good fossil assemblages give the age as Upper Triassic (Dow & Dekker, 1964, p. 13).

JURASSIC

In the South Sepik region the stable shelf environment of the Triassic continued into the Lower Jurassic, when the uppermost part of the Kana Volcanics was laid down. The period of earth movement and erosion which followed is shown by a marked unconformity in the headwaters of the Jimi River (Dow & Dekker, 1964). After intense basic marine volcanism (Mongum Volcanics), probably in Middle Jurassic time, extensive shallow seas were formed, in which a uniform shale sequence was laid down over most of the Highlands of New Guinea in the Upper Jurassic. The shale is called the Maril Shale in the southeast, and the Sitipa Shale in the South Sepik region. South of the Lagaip Fault Zone, the Lagaip Beds were laid down in a narrow trough in Upper Jurassic to Cretaceous times.

Mongum Volcanics

The name Mongum Volcanics was proposed by Dow & Dekker (1964) for the basic submarine volcanics which conformably overlie the Lower Jurassic Balimbu Greywacke and are conformably overlain by the Upper Jurassic Maril Shale in the headwaters of the Jimi River. There the formation is 250 m thick and consists principally of basaltic agglomerate and pillow lavas interbedded with conglomerate, tuffaceous sediments, and minor lenses of limestone.

In the South Sepik region, similar basic marine volcanics underlie the Maril Shale north of Olimos, between the Maramuni and Yuat Rivers. The Balimbu Greywacke is absent in this area and the formation appears to rest unconformably on the Kana Volcanics.* Owing to poor outcrop no section could be measured, but the air-photographs indicate an approximate thickness of 900 m.

The lower half of the formation consists of amygdaloidal basalt and basalt agglomerate with interbedded red and green tuff and tuffaceous greywacke. In the upper half tuffaceous greywacke and siltstone predominate over basalt and agglomerate. Subordinate pink crystalline limestone and a massive bed of wollastonite-bearing quartzite crop out near the top of the formation. The upper boundary is taken at the top of the highest volcanic rock.

Farther west, a small wedge of amygdaloidal andesite, vitric tuff, and lithic tuff, belonging to the Mongum Volcanics, is upfaulted within the Maril Shale.

* Poorly preserved fossils from near Yalifa (5° 03'S; 143° 54' E), which were thought to be in the upper part of the Kana Volcanics, have been dated as Lower Jurassic (S.K. Skwarko, pers. comm.) and it now appears likely that the Balimbu Greywacke is locally present in this area. The sequence at this locality consists of blue-grey feldspathic sandstone which resembles some of the rock types found in the Balimbu Greywacke.

The Mongum Volcanics consist of altered basaltic and perhaps andesitic rocks, in which most of the plagioclase has been albitized and the ferromagnesian minerals altered to calcite, chlorite, iron oxide, albite, and quartz. The lithic tuffs are composed mainly of fragments of altered basalt, and the massively bedded white quartzite consists mainly of detrital quartz with radiating sheaves of wollastonite, isolated prisms of pseudo-wollastonite(?), and a little scapolite and diopside. The quartzite probably represents a calcareous quartz arenite which has been metasomatized by the basic volcanic sills which intrude the Mongum Volcanics.

No fossils were found in the Mongum Volcanics, but in the Jimi Valley, Lower Jurassic fossils in the Balimbu Greywacke and Upper Jurassic fossils from the Maril Shale indicate a Middle Jurassic age (Dow & Dekker, 1964).

Sitipa Shale
(new name)

Lithology. Grey and green, generally calcareous, siltstone and shale.
Distribution. Thin fault wedge between Sitipa and Salumei Rivers.
Derivation of name. Sitipa River.
Type section. Middle reaches of Sitipa River; no type section measured.
Stratigraphic relationships. Generally bounded by faults, but at one locality between April and Sitipa Rivers possibly overlain conformably by Salumei Formation. Laterally equivalent to Maril Shale.
Thickness. Not known.
Fossils and age. Malayomaorica bivalve faunas clearly indicate Upper Jurassic (Kimmeridgian) age.

The formation consists of shale and siltstone and a little impure limestone and fine-grained sandstone. The shale and siltstone are commonly colour-banded light grey and green, but rare beds of grey-black and red shale were also seen.

Outcrops are mostly small and massive, and some weather in a manner typical of the Maril Shale of the same age found to the east, that is they form steep stream banks in which the rock frets into small angular fragments. In places the sequence is laminated, with well defined bands of silty material. Rare beds of indurated fine-grained quartz sandstone and feldspathic sandstone may be present. They are up to 30 cm thick, but are generally much thinner, and commonly show small-scale cross-bedding and slump structures.

Fossils were found in four localities. They are regarded by S. K. Skwarko (pers. comm.) as Upper Jurassic, probably Kimmeridgian, and therefore correlatives of the Maril Shale in the Maramuni River 80 km to the east.

Maril Shale

The name Maril Shale was proposed by Edwards & Glaessner (1953) for a predominantly shale sequence in the Wahgi Valley southeast of the map area. Subsequent mapping has shown that the formation extends along the Jimi Valley (Bain, Mackenzie, & Ryburn, in prep.) to the divide between the Yuat and Maramuni Rivers. In the map area the sequence consists mainly of dark to light grey calcareous shale and siltstone containing rare thin beds of indurated quartz sandstone.

Some of the shale is thin-bedded or laminated, but most of it is massive and forms characteristic fretted outcrops as described under the Sitipa Shale. In the lower Sau River sporadic outcrops of laminated to thin-bedded pink and cream quartzite were seen within the Maril Shale, but their thickness is not known.

The lower part of the formation, as in the Jimi Valley, is coarser in grain, and consists mainly of massive dark-coloured siltstone grading imperceptibly into fine-grained greywacke. Thin partings of shale about a metre apart can be seen where the beds are well exposed, but most of the sequence appears to be unbedded.

The shale is intruded by the Maramuni Diorite, and hornfelsed near the contact. In places, the shale has been altered to phyllite, possibly as a result of deformation along major faults.

The presence of *Malayomaorica malayomaorica* and *Inoceramus* sp. cf. *haasti* in the Maramun area and lower Sua River indicate that the Maril Shale is Upper Jurassic (Kimmeridgian).

In the Jimi Valley and in the map area the Maril Shale is much thicker than in the type area in the Wahgi Valley, where 1 100 m was measured by Rickwood (1955). In the Jimi Valley the formation exceeds 2 400 m (Bain et al., in prep.), and though it is much faulted in the map area the thickness is about the same. The Maril Shale was laid down in a northwesterly trending trough between the Maramuni River and the head of the Jimi River. Rickwood has shown that the formation thins markedly to the south against the Kubor Range, and the shoreline was probably not far to the south.

Ambunti Metamorphics
(new name)

Most of the Sepik Valley is underlain by metamorphic rocks which we have called the Ambunti Metamorphics. They range from low-grade slate, phyllite, and sericite schist in the east, to amphibolite facies rocks in the west.

Lithology. Slate, phyllite, sericite schist, muscovite and biotite schist; pelitic, quartzofeldspathic, and basic schists and gneisses of amphibolite facies.
Distribution. Most of hills rising out of Sepik Plain between Leonhard Schultze and Karawari Rivers; several large areas also exposed near to and south of May River Patrol Post.
Derivation of name. Government station of Ambunti.
Type area. Ambunti Hills (143° 45′, 4° 10′).
Stratigraphic relationships. Unconformably overlain by Tertiary (f_{1-2} Stage) Wogamush Beds and Karawari Conglomerate. Lateral equivalent (Gwin Metamorphics, 50 km west of map area) possibly overlain by unaltered Cretaceous sediments.
Thickness. Not known.
Age. Probably Mesozoic, but possibly includes Lower Tertiary rocks; definitely older than middle Miocene. Metamorphism lower Miocene or older.

The Ambunti Metamorphics fall naturally into two divisions: (1) low-grade rocks between the Karawari and April Rivers, and (2) higher-grade amphibolite to the west.

Most of the low-grade rocks lie within the area not covered by air-photographs, so our knowledge of them is confined to sporadic widely spaced outcrops along the main stream channels, and observations made by Behrmann's expedition before World War I. All the outcrops seen consist of low-grade metamorphic rocks, mainly slate, phyllite, and sericite schist, but towards the April River higher-grade fine-grained biotite and muscovite schists and banded gneisses crop out.

In all the low-grade rocks the foliation has completely obliterated the bedding. The foliation dips at low angles and trends roughly parallel with the west-north-westerly regional strike of the main faults in the area. Quartz veins are common in the lower-grade metamorphics: they range up to about 10 cm thick and a metre long, and though rather irregular, most are parallel with the foliation.

East of Ambunti, where the Chambri Diorite intrudes the metamorphics, the rocks are higher in metamorphic grade. Coarse-grained muscovite and biotite schists are common and small metamorphosed intermediate and basic intrusives are found throughout. The basic rocks have been recrystallized to amphibolite, while the intermediate rocks have been altered to strongly foliated orthogneiss.

Along the April River the metamorphism is slightly higher in grade, and many of the rocks have a marked gneissic fabric. The only specimen examined in thin-section is a banded gneiss consisting of white lenses of quartz, up to 6 mm thick and about 10 cm long, intercalated with finely banded biotite gneiss. The lenses consist mostly of granular quartz, but contain minor albite, muscovite, and apatite; the gneiss is dark brown and consists of quartz, biotite, muscovite, albite, some chlorite, and a little iron oxide, sphene, and apatite.

The higher-grade rocks west of the April River are better exposed and hence were mapped in more detail. They fall within the amphibolite facies of regional metamorphism. Like the lower-grade metamorphics they have a marked foliation which has obliterated bedding: the foliation also dips at low angles, but the strike has no consistent regional trend.

Twenty-five thin sections of the higher-grade rocks have been examined. The following rock types were noted: quartz-garnet-muscovite gneiss, containing some kyanite and staurolite; biotite-staurolite schist; hornblende-epidote amphibolite; garnet-dolomite-muscovite-quartz gneiss; hornblende-diopside amphibolite; and quartz-albite-muscovite schist. Apatite and sphene are common accessories in most of the rocks.

The age of the Ambunti Metamorphics is unknown, but an upper limit is given by the Tertiary f_{1-2} Stage Wogamush Beds and Karawari Conglomerate which unconformably overlie them in several places. According to Paterson & Perry (1964), the Gwin Metamorphics in the August River 50 km west of the map area, which are almost certainly an extension of the Ambunti Metamorphics, are overlain by unaltered sediments containing Cretaceous Foraminifera. However, the mapping in the August River was done without the aid of air-photographs, and a re-examination of the field evidence since the air-photographs became available throws doubt on this relationship.

It is possible that the high-temperature/low-pressure Ambunti Metamorphics to the north of the Frieda Fault and the low-temperature/high-pressure glaucophane-lawsonite schists of the Salumei metamorphics to the south constitute paired metamorphic belts similar to those described in Japan, the Celebes, and other circum-Pacific areas (e.g. Landis & Coombs, 1967). If this is so the age of metamorphism of the Ambunti Metamorphics would be post-Eocene and pre-middle Miocene in accordance with that of the metamorphic phase of the Salumei Formation.

The age of the rocks that were metamorphosed to form the Ambunti Metamorphics is considered most likely to be Mesozoic (and possibly Eocene). It is probable that these rocks are of equivalent age to the Mesozoic and Lower Tertiary formations immediately to the south, and that they were deposited in the axial region of a geosyncline and subsequently metamorphosed. The possibility that they are older cannot, however, be discounted.

CRETACEOUS-EOCENE

The Lagaip Beds continued to be deposited south of the Lagaip Fault Zone, but to the north sediments and interbedded spilites (Salumei Formation) were being laid down in a west-northwesterly trending eugeosyncline. Sedimentation continued into the Eocene north of the fault.

Salumei Formation
(new name)

The Salumei Formation is the name proposed for a monotonous sequence of fine-grained Upper Cretaceous to Eocene marine sediments, which include sandstone, limestone, and volcanic beds. They crop out from near Kompiam in the south to the Sepik Plains in the north, and to the May River in the west. The beds were previously mapped as part of the Lagaip Beds (Dow, Smit, & Bain, 1967, unpubl.), but have since been shown to form a separate unit. Southwest of the April Fault Zone as far as the May River the beds have been metamorphosed to greenschist and blue schist facies rocks. They are known as the Salumei Formation (metamorphic phase) and are hereafter called the Salumei metamorphics, which are described separately.

Lithology. Mostly fine-grained marine calcareous and non-calcareous siltstone and shale, subgreywacke, and lenses of fine-grained limestone and calcarenite; submarine agglomerates and lavas, and rare volcanolithic pebble conglomerate, in few places.
Distribution. Northern fall of Central Range between Tarua River (143°45′E, 5°5′S) and May River (142°00′E, 4°45′S).
Derivation of name. Salumei River, which drains large area underlain by formation.
Type section. In Karawari River northwest of Pundugum hamlet (148°28′, 4°50′).
Stratigraphic relationships. Base not seen. Contacts with older units faulted, except perhaps in Sitipa area, where it may rest conformably on Jurassic Sitipa Shale; overlain unconformably by Miocene Pundugum Formation and Wogamush Beds.
Thickness. At least 3 000 m.
Age. Upper Cretaceous to Eocene (based on Foraminifera). Lower Cretaceous (Neocomian) ammonite fragment (*Polyptychites* or *Simbirskites*?) found on surface in Wesas River probably derived from this formation (S.K. Skwarko, pers. comm.).

The Salumei Formation is composed predominantly of siltstone and shale, with subgreywacke and sporadic interbedded submarine volcanic agglomerates and lavas. The sediments are commonly calcareous or micaceous and contain large lenses of limestone and a few pebble bands. The beds are generally massive, although coarse laminae can be distinguished in places, and some of the siltstone, as in the Karawari River, is thinly bedded. Most of the shale and siltstone is light to dark grey, but some is green, buff, and red.

Many of the arenites are composed partly of volcanic material; they are commonly thickly bedded, and contain thin interbeds of siltstone or mudstone, and are locally micaceous or rich in quartz. The pebble conglomerate contains pebbles of greenish basic volcanics, coloured sediments, and some quartz, although locally developed quartz-pebble conglomerates are known. In places the conglomerate is clearly intraformational, and contains large angular, and commonly elongated, fragments of coloured mudstone.

The subgreywacke fraction is commonly dark greenish grey and well indurated. The degree of induration ranges from hard 'silicified' rocks near the Maramuni Diorite to almost friable rocks which show little sign of deformation.

A few lenses of limestone, up to 100 m thick and several kilometres long, occur throughout the sequence. Most of them are massive, fine-grained, and buff-coloured, and commonly crowded with Foraminifera. Some, such as the lens exposed at the head of the Wogupmeri River, are coarser in grain and composed of small well rounded shell fragments and benthonic Foraminifera. The limestone lenses generally grade laterally into marly siltstone and commonly contain much non-calcareous clastic material. Many of the lenses of coarser limestone are calcarenite breccias rich in Foraminifera, shelly fragments, and angular fragments of volcanic rocks.

Diagnostic Foraminifera are common in both the limestone lenses and fine-grained sediments, and they show that the Salumei Formation ranges from Upper Cretaceous to Eocene. The Upper Cretaceous faunas are commonly planktonic and consist of *Globotruncana* sp., *Gublerina* sp., *Planoglobulina* sp., *Pseudotextularia* sp., *Heterohelix* sp., *Rugoglobigerina,* and *Reussella* sp., although some benthonic forms are present.

The abundant Eocene fauna consists mainly of benthonic forms such as *Nummulites* sp., *Discocyclina* sp., *Fasciolites* sp., *Biplanispira* cf. *fulgeria* (Whipple), *Operculina*? sp., *Rotalia, Nummulites* cf. *javanus, Borelis, Heterostegina,* Miliolidae, and *Pellatispira* sp. Most of the foraminiferal limestones also contain fragments of molluscs, corals, echinoid spines, and bryozoans as well as much algal material (D. J. Belford, pers. comm.).

The Salumei Formation was laid down at much the same time as the bulk of the Lagaip Beds, but there are no volcanic rocks or volcanolithic sediments in the Lagaip Beds.

Volcanic rocks are characteristic of the Salumei Formation, and their presence is one of the criteria which distinguish the formation from the Lagaip Beds to the south. The formation consists mainly of green or red massive albitized basic volcanic rocks (spilites) in which the original texture has generally been obliterated. The presence of relict pillow structures and interbedded marine sediments show that most of them were laid down in a marine environment.

Many of the rocks regarded as lavas in the field were found to be altered agglomerates and crystal tuffs, and thus the proportion of lavas to pyroclastics is uncertain.

Limestone is commonly associated with the volcanic rocks. Many of the limestone lenses are separated from the underlying basic lavas by a zone of fragmental lava and limestone. Varying proportions of subangular and commonly scoriaceous lava fragments, ranging from small pebbles to large boulders, are intermingled with limestone clasts of similar dimensions within this zone (Pl. 5, fig. 2).

The depositional environment of the Salumei Formation is uncertain, but the greywacke beds throughout the formation exhibit turbidite features such as graded bedding, fluting, and convolute laminations, which suggest a deep-water environment.

The formation is too extensively faulted and folded to establish the succession, and both the sediments and volcanics appear to interfinger and lens out over short distances.

The only section measured is in the Karawari River northwest of Pundugum hamlet, where the structure is fairly simple. Here the formation is at least 2 500 m thick, but the bottom was not seen and the top is eroded. An almost complete succession may be exposed between the April and Sitipa Rivers, where about 3 000 m of Salumei Formation is apparently overturned and conformably overlies the Sitipa Shale. Thus it appears that the Salumei Formation is at least 3 000 m thick, but could be much thicker.

The formation is overlain by the Pundugum Formation, and the boundary is marked by a change to coarser-grained tuffaceous sediments. The presence of pebbles of Eocene limestone in conglomerates near the base of the Pundugum Formation attest to a period of erosion after the deposition of the Salumei Formation, and it is almost certain that the two formations are separated by a widespread unconformity. The contact is poorly exposed and generally inaccessible, and as the structure is also complex, it was impossible to prove the existence of the unconformity.

Detailed description

The rocks in the various localities are described in detail below from east to west:

Karawari River northwest of Pundugum hamlet. Approximately 2 500 m of light grey micaceous siltstone and mudstone with calcareous nodules crop out along the Karawari River. They are soft, poorly indurated to well indurated, and thinly bedded (Pl. 6, fig. 1), and have a closely spaced fracture pattern in the finer beds. There are some arenaceous beds (from 2½-45 cm) within the sequence (Pl. 6, fig. 2), but these are generally separated by a greater thickness of shaly siltstone which in places is laminated. The beds within a kilometre of the Maramuni Diorite consist of contorted red to buff tuffaceous siltstone. They are finely laminated and are highly indurated.

There is a 3-m bed of pebble conglomerate near the top of the section.

Between the Wogupmeri River and Kasagali (5°04'S; 143°08'E). The rocks in the head of the Wogupmeri River are only moderately folded and it appears that the section traversed is probably less than 600 m thick. Shale and siltstone greatly predominate; they are dark grey to light grey, and are generally cleaved and indurated, but show little evidence of recrystallization. The rocks are all massive and no bedding was seen except in the limestone lens described below; much of the shale is calcareous and ramifying calcite veins are common in places.

A gently folded bed of limestone, between 60 and 120 m thick, crops out prominently in this locality. It is apparently interbedded with the shale, which is poorly exposed. The limestone is a grey to cream partly recrystallized calcarenite, which contains abundant Eocene benthonic Foraminifera in places. Bedding is commonly seen as well developed partings which give a flaggy appearance to the outcrop.

Near the crest of the main range between the Wogupmeri and upper Korosameri Rivers a polymict conglomerate crops out. It consists of well rounded pebbles and cobbles of quartz, silicified shale, schist, and some gabbro set in a matrix of tuffaceous sandstone. The rock is moderately indurated, and is thought to belong to the Pundugum Formation. The loose blocks of massive dark fine-grained micaceous greywacke and some basic crystal tuff on the hillsides near the conglomerate probably belong to the same formation. A large number of dykes of porphyry, which are related to the Maramuni Diorite, intrude both the Salumei and Pundugum Formations in the headwaters of the Wogupmeri River.

A highly indurated and distorted conglomerate in the headwaters of the Korosameri River is probably also part of the Pundugum Formation.

Farther upstream in the Kasagari River the sequence consists of green, cream, pink, or mauve shale or phyllite. The bedding has been obliterated by the strong cleavage, which dips consistently to the east at 25° to 40° and appears to have resulted from a major thrust fault.

Between Yokopos River and Sikipas Creek the formation is intruded by an elongate ultramafic body and an adjacent diorite intrusion which crop out along the watershed between the Yokopos and Wisas Rivers.

South of the intrusions the formation is sheared and folded and the section examined is probably not continuous. Slickensided massive black shale, maroon and greenish grey hard siltstone, algal limestone, and basalt breccia with a limestone matrix crop out in the Yokopos River. North of the Yokopos River a gently dipping 25-m bed of foraminiferal limestone has yielded forms of Eocene age. The association of limestone and volcanic rocks is characteristic of the Eocene part of the Salumei Formation. Between the Eocene limestone and the diorite intrusion black shale, red and green siltstone, and fine feldspathic sandstone were seen, but extensive shearing and steep dips suggest that the structure is complex, possibly due to the emplacement of the diorite and ultramafic bodies. Numerous dykes and apophyses of andesite porphyry and microdiorite intrude the formation here.

North of the ultramafic body Eocene Foraminifera occur in a marly limestone in Sikipas Creek. The characteristic association of limestone and basaltic breccia was confirmed by the boulders in the streams. One boulder was composed of fragments of scoriaceous basalt set in a limestone matrix. Close to the ultramafic body steeply dipping alternating thin beds of greywacke and siltstone crop out in Sikipas Creek. These are commonly slump-bedded and graded. Red siltstone and slump breccia, composed of rolled fragments and wisps of finely laminated shale set in a matrix of gritty greywacke, also crop out. Complex structure is indicated by shearing and overturned bedding. The numerous small lenses of sheared serpentine within the Salumei Formation in this area were probably forced up along faults and shear zones.

Between Korasameri River and Bisorio village light grey to black siltstone and thinly bedded shale predominate. The shale contains nodules of light grey finely crystalline limestone. Highly contorted red, light to dark grey, and purple shale containing fragments of volcanic rock are present, and small aplitic intrusives were seen in places.

The grey to black siltstone and shale are overlain by red shale followed by dark grey to black and green basic volcanic agglomerate. The agglomerate contains fragments of the red siltstone and is cemented with a red jasper-like material. Some of the lava has a nodular appearance and is dark purple. The volcanics are overlain by thin to medium-bedded light and dark grey shale with small limestone nodules. The boulders of limestone in the creek, which contain Upper Cretaceous Foraminifera, were probably derived from limestone lenses higher in the sequence.

The sequence is then cut by a fault marked by a band of serpentinite 200 to 300 m wide. On the other side of the fault the same grey mudstone and siltstone with beds of limestone up to 15 cm thick crop out. It was not possible to measure the thickness of this succession.

Between Bisorio village and Sikipas Creek the Salumei Formation consists of light grey rather micaceous sandstone and siltstone with interbeds of highly contorted reddish siltstone and limestone. The limestone ranges from calcarenite, limestone breccia, and foraminiferal limestone, to fine-grained buff to dark grey limestone. Most of the streams contain boulders of fine pebble conglomerate, volcanic agglomerate, and volcanolithic sandstone derived from the Burgers and Pundugum Formations. A little micaceous siltstone is also present. Bedding is confused, but the exposed sequence is at least 300 m thick.

Middle reaches of the Salumei River. North of Bikalu hamlet the Salumei Formation consists largely of moderately indurated well bedded greywacke and siltstone strongly folded about northwesterly trending axes. The sequence is at least 1 200 m thick as measured between adjacent fold axes.

Most of the greywacke and siltstone beds range from 5 to 30 cm thick. They show graded bedding, micro-cross-bedding, convolute lamellae, and load structures. One 5-m bed of dark siltstone, containing scattered pebbles of quartz diorite, porphyry, basalt, green sandstone, and greywacke, was seen within a sequence of alternating graded greywacke and siltstone. These beds appear to have been deposited by turbidity currents.

The greywacke contains abundant quartz and mica, and much carbonate material in the matrix. Coarser, more gritty beds are present.

Farther upstream in the Salumei River dark grey micaceous sandstone and siltstone predominate. They are generally thin-bedded (5-8 cm) and contain slumps, graded beds, and load casts which indicate that this part of the sequence is inverted. Rare beds of conglomerate about 60 cm thick contain pebbles of quartzite, marble, basic volcanics, and some coralline debris.

Between the April and Sitipa Rivers the Salumei Formation is poorly exposed. Most of the outcrops consist of light and dark grey shale and siltstone, with interbeds of contorted light and buff-coloured finely crystalline limestone with a total thickness of about 60 m. The succession includes about 100 m of dark green volcanolithic greywacke. Much of the red or green siltstone in the middle of the sequence is tuffaceous; it contains a thin bed of highly indurated pebble conglomerate. The beds dip steeply to the east, but could be overturned. Although very few bedding planes were observed, the section is probably about 3 000 m thick.

Lower Bamali River. South of the April River a large fault block of Salumei Formation occurs within low-grade Salumei metamorphics. The Salumei Formation consists mainly of fine-grained sediments with lenses of submarine volcanics and limestone. The volcanic rocks consist mainly of thin to medium-bedded green lavas of intermediate to basic composition, and are interbedded with grey or greenish coarse to fine tuffaceous sandstone. Well indurated quartz sandstone and greywacke are common, and the coarser varieties grade into pebble conglomerate. Most of the volcanics crop out as hard extensively sheared and jointed flows, finely crystalline and containing numerous green shards. Some of the volcanics are crystal tuffs, which grade locally into tuffaceous subgreywacke or angular grit.

The sequence is about 300 m thick, and the Foraminifera from the interbedded limestone lenses indicate an Eocene age.

Head of Bamali Creek. Little altered sediments intercalated with altered basic volcanic rocks occur as fault wedges within the ultramafic rocks at the head of Bamali Creek. The succession and thickness are unknown, but the beds are similar to the Salumei Formation to the west and east.

Grey and black to green or red massive shale and siltstone predominate. Bedding is rarely seen, but where present consists of thin beds of lighter-coloured siltstone.

Light grey or greenish feldspathic sandstone and subgreywacke occur as beds up to 1 m thick and make up about 20 percent of the sediments. They are all fine-grained, massive, and highly indurated. The hillsides over much of the area are littered with scree from these resistant beds.

The subgreywacke is fine and even-grained, and consists of subangular to subrounded grains of quartz, plagioclase, fragments of fine-grained rocks, and some muscovite, set in a recrystallized clayey matrix. The matrix generally consists of sericite and chlorite, but where muscovite and biotite have formed, the rocks grade into quartz-mica schist. The accessories are epidote, sphene, zircon, and iron oxides.

Lenses of calcarenite up to 100 m thick and several kilometres long are found in this area. In places they contain abundant Foraminifera of Eocene age, as in the Salumei Formation elsewhere. The calcarenite is white, red, or green, generally recrystallized, and commonly fine-grained; it contains patches of well preserved Foraminifera, and was probably deposited in deep water.

The limestone is almost invariably associated with altered basic volcanics. Most of the volcanics are massive dark green rocks, in which the original texture has almost been destroyed, and only rarely can the agglomeratic or pillow structures be distinguished. Most of the pyroclastic rocks contain varying amounts of calcite, generally as recrystallized fragments of fossil shells. The pyroclastic rocks grade into limestone, in which the original sedimentary textures are better preserved.

One unusual fine red and green calcarenite contains scattered angular fragments of basalt scattered randomly through the rock.

The volcanic rocks consist of altered basic crystal tuff and agglomerate and spilitic lavas. The tuff is fine-grained and consists of grains of plagioclase (altered to albite), quartz, epidote, and pyroxene, set in a recrystallized matrix of chlorite, tremolite-actinolite, and epidote. Though massive in hand specimen, most of the rocks have a moderate preferred orientation under the microscope.

The agglomerate is relatively fine-grained and consists of subrounded to subangular fragments of basic volcanic rocks, broken crystals of plagioclase (An_{27}; altered to albite), small fragments of pyroxene (altered to epidote), and a little orthoclase and muscovite. Patches and veins of calcite and zeolites are common.

The pillow lava consists of clinopyroxene, plagioclase laths (altered to albite), granules of epidote, and patches of chlorite with some biotite and muscovite. Pods and amygdales of chlorite, calcite, and zeolites are common.

A highly indurated pebble and cobble conglomerate, composed of well rounded fragments of indurated greywacke and siltstone and some basic volcanic rocks, is also apparently associated with the limestone lenses, although it was seen only in Bamali Creek as boulders.

The volcanic rocks and limestones, though they have reacted to stress as competent blocks, are extremely contorted in places, probably owing to slumping.

Headwaters of the Frieda River. North of Wabia hamlet in the headwaters of the Frieda River the beds consist predominantly of light-coloured subgreywacke with minor light grey phyllitic shale. The greywacke is composed mainly of volcanic detritus and contains much mafic material. It shows good graded bedding, and contains numerous angular clasts of dark grey or black siltstone, up to 15 cm long, set in a sandy matrix. The steep ridge behind the village appears to consist mostly of greywacke. Farther north there is a succession of interbedded volcanolithic greywacke and light grey slate and shale with minor hard red (jasper-like) siltstone, overlain by a lens of light buff limestone crammed with Eocene Foraminifera. The sediments to the north are finer in grain, and consist predominantly of light grey to red and green shale and siltstone. North of Unamo hamlet they are sheared and contorted and contain some interbeds of sandstone. Still farther north, in the lower reaches of the Kalibai Creek, the sequence consists of strongly sheared dark carbonaceous shale riddled with quartz veins.

Lagaip Beds
(new name)

The name Lagaip Beds was first used by Dekker & Faulks (1964, unpubl.) for fine-grained marine sediments which crop out in the Lagaip and Lai Rivers in the southeastern part of the map area. Similar fine-grained Lower Tertiary sediments north of the Central Range were also mapped by them as Lagaip Beds; in 1966, the northerly and northwesterly extension of these beds was mapped as Lagaip Beds (Dow et al., 1967, unpubl.). Since then, mapping has shown that the sediments north of the Central Range are in fact sufficiently distinctive to be mapped as a separate formation—the Salumei Formation.

The Lagaip Beds have been shown by later mapping (Smit, 1968, unpubl.) to extend westwards as far as the West Irian border.

Lithology. To west: black and dark grey slate, shale, and siltstone, commonly pyritic; minor subgreywacke; thick beds of quartz sandstone towards top of unit. To east: sediments lighter in colour and almost invariably calcareous; lenses of limestone and thin-bedded quartz sandstone common in places.
Distribution. Upper reaches of Lai River, along length of Lagaip River, and westwards to West Irian border. Fine-grained sediments in lower Lai and Sau Rivers near eastern margin of map area doubtfully referred to Lagaip Beds.
Derivation of name. Lagaip River.
Type section. Lower reaches of Lai River; no section measured.
Stratigraphic relationships. Bottom not seen, but similar sediments of Jurassic age in Strickland Gorge southwest of map area, rest non-conformably on granitic rocks; overlain, probably unconformably, by lower Miocene marine sediments.
Thickness. Not measured; about 3 000 m.
Fossils and age. Ammonites of Callovian (top of Middle Jurassic) age; Foraminifera ranging from Lower Cretaceous (probable Albian) to Middle and Upper Cretaceous and Upper Paleocene to middle Eocene found at scattered localities throughout map area.

The Lagaip Beds fall broadly into two units, but in view of the ruggedness of the terrain and the complex lateral variations in the formation in the head of the Lagaip River, it was not possible to map them separately. (1) The rocks west of Porgera are almost all dark grey and black fine-grained sediments which contain several thick beds of quartzite and quartz sandstone near the top. (2) East of Porgera the sediments are also predominantly fine-grained, but they are lighter in colour, commonly calcareous, and contain many patches of fine-grained limestone, most of which appear to be confined to one stratigraphic horizon in the Upper Cretaceous. Also included in the Lagaip Beds in this area are extensive beds of shale and siltstone containing thin beds of fine-grained quartz sandstone (Pl. 7, fig. 1).

Since the field work was completed, geologists of B.P. Petroleum Development Australia Pty Ltd have measured a section across an overturned syncline in the Lagaip Beds near Muriaga. Fine-grained sediments containing middle Eocene and lower Miocene Foraminifera were sampled (A. Findlay, pers. comm.); so the Lagaip Beds as mapped include younger beds than previously thought. The middle Eocene beds in the section are purple-red calcareous siltstone and shale which can probably be correlated with similar beds found in places along the upper Lagaip River between Lake Iviva and Mokasip Creek. These undoubtedly belong to the Lagaip Beds, so it seems certain that the Lagaip Beds extend well into the Eocene and are therefore comparable in age with the Salumei Formation (Fig. 3).

The status of the Miocene sediments in the section is less certain because Tertiary e Stage sediments a short distance to the south overlie the Lagaip Beds, almost certainly unconformably. As the rocks in the area are tightly folded and considerably faulted, an unconformity might well have been missed in the measured section, and it seems likely therefore that the section included a remnant of undifferentiated Miocene rocks similar to those mapped to the north.

Porgera and westwards. In the Porgera area the Lagaip Beds have been described (Ward, 1949, unpubl.; Horne, 1967, unpubl.) as steeply dipping grey to black fine-grained thinly bedded shale. The sequence also includes a little thin to medium-bedded quartz sandstone and a massive sandstone bed of unknown thickness, composed mainly of fine well sorted quartz grains.

West of Porgera the Lagaip Beds consist mainly of fine-grained dark shale and slate with a few coarser-grained beds of subgreywacke. The rocks are commonly well indurated, and small quartz veins are common, particularly in the slate. Most of the beds are steeply dipping and highly cleaved; they are much faulted and locally distorted and tightly folded. Syngenetic pyrite occurs throughout the sequence as nodules, veins, and scattered crystals up to 6 mm across. The boulders and pebbles in stream deposits are stained with iron oxides.

Ammonites (*Macrocephalites*) collected from loose boulders, but undoubtedly from within the formation, suggest an upper Callovian (top of Middle Jurassic) age (S. K. Skwarko, pers. comm.).

Farther west are similar dark grey siltstone and shale, which in most places are faulted and folded. Quartzite is prominent and appears to occur in one stratigraphic horizon.

The Lagaip Beds near Telefomin (southwest of the map area) consist mainly of dark grey and black slate and shale, interbedded with minor dark fine-grained and lighter-coloured greywacke. The black slate and shale are locally carbonaceous and the coarser-grained sediments contain detrital mica in addition to flakes of sericite which have been developed along the cleavage planes. In thick sequences of slate the cleavage has obliterated all trace of the bedding, but where greywacke beds are present, thin bedding can generally be seen. The angle between bedding and cleavage is up to 30°.

The sequence is tightly folded and the rocks are generally well indurated, but the metamorphic grade is low. Most of the finer-grained sediments have been transformed into slate, but in the coarse-grained greywacke beds only a widely spaced fracture cleavage has been developed. Some of the outcrops of massive slate contain thin beds of greywacke which have been boudinaged, with the long axes of the boudins parallel to the axes of nearby folds.

Andesite porphyry dykes intrude the Lagaip Beds; they are commonly metasomatically altered. Near the porphyry intrusions the slates contain numerous quartz veins and abundant veins and concretions of pyrite up to 30 cm wide.

Ammonites of probably Callovian age have also been collected from this area.

Quartz sandstone is an important constituent of the upper part of the Lagaip Beds in the Telefomin area. An incomplete section was measured as follows:

Thickness (m)	
150	Cliff of quartz sandstone, and feldspathic and lithic sandstone with a glauconitic matrix.
30	Medium to thick-bedded micaceous lithic sandstone and quartz sandstone with thin interbeds of dark siltstone.
15	No outcrop.
24	Thin-bedded light grey quartz-feldspar greywacke interbedded with dark micaceous siltstone.
30	No outcrop.
45	Medium to thin-bedded micaceous dark-coloured siltstone.

The quartz sandstone beds appear to be confined to the upper part of the Lagaip Beds and there is little doubt that with more detailed work they could be mapped as a separate unit.

East of Porgera. The Lagaip Beds cropping out along the Lagaip Fault Zone in the upper reaches of the Lagaip River, and along the Lai River, differ from those to the west: they are lighter in colour; most are calcareous and commonly contain limestone interbeds; and quartz sandstone makes up a much larger proportion of the section, both as massive beds up to 100 m thick, and as thin beds rhythmically interbedded with the shale.

Along the Lagaip Valley between Mokasip Creek and Kepilam, the Lagaip Beds show considerable lateral variation: they consist of light grey to medium grey calcareous shale and siltstone which grade into calcareous sandstone or marl and fine-grained limestone. Clean well sorted quartz sandstone beds, from 1 to 100 m thick, are found throughout this area, particularly in the west. Most are green or light grey and show no bedding; they are generally friable and contain glauconite in places.

The limestone is cream or grey, and fine-grained, and forms beds and lenses which are resistant to erosion and stand out as cliffs or strike ridges. It grades laterally and vertically into marl, calcareous siltstone, and calcareous sandstone, but appears to be confined to one stratigraphic horizon at least 300 m thick which extends from Muriaga to Kepilam. Foraminifera of Upper Cretaceous age have been found all along this horizon.

Along the south side of the Lai Valley between Lake Iviva and Tchak River, and along the Ambum River, the Lagaip Beds are similar to those of the upper Lagaip River. Fine-grained light blue or grey quartz sandstone is predominant; it is generally micaceous, commonly contains plant remains, and occurs as beds between 5 and 15 cm thick (rarely up to 60 cm), interbedded with subordinate shale and siltstone. Graded bedding, micro-cross-bedding, and load casts are common in places. The sandstone grades into grit and fine-grained quartz-pebble conglomerate.

The shale and siltstone are almost invariably calcareous and range from light grey to light blue, and more rarely from purple to red. They are generally subordinate to the sandstone, but locally beds up to 100 m thick contain only rare thin interbeds of sandstone. Ramifying calcite veins and scattered calcareous nodules are common; pyrite nodules up to 5 cm across have also been seen.

Fine-grained light grey or white limestone is characteristic of this area. It occurs as massive beds 5 to 60 cm thick; some rare flaggy beds up to 2 m thick are also present. Upper Cretaceous Foraminifera have also been found in the limestones, and they probably belong to the same stratigraphic horizon as those in the Lagaip River.

A cold mud spring occurs west of Wabag in a swamp formed on calcareous shale and limestone of the Lagaip Beds. Grey mud oozes out of the top of a mound which it has built 7½ to 9 m above the surrounding swamp. Pieces of calcite and calcareous shale and rare limonite nodules (probably oxidized pyrite nodules) have been rafted up by the mud.

Environment of deposition

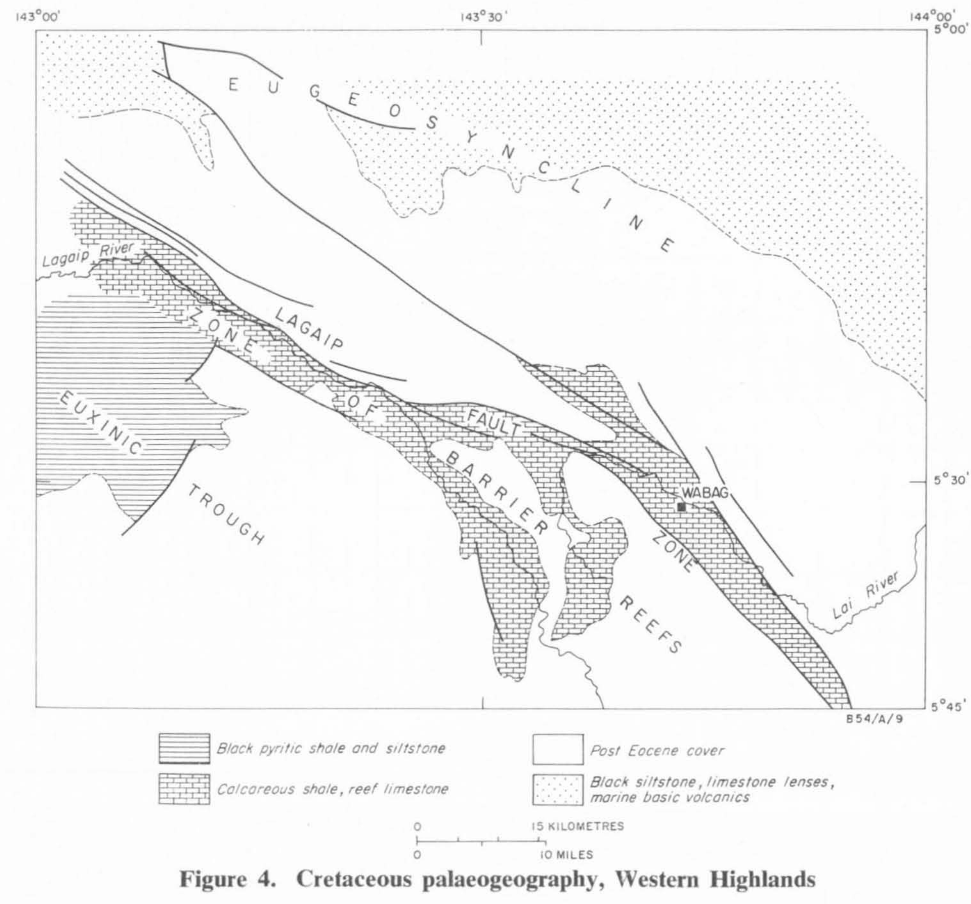

Figure 4. Cretaceous palaeogeography, Western Highlands

The southeastern part of the map area shows very well the contrasting depositional environments which existed during the Cretaceous and Eocene. North of what is now the Central Range, the Salumei Formation, which consists of turbidites, submarine volcanics, and limestone reefs, was laid down in a eugeosyncline (Fig. 4), and at the same time black pyritic shale and siltstone and some quartz sandstone were deposited in an euxinic environment in the Porgera area. The euxinic environment extended westwards as far as the West Irian border, and was apparently controlled by a fairly deep isolated fault trough in which circulation was restricted.

The Lagaip Fault Zone marks the boundary between the two environments, and it also probably forms the edge of the tectonically stable Australian continental block (see p. 72). This marginal zone is between 16 and 24 km wide, and the sediments deposited here differ markedly from the other two environments. It is postulated that it was a zone of shallow water, probably with discontinuous limestone reefs, which together with the continental slope to the north formed an effective barrier to the southward migration of volcanic detritus from the eugeosyncline in the north. The sediments of the zone—lenses and discontinuous beds of limestone up to about 100 m thick grading laterally into calcareous siltstone, shale, and sandstone, and interbedded quartz sandstone containing plant remains—are consistent with this picture of a shallow-water barrier zone.

Kumbruf Volcanics

The name Kumbruf Volcanics was originally proposed by Dow (1962, unpubl.) for a predominantly volcanic sequence of probable Upper Cretaceous age cropping out in the Simbai Valley (5°20'S, 144°34'E). The formation, which was subsequently described by Dow & Dekker (1964), consists predominantly of basaltic agglomerate with subordinate pillow lavas, black siltstone, calcareous siltstone, and tuffaceous sandstone.

Within the map area, the rocks exposed to the east of the Jimi Fault, between the Yuat and Clay Rivers (4°50'S, 143°58'E), are correlated with the Kumbruf Volcanics.

The Kumbruf Volcanics are not well exposed in the map area. They are highly altered and complexly deformed, and the complete stratigraphic sequence has not been established. Basic and intermediate volcanic rocks, though they make up less than half of the unit, are the most striking component. Shale, siltstone, and some greywacke form subordinate interbeds within the volcanics, but they also form thick sequences separating the main volcanic members. In a less complexly deformed sequence, these beds could probably be mapped separately.

The volcanic components range from basalt to andesite in composition, and consist mainly of agglomerate. The agglomerate is composed mainly of subrounded fragments of purple and green crystal tuff and lava set in a dark green highly indurated tuffaceous matrix. Glass shards and broken crystals of hornblende and pyroxene are common in the matrix. Dense welded tuffs, and possibly lava flows, with well developed flow structure are also common. A thick volcanic breccia composed mainly of large angular fragments of shale was also seen.

Typical of the volcanic sequence is the following section examined on the eastern side of the divide between the Yuat and Clay Rivers.

Thickness (m)	
15	Massive agglomerate composed of fragments of green and purple welded tuff set in a matrix of crystal tuff.
3	Red massive siltstone.
0.6	Subgreywacke and pebble conglomerate.
7.5	Light grey impure limestone.
15	Agglomerate.
3	Volcanic breccia and volcanic boulder conglomerate.
15	Red siltstone with an interbed of limestone about 4½ m thick.

The sedimentary rocks interbedded with the volcanic rocks are mainly red, green, and grey shale and siltstone, containing rare beds of green and grey highly indurated greywacke up to 1 m thick. Grey and pink partly recrystallized limestone occurs as lenses within the sedimentary rocks. Foraminifera and small shell fragments can be seen in the less recrystallized parts of the limestone lenses.

Dolerite and gabbro intrude the Kumbruf Volcanics, and where the country rocks are highly altered, these intrusives cannot be distinguished from the volcanic rocks. Ten kilometres east of the map area the rocks are hydrothermally altered, apparently as a result of a nearby diorite intrusion, which can be seen on the air-photographs to the east as an area of close dendritic drainage.

A sample of a limestone lens within the Kumbruf Volcanics was found by D. J. Belford (pers. comm.) to contain Foraminifera tentatively identified as *Marsonella* (Upper Cretaceous).

TERTIARY

TERTIARY a-b? STAGE (EOCENE)

Deposition of the Salumei Formation and Lagaip Beds continued into the Eocene.

At some time between the Eocene and middle Miocene the Salumei Formation was folded and metamorphosed to form the Salumei Formation (metamorphic phase).

Salumei Formation (metamorphic phase)

The metamorphic phase of the Salumei Formation (called here the Salumei metamorphics) crops out between the April and May Rivers; it is bounded on the north partly by the Frieda Fault and on the south by the Lagaip Fault Zone. The Salumei metamorphics consist of slate, phyllite, sericite schist, marble, altered basic and intermediate volcanic rocks, quartzofeldspathic sandstone, and subgreywacke. Some higher-grade rocks are present, including quartz-muscovite schist, and metavolcanics containing lawsonite-glaucophane assemblages which belong in the glaucophane schist facies of metamorphism.

The slate, phyllite, and sericite schist exhibit a strong cleavage which is commonly strongly folded or crenulated, and in many places they are riddled with small irregular and ramifying veins of quartz. Bedding can rarely be seen, but where present it is extremely contorted, and no consistent structural trends can be distinguished.

Only one specimen of the fine-grained metasediments, a slightly higher-grade quartz-muscovite schist, was examined in thin section. It is a fine-grained greenish grey rock consisting of angular grains of quartz (40%), set in a recrystallized foliated matrix of muscovite, quartz, plagioclase, and a chlorite with anomalous bright purple birefringence. The accessories are biotite, epidote, and iron oxides. The rock is probably an altered fine-grained greywacke or tuffaceous sandstone.

Beds of massive quartz sandstone and subgreywacke between 15 cm and about 1 m thick are common throughout the Salumei metamorphics. They are greenish grey or cream in colour and invariably fine-grained and well sorted. Quartz sandstone is predominant. It is composed of subangular to subrounded grains of quartz, some angular grains of plagioclase, schist, and biotite, set in a recrystallized matrix (up to 10%) of chlorite, calcite, epidote, albite, sericite, pumpellyite(?), and accessory sphene and iron oxides.

With an increase in the proportion of matrix the sandstone grades into recrystallized subgreywacke composed of recrystallized grains of quartz and a few fragments of chert and phyllite set in a recrystallized matrix (25%) of sericite and quartz, with some chlorite, biotite, prehnite, and epidote.

Volcanic rocks, which show a considerable range in the degree of alteration, are common. The less altered varieties can be seen just west of Bamali River, where massive black slate is interbedded with layers up to 30 m thick of medium to thick-bedded dark basic tuff and dark tuffaceous subgreywacke. The tuff commonly grades into thick beds of angular coarse to medium-grained subgreywacke. The shale has a fracture cleavage roughly parallel to the axial plane of the folds. The cleavage is commonly only poorly developed, and it is clear that the sequence was more competent than the surrounding massively bedded slate and phyllite, which have a well developed cleavage.

In the Bamali River area the volcanics and subgreywacke are commonly still recognizable, although they have been sheared, cleaved, and in places contain porphyroblasts of feldspar, chlorite, and sericite. The fine crystalline tuffs have been texturally more affected by the metamorphism, and have commonly been converted into greenschists interbedded with more massive altered agglomerates and basic flows.

The crystal tuffs consist of broken crystals and fragments of plagioclase (altered to albite), quartz, fine-grained volcanic rocks, and some fragments of altered pyroxene and orthoclase. Interstitial calcite, epidote, chlorite, and zeolites are present in varying amounts. With increasing metamorphism they grade into recrystallized tuffs in which the original textures have been almost completely obliterated.

Farther west in the vicinity of the Gufug Gneiss, metamorphism was apparently much more intense and even the coarser-grained beds of the Salumei metamorphics have been markedly affected. The semi-schistose metagreywackes and metavolcanics are interbedded with phyllite and slate. Intraformational conglomerate, consisting mainly of pebbles and fragments of slate set in a schistose matrix, is also present. The pebbles have been flattened to an extreme degree parallel to the cleavage planes.

Some of the meta-igneous rocks in the headwaters of the Bamali River contain glaucophane and lawsonite, which are indicators of high-pressure metamorphism. Two of the rocks are probably altered basic crystal tuff or fine-grained agglomerate. They consist mainly of masses of fibrous actinolite, aggregates of granular euhedral or subhedral lawsonite, and sheaves of glaucophane. Sodic pyroxene (omphacite?) occurs as clumps of anhedral crystals. Quartz, calcite, epidote, albite, and sphene are present, and minute crystals associated with the glaucophane and actinolite are possibly pumpellyite.

Two other specimens appear to be metamorphosed microdiorite. They show a distinct preferred orientation, and consist of recrystallized quartz and quartz-albite aggregates, separated by fine-grained felted masses of actinolite, chlorite, and calcite, with some clinozoisite, lawsonite, and glaucophane.

The contact between the Salumei metamorphics and the Gufug Gneiss, where seen, was faulted or consisted of a zone of small faults. Field evidence suggests that there may be a gradual transition from greenschists of the Salumei metamorphics to coarse glaucophane schist, garnet gneiss, and eclogite of the Gufug Gneiss. Thus, small outcrops of glaucophane schist, garnet-rich amphibolite, and eclogitic gneiss occur within the slate and phyllite close to the mapped contact. Similarly outcrops of sericitic subschist and slate have been found within the Gufug Gneiss. The anomalous outcrops in both units may represent fault wedges, but they could equally well be part of a transition zone.

Although no fossils have been found in the Salumei metamorphics, they are undoubtedly the metamorphosed equivalent of the Salumei Formation. Between the Bamali and April Rivers, fault blocks of indurated Salumei Formation occur within the metamorphic phase. In this area there is also a gradual change in the degree of metamorphism, particularly in the finer-grained sediments. Over a zone about 8 km wide, hard indurated jointed siltstone and shale, with an incipient cleavage, grade into well cleaved slate and phyllite, with abundant small quartz veins parallel to the cleavage planes. In the transitional zone the limestone lenses are partly or wholly recrystallized to marble, but the interbedded massive volcanics are very little altered and show no cleavage. Fine crystalline tuffs were seen to grade into chloritic and sericitic rocks with a marked foliation. As the microfauna from the unmetamorphosed parts of the Salumei Formation west of longitude 142°50′E are all Eocene, the metamorphosed parts are also probably Eocene.

Gufug Gneiss
(new name)

The name Gufug Gneiss has been given to an interesting suite of coarse glaucophane-bearing schist (Pl. 7, fig. 2) and gneiss and associated eclogite (Pl. 8, fig. 1) cropping out within the metamorphic phase of the Salumei Formation.

Lithology. Schist and gneiss with variable proportions of glaucophane, epidote, garnet, and white mica; eclogite.
Distribution. Narrow fault wedges along north front of Central Range between Leonhard Schultze and Frieda Rivers.
Derivation of name. Gufug Creek (142°20′, 4°50′), a tributary of Leonhard Schultze River.
Type area. Gufug Creek.
Stratigraphic relationships. Apparently occurs as fault wedges in Salumei metamorphics, but there is some evidence which suggests a transition from Gufug Gneiss to Salumei metamorphics.
Age. Not known; probably equivalent to Salumei metamorphics (i.e. Cretaceous? and Eocene). Metamorphism probably post-Eocene and pre-middle Miocene.

The principal rock types are hard coarsely crystalline blue and green schist and gneiss, containing glaucophane, epidote, garnet, and white mica in varying proportions. Minor eclogite, composed mainly of green clinopyroxene and pink garnet porphyroblasts up to 3 cm in diameter, and some quartz and feldspar-bearing glaucophane schist, blue-green amphibolite, calcite and dolomite-bearing schist, and hard metaserpentinite (Bowenite) are also present.

The Gufug Gneiss appears to have been derived mainly from basic igneous rocks, tuffaceous sediments, calcareous and dolomitic sediments, and shales, similar to those of the Salumei Formation. Metamorphism has been of the high-pressure/low-temperature glaucophane schist type (Fyfe, Turner, & Verhoogen, 1959), which has produced similar rocks elsewhere in the circum-Pacific region.

Stable mineral assemblages in the Sepik glaucophane schists can be divided into three main types: (1) glaucophane-lawsonite, (2) glaucophane-epidote, (3) sodic pyroxene-garnet, although intermediate types are common.

The *glaucophane-lawsonite assemblages* are locally developed within greenschist facies rocks of the Salumei metamorphics and are not found within the Gufug Gneiss. They are basic metavolcanic rocks that are texturally little altered. Other minerals in this assemblage include quartz, albite, clinopyroxene, epidote, actinolite, chlorite, white mica, calcite, sphene, and pumpellyite(?). Aragonite has not been identified. The pyroxenes appear to be relict, and range in composition from augite to jadeitic pyroxene (indicated by d221 spacings from X-ray powder photographs). In several specimens actinolite seems to be in stable association with glaucophane.

The *glaucophane-epidote assemblages* are coarsely crystalline and constitute a large part of the Gufug Gneiss. In addition to plentiful glaucophane and epidote, the following minerals are common: quartz, sodic plagioclase, sodic pyroxene, zoisite, garnet, phengitic muscovite, paragonite, chlorite, calcite, dolomite, sphene, rutile, and apatite. Aragonite and lawsonite have not been identified. Some of the glaucophane is very pale, but much of it is strongly coloured; some consists of crossite (OAP = 101). Blue-green amphibole is present in a few specimens and in one case is rimmed with crossite. The pyroxene is generally pale green, and is probably similar in composition to the eclogitic pyroxenes. Colourless jadeitic pyroxene is associated with quartz in at least one specimen, indicating metamorphic pressures in excess of 4 kilobars (e.g. Fyfe & Mackenzie, 1969). Garnet is commonly associated with glaucophane, epidote, and quartz and usually shows some alteration to chlorite. However, some chlorite appears to be stable in the glaucophane-epidote assemblages.

Paragonite (d001 19.2A) and phengitic muscovite (d001 19.8A) are common and co-exist in several specimens. Dolomite and calcite are common, both singly and together, and in some cases make up the bulk of the rock.

The glaucophane-epidote assemblages appear to have been derived from the basic igneous rocks, greywacke, and argillaceous and carbonate-rich sediments of the Salumei Formation.

The *sodic pyroxene-garnet assemblages* (eclogite) are intimately associated with the glaucophane epidote assemblages. Euhedral pink garnet porphyroblasts up to 3 cm in diameter are embedded in a fine-grained granoblastic matrix of green pyroxene. The approximate proportions of the jadeite, acmite, and diopside end members in pyroxenes from four specimens were obtained by measuring the refractive index and the d221 spacings; they were found to fall within the aegerine-augite, chloromelanite, and omphacite fields (Essine & Fyfe, 1967). Glaucophane, epidote, zoisite, and phengitic micas are also common major components; chlorite, sphene, rutile, quartz, sodic plagioclase, and apatite are accessories.

Glaucophane-bearing assemblages are now known from a number of widely dispersed localities within the New Guinea Mobile Belt. Mineral assemblages in the stone implements described by Verhofstad (1966) are of the lawsonite-glaucophane type, and contain sodic pyroxene and pumpellyite(?). They probably originated in the northern fall of the central ranges of West Irian 240 km west of the Sepik area.

A crossite-sericite schist has been reported from the Cyclops Mountains on the north coast of West Irian (Gisolf, 1921), and W. B. Dallwitz (pers. comm.) has reported a lawsonite-'richterite'-leucoxene assemblage from the Waria River in western Papua. Recently, metavolcanics containing glaucophane, lawsonite, and sodic pyroxene were collected by the Bureau of Mineral Resources near Mount Suckling in eastern Papua (H. L. Davies, pers. comm.).

The wedges of Gufug Gneiss seem to be bounded by faults, some of which do not appear to have great displacement. South of Gufug Creek the bounding fault appears to have a small throw and the boundary with the Salumei metamorphics may be transitional. However, it is evident that faulting has played a major part in the positioning of these bodies. A number of isolated lenses and blocks of eclogite and gneiss up to 15 m across were found within low-grade Salumei metamorphics outside the main bodies of Gufug Gneiss, particularly to the north of the easternmost fault wedges. These small lenses are probably tectonic blocks that have migrated up fault zones together with small lenses of serpentenite with which they are commonly associated. The boundaries of these tectonic blocks are generally sheared.

Metamorphism of the Gufug Gneiss probably occurred at deeper levels within the Mobile Belt than the Salumei metamorphics with which it is now associated. The phyllite and subschist of the Salumei metamorphics are mainly low-grade greenschist facies, although glaucophane-lawsonite assemblages occur locally in metavolcanics west of Bamali River. The lack of lawsonite and the coarse textures in the Gufug Gneiss may indicate a somewhat greater metamorphic temperature than the temperature of formation of the glaucophane-lawsonite assemblages.

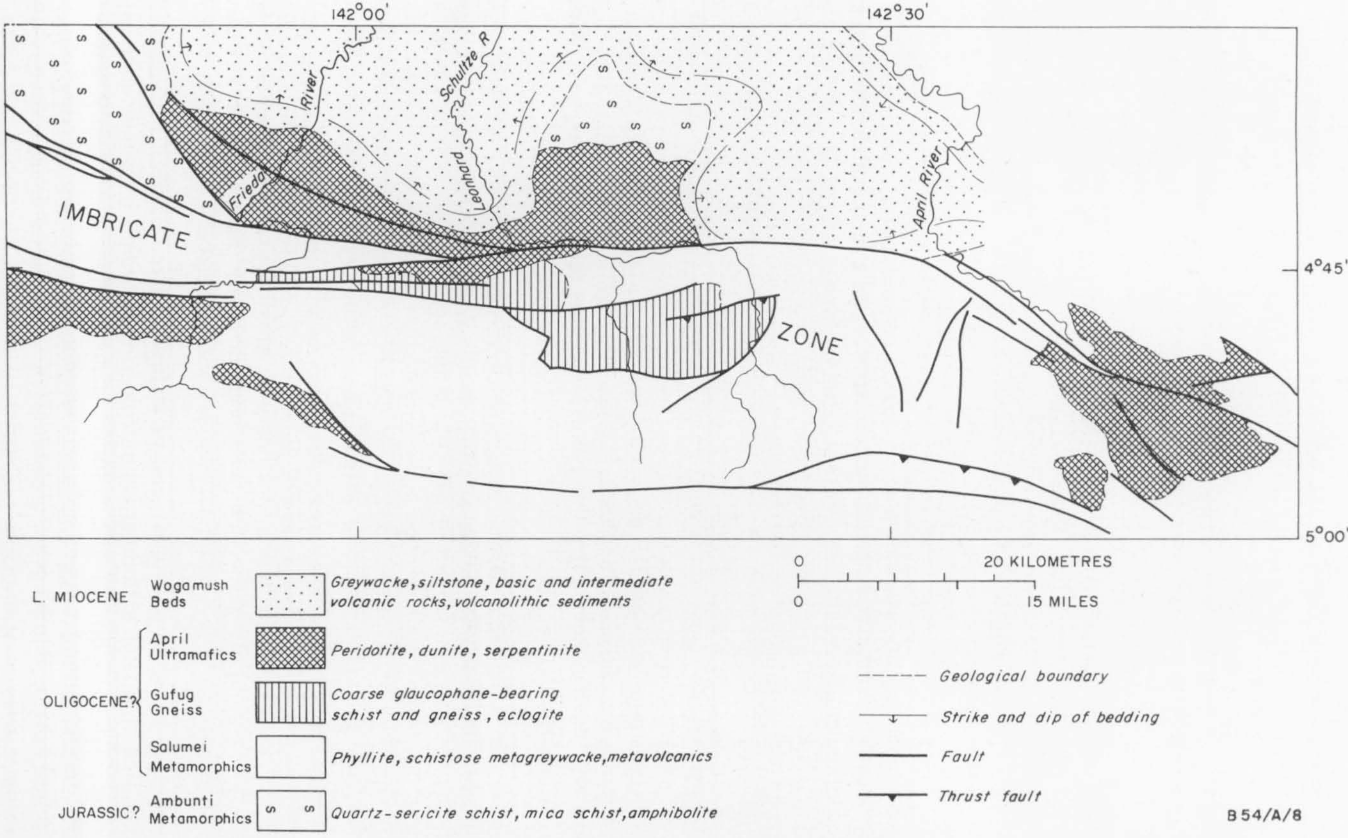

Figure 5. Distribution of glaucophane schists

The Salumei metamorphics and the Gufug Gneiss are confined to a unique flexure (Fig. 5) where the trend of the Frieda Fault Zone changes from northwest to west. The main movement on the fault zone was probably right lateral, and if this is the case it would cause the flexure to be a region of compression; and the very local development of the Salumei metamorphics would thus be explained. It is conceivable in such an environment that tectonic over-pressures could be produced to form the high-pressure metamorphics characteristic of the Gufug Gneiss.

The conspicuous absence of dioritic intrusions in this area would also be explained if the area has been one of high compression.

The Sepik glaucophane schists closely resemble those from California, New Caledonia, and the Celebes, both in mineral composition and geological setting. The glaucophane-lawsonite assemblages closely correspond to the type II and III schists of Coleman & Lee (1963) from the Cazadero area in California, and to extensive glaucophane schists within the greenschists of northwest New Caledonia (Coleman, 1967).

The coarsely crystalline glaucophane-epidote and eclogitic assemblages are well represented in California (type IV of Coleman & Lee), and in New Caledonia. As in many places along the Pacific margin they are associated with ultramafic intrusion, and probable transcurrent faulting is apparent. The eclogitic assemblages are thought to be produced under the same temperature and pressure conditions as the glaucophane-epidote assemblages, but under low partial pressure of water vapour, that is, under anhydrous conditions (D. Green, pers. comm.).

TERTIARY e STAGE (LOWER MIOCENE)

After a period of erosion in the lower Tertiary, sedimentation commenced over the whole of the map area early in the Tertiary e Stage: tuffaceous arenites (the Pundugum Formation) were laid down north of the Lagaip Fault Zone, while a predominantly calcareous lutite sequence (the Yangi Beds) was being laid down to the south.

These two formations are separated by a belt, approximately 20 km wide, of Miocene rocks along the Lagaip Fault Zone which cannot be referred to either unit; these sediments have been mapped as Miocene (undifferentiated) and they probably include, in places, lateral equivalents of the Burgers Formation (see p. 51). The sediments are predominantly calcareous sandstone and siltstone.

Pundugum Formation
(new name)

The name Sau Beds was proposed by Dekker & Faulks (1964, unpubl.) for a thick sequence of arenaceous beds overlying the Salumei Formation in the eastern part of the South Sepik region. Subsequently (Dow et al., 1967, unpubl.) incorporated the unit in the Lagaip Beds as the Sau Greywacke Member. Later work has shown that these beds warrant formation status, and to avoid confusion it is therefore proposed that the Sau Beds be redefined and renamed the Pundugum Formation.

Lithology. Greywacke, tuffaceous greywacke, siltstone, fine pebble conglomerate; some small lenses of limestone.
Distribution. Arafundi watershed, headwaters of Maramuni, Tarua, and Sau Rivers, and small faulted wedges in headwaters of the Korosameri and Salumei Rivers. Not mapped farther west, but small fault wedges probably occur in Salumei Formation. Similar sediments in Sau Valley also mapped as Pundugum Formation.
Derivation of name. Pundugum Village in headwaters of Arafundi River (143°35', 4°50').
Type section. Arafundi Valley between Karawari Fault in south and Imboin village in north. Near Pundugum village.
Stratigraphic relationships. Overlies Salumei Formation, probably with angular unconformity; overlain, probably unconformably, by Karawari Conglomerate in type area and by Tarua Volcanic Member of Burgers Formation to south.
Thickness. About 4 000 m estimated from air-photographs in Kompiam area (Dekker & Faulks, 1964, unpubl.), but part of formation possibly repeated by faulting. Much thinner in Pundugum area, where only 300 m was measured, with a possible maximum of about 900 m.
Age. Tertiary e Stage (upper Oligocene to lower Miocene).

The Pundugum Formation in the type area consists of coarse to medium-grained sediments underlying the Karawari Conglomerate. The lower part of the formation consists mainly of light to dark grey micaceous sandstone, siltstone, and mudstone, with interbedded red and cream siltstone, and some quartz-pebble conglomerate. The upper part is coarser in grain, and contains many thick beds and large lenses of fine pebble conglomerate, coarse subgreywacke, and tuffaceous sandstone. The conglomerate contains pebbles of quartz, microdiorite, and indurated shale. Although well indurated these beds are not metamorphosed and are only gently folded.

To the south, where it is exposed in the headwaters of the Sau, Tarua, and Maramuni Rivers, the formation is much thicker, and consists of up to 4 000 m of micaceous greywacke and interbedded siltstone, which become tuffaceous towards the top of the formation. Farther west in the headwaters of the Salumei and Korosameri Rivers the sediments are mainly feldspathic subgreywacke and tuffaceous sandstone, with some lenses of coralline limestone.

The base of the formation has been arbitrarily placed where the predominantly fine-grained beds of the Salumei Formation give way to arenites. The contact with the overlying Karawari Conglomerate is rarely seen as it is masked by the large flanking talus slopes, but in the one well exposed section the contact appears to be conformable. Regional considerations, however, suggest that the contact is an unconformity (see p. 51). Where volcanic rocks are present in the Karawari Conglomerate, the top of the Pundugum Formation is placed at the base of the first volcanic bed, which generally corresponds fairly closely with the first break in slope below the prominent cliffs which make up most of the Karawari Conglomerate. Where the volcanic rocks are absent the base of the first massive conglomerate bed marks the top of the Pundugum Formation.

The contact between the Pundugum Formation and the overlying Burgers Formation to the south is similar in all respects to the contact with the Karawari Conglomerate, and the boundary is defined in the same way (see p. 51).

Limestone lenses within the formation contain Tertiary e Stage Foraminifera in the headwaters of the Korosameri and Salumei Rivers, and pebbles of Eocene limestone have been found in a conglomerate near the base of the formation in the Sau River. The formation cannot be younger than Tertiary e Stage because the basal parts of the overlying formations have been dated as Tertiary f_{1-2} Stage. The age of most of the Pundugum Formation is therefore Tertiary e Stage, though it is possible that the lowermost beds are slightly older.

The greater proportion of conglomerate and tuffaceous sediments in the upper part of the Pundugum Formation testify to the quickening of volcanic activity and consequent shallowing of the seas towards the end of the Tertiary e Stage. The volcanic activity reached a climax in the Tertiary f_{1-2} Stage, when the volcanic rocks of the Karawari Conglomerate, Burgers Formation, and Wogamush Beds were laid down.

Detailed description

Light to dark grey mudstone, siltstone, and sandstone, interbedded with red and cream siltstone, have been mapped near Pundugum hamlet. The dark siltstone and sandstone are micaceous; and the sandstone is generally lighter in colour because it is composed predominantly of fragments of quartz and feldspar (specimen 1192). The bedding ranges from massive to thin-bedded; in the massive layers thin micaceous lenses commonly occur parallel to the bedding. In the micaceous lithic sandstone, zones of scattered quartz pebbles and layers of fine well rounded pebble conglomerate are common. The pebbles are mainly of quartz, but also of dark grey, green, and red indurated shale. The sandstone though subordinate forms a considerable part of the unit throughout.

A section of the uppermost part of the formation is exposed in the same area. The sequence, which is about 100 m thick, consists of sandstone and interbedded siltstone overlain by poorly sorted boulder conglomerate interbedded with and overlain by sandstone and siltstone. The lower sandstone ranges from light to dark grey and contains zones of scattered pebbles and lenses of pebble conglomerate. The siltstone interbeds range from thin to medium-bedded and from blue-green to grey. The massive boulder conglomerate contains boulders and pebbles of microdiorite, dark grey fine-grained sandstone, dark grey-black indurated siltstone and mudstone, red and pink siltstone, and quartz, but no basic volcanics are present. The sandstone interbedded with and overlying the conglomerate is medium-bedded, grey, and micaceous; the siltstone is blue-grey. These beds grade into green tuffaceous sandstone and siltstone, crystal tuffs, and agglomerate of the Karawari Conglomerate.

Farther downstream and west of the Arafundi River outcrops of the Pundugum Formation consist of coarse-grained micaceous lithic sandstone interbedded with pebble conglomerate and grey and red siltstone. The outcrops are overlain by the agglomerate and minor basalts of the Karawari Conglomerate. Downstream along the Arafundi River the overlying pyroclastic rocks are interbedded with pebble and boulder conglomerate and micaceous sandstone and siltstone, which testify to the rapid vertical variation in the Karawari Conglomerate.

The section below the Tarua Volcanics in the Kompiam area is typical of the Pundugum Formation in the headwaters of the Sau, Tarua, and Maramuni Rivers. It was traversed by Dow (1961, unpubl.) who measured the thickness on air-photographs:

Thickness (m)	
	(top)
1 050	Dark grey and blue highly indurated greywacke, and tuffaceous sandstone which grades into waterlaid tuff near the top. The most common rock type consists of subangular fragments of basic igneous rocks, feldspar, and ferromagnesian minerals chaotically dispersed in a fine tuffaceous matrix. The beds range from thin-bedded to massive and are interbedded with laminated and thin-bedded siltstone, which constitutes about one-third of the sequence. Small lenses of argillaceous limestone up to 9 m thick are common in this member near Kompaim; they contain gastropods, bryozoans, and indeterminate Foraminifera.
600	This interval is poorly exposed on the line of traverse. It consists mainly of arenaceous sediments similar to the above, intruded by many gabbro and dolerite dykes.
900	Mainly conglomerate, with well rounded pebbles of greywacke, siltstone, and quartz, in a sandstone matrix. Micaceous greywacke, and peaty claystone and siltstone, containing wood fragments and other carbonized vegetable matter, make up nearly half the interval.
1 500	Mainly thick-bedded coarse to medium-grained micaceous greywacke with thin interbeds of shale and siltstone. The greywacke is dark-coloured and consists of subrounded fragments of greywacke, siltstone, chert, and quartz, set in a matrix of fine-grained siltstone. Thick lenses of conglomerate are common; they consist of schist, quartz greywacke, and siltstone, in a sandstone matrix. Carbonaceous material is common throughout the section.

It is unlikely that the greatly increased thickness in this area is due to repetition by faulting, as the air-photographs show that the formation is between 2 700 and 3 900 m thick along the length of the Central Range between the headwaters of the Korosameri River and the Sau River.

A notable feature of the formation in the Sau River is the presence of conglomerate over 300 m thick about 100 m above the base. It consists of well rounded pebbles and cobbles of limestone, gabbro, and some indurated sediments, set in a matrix of coarse greywacke. The presence of Foraminifera in the pebbles of limestone testifies to a period of erosion between the deposition of the Salumei and Pundugum Formations.

In the headwaters of the Korosameri River, north of Kasagali, a highly indurated green conglomerate is doubtfully referred to the Pundugum Formation. It consists of quartz, chert, and altered basic rocks in a green grit matrix; the pebbles appear to have originally been well rounded, but most are now distorted. The conglomerate is near-vertical and about 1 000 m thick.

Farther north, near the top of the ridge between Yafe Creek and Wisas River, a similar but much less indurated conglomerate crops out. The outcrop was too small to map, but probably belongs to the Pundugum Formation.

Yangi Beds
(new name)

Yangi Beds was the name proposed by Dekker & Faulks (1964, unpubl.) for Miocene sediments in the southern part of the map area. They grade northwards into the Tibinini limestone member.

Lithology. Mudstone, marl, calcareous siltstone, sandstone; interbeds of limestone.
Distribution. Dissected plateau forming divide between Lagaip and Andebare Rivers in southern part of map area; southern and western extensions not mapped.
Derivation of name. Mount Yangi at head of Andebare River.
Type area. Headwaters of Andebare River.
Stratigraphic relationships. Overlies Lagaip Beds, probably unconformably; grades northwards into Tibinini limestone member.
Thickness. About 1 500 m.
Fossils and age. Tertiary e Stage Foraminifera found in Waga River; uppermost beds probably Tertiary f_{1-2} Stage.

Dekker & Faulks (1964, unpubl.) describe the Yangi Beds as follows: 'In the McNicoll Range [10 km] south of Porgera, thick limestone beds containing chert are interbedded with calcareous shale. Grey friable sandstone containing carbonaceous plant remains also contains thin interbeds of shale. Farther to the south in the headwaters of the Andebare River, at least 8 000 feet [2 400 m] of interbedded mud, silt, sand, and chalk were measured. These sediments are exceedingly rich in foraminiferal remains. The chalky limestone has a distinctly foetid odour, although on analysis it was found to contain no hydrocarbons'.

A summary of the type section, measured by chain and compass in the head of the Andebare River, is given by Dekker & Faulks:

(sequence incomplete)

Thickness (m)	
330	Fine grey muddy siltstone
420	Grey siltstone with calcareous cement
	(Probable faulted synclinal axis)
450	Massive grey foraminiferal mudstone.
450	Calcareous muddy silt and sandstone. Limestone bed near base.
	(Probable faulted anticlinal axis)
240	Calcareous sandstone with chalk and calcilutite beds. Some limestone beds near top.
120	Muddy sandstone.
180	Grey massive mudstone.

Though the beds along the line of section all dip to the north, the air-photographs show quite plainly that they have been folded and faulted. The measured section therefore consists of the same 900 m of sediments repeated by a syncline and anticline which have been overturned to the south and faulted along their crest and keel.

The thickness of the Yangi Beds cannot therefore be determined accurately, but examination of the air-photographs indicates that the total is not likely to exceed 1 500 m.

Tibinini limestone member

Dekker & Faulks (1964, unpubl.) used the name Tibinini Limestone for the very thick limestone which forms spectacular cliffs on the south side of Lagaip Valley. It is here described as a member of the Yangi Beds.

Lithology. Grey to white, generally fine-grained limestone; some interbeds of calcareous shale.
Distribution. Along south side of Lagaip Valley between Porgera and Kepilam.
Derivation of name. Tibinini village.
Type area. Cliffs north of Mount Kaijende.
Stratigraphic relationships. Overlies Lagaip Beds unconformably; probably grades laterally into Yangi Beds.
Thickness. Not measured; betwen 900 and 1200 m.
Fossils and age. Uppermost beds on Mount Kaijende contain Tertiary f_{1-2} Stage Foraminifera; only long-ranging Miocene forms found in rest of unit, but lower half probably Tertiary e Stage.

The Tibinini limestone member forms the spectacular cliffs (Pl. 8, fig. 2) which bound the head of the Porgera Valley and the southern flank of the Lagaip Valley near Tibinini Village. The elevated surface of the limestone is weathered into a karst topography on a gigantic scale—spires and arêtes of limestone up to 100 m high are common on Mount Kaijende.

The Tibinini limestone member consists of about 900 to 1 200 m of massive to thick-bedded fine-grained grey to white limestone with interbeds of marl and some chalky beds crowded with macrofossils, including corals. The limestone has generally been recrystallized and diagnostic Foraminifera are uncommon, but Tertiary f_{1-2} Stage forms were found in situ near the summit of Mount Kaijende (sample supplied by Dr P. Williams, ANU), and in loose boulders from Mount Kaijende (sample supplied by Dr M. Bik, CSIRO Land Research Unit).

Near Kepilam the Tibinini limestone member can be seen on the air-photographs to unconformably overlie a large steep fold in the Lagaip Beds. However, the contact has been seen in only a few places over a distance of only a few metres, and no unconformity was detected. The youngest fossils found in the Lagaip Beds are Eocene, and the absence of lower Oligocene strata is probably due to erosion before the lower Miocene.

Though evidence is lacking, it seems probable that the Tibinini limestone member grades laterally into the Yangi Beds.

Miocene (undifferentiated)

Sediments of lower Miocene age (probably Tertiary e stage), which cannot be referred to either the Pundugum Formation or the Yangi Beds, have been mapped as 'undifferentiated Miocene'.

They crop out as a belt 16 to 24 km wide, along the northern side of the Lagaip Valley between the head of the Salumei River and the southern margin of the map area.

The rocks are only slightly indurated and consist almost entirely of calcareous sediments—mainly calcareous siltstone, marl, and calcareous quartz sandstone. They are generally thin-bedded to medium-bedded, and are commonly highly contorted, mostly as a result of slumping before consolidation.

Red and green marl and calcareous siltstone appear to be restricted to one stratigraphic horizon overlying a thick bed of limestone which forms prominent hogbacks in the vicinity of Yeim village. The limestone is indurated, cream or less commonly pink, and is invariably fine-grained; it grades vertically and horizontally into indurated marl, and has a maximum thickness of about 300 m.

The southern part of the belt is made up of finer-grained sediments more akin to the Yangi Beds. A small part of the section was measured by Dekker & Faulks (1964, unpubl.).

Thickness (m)	
135	Thin-bedded calcareous shale.
135	Fine-grained white limestone.
210	Grey fine-grained thin-bedded calcareous shale.

TERTIARY f_{1-2} STAGE (MIDDLE MIOCENE)

The increased volcanic activity near the end of the Tertiary e Stage reached a climax during the f_{1-2} Stage when discontinuous island arc volcanics were laid down across the map area. The volcanic rocks and derived coarse-grained sediments have been mapped as the Burgers Formation, Karawari Conglomerate, and Wogamush Beds.

The upper part of these formations may be younger than the f_{1-2} Stage, but the only Foraminifera found are long-ranging Miocene genera. The formations probably do not extend into the upper Miocene.

Karawari Conglomerate
(new name)

Karawari Conglomerate is the name chosen for a sequence of massive conglomerate and volcanic rocks, which crops out between the Arafundi and Wogupmeri Rivers, along the middle reaches of the Karawari River.

Lithology. Pebble and cobble conglomerate, pebbly sandstone; thick lenses of basic and intermediate volcanic rocks at base.
Distribution. Headwaters of Karawari River.
Derivation of name. Karawari River.
Type area. Arafundi River; no type section measured.
Stratigraphic relationships. Relationships with underlying units not clear; equivalent of Tarua Volcanic Member and Burgers Formation in south, and of Wogamush Formation to west of map area.
Thickness. At least 600 m.
Fossils and age. No fossils found. Overlies upper Oligocene to lower Miocene (Tertiary e Stage) Pundugum Formation and almost certainly of same age as Burgers Formation (Tertiary f_{1-2} Stage).

The Karawari Formation crops out as large gently dipping massive slabs, terminated by vertical cliffs up to 600 m high. Only the basal part of the formation can be examined in outcrop; information on the upper part of the sequence is based on boulders which have survived transport in the rivers.

The boundary between the Pundugum Formation and the Karawari Conglomerate appears to be gradational, and is placed arbitrarily at the lowermost cliff-forming conglomerate, even though there are conglomerate beds within the Pundugum Formation. Where volcanic beds are present, the boundary is placed at their base.

The Karawari Conglomerate consists mainly of massive pebble and boulder conglomerate, basic to intermediate agglomerate and lava, and tuffaceous sandstone. The lithology, however, varies considerably, both laterally and vertically.

The larger components in the polymict conglomerate are generally well rounded. The beds are characteristically massive, and form spectacular cliffs up to 600 m high, cleft by deep narrow ravines. Bedding is defined by vague lenses of sandstone, pebbly sandstone, and minor grey and red siltstone.

In the Arafundi area volcanic rocks are present in the basal part of the formation. The overlying conglomerate is composed almost entirely of volcanic rocks set in a tuffaceous matrix, and grades into agglomerate and crystal tuff. In the Karawari River there are very few pebbles of volcanic rock in the conglomerate and most of the pebbles and boulders consist of quartz, indurated sedimentary rocks, schist, limestone, and microdiorite. Boulders of well sorted quartz-pebble conglomerate occur also in the upper part of the unit in the Arafundi area.

The conglomerate is composed mainly of rounded fragments of basalt and andesite agglomerate up to 30 cm across, set in a matrix of crystal tuff (Pl. 9, fig. 1). The presence of basalt lava flows is inferred from the abundance of large basalt boulders in many of the tributaries of the Arafundi River, but they were not found in situ.

The volcanic rocks range from basalt to andesite, basaltic andesite being most common. The basaltic andesite consists of phenocrysts of plagioclase (An_{40-60}), orthopyroxene, and clinopyroxene, set in a groundmass of glass, iron oxides, and microlites. Perlitic cracks have been noted in the more glassy varieties, and trachytic texture is common in the less glassy rocks. The basaltic andesite grades into andesite or olivine basalt. In the andesite the composition of the plagioclase is about An_{40}.

The basalt consists of phenocrysts of plagioclase, clinopyroxene, and olivine set in a crystalline groundmass of feldspar, pyroxene, iron oxide, and generally olivine.

The Karawari Conglomerate is believed to be a correlative of the Burgers Formation and the Wogamush Beds. The three formations crop out as isolated units, but all were formed by the rapid deposition of coarse detritus derived from andesitic and basaltic volcanoes. They overlie Tertiary e Stage and older rocks, and both the Wogamush Beds and Burgers Formation contain Tertiary f_{1-2} Stage Foraminifera.

The relationship between the Karawari Conglomerate and the underlying Pundugum Formation is not fully understood. Much of the evidence, given below, indicates a hiatus between the two formations, but such a break could not be detected in the continuous sections across the boundary which were examined in the field. The nature of the deposits, composed as they are of lensing conglomerate and agglomerate, could easily mask an unconformity, particularly if the hiatus was caused by a series of small earth movements during deposition.

The evidence of the hiatus is as follows:

(1) Tertiary e Stage limestone pebbles are found in the Karawari Conglomerate.

(2) In the middle Karawari River and Arafundi River area the Pundugum Formation is much thinner than to the south, probably as a result of erosion before the deposition of the Karawari Conglomerate.

(3) The Maramuni Diorite intrudes the Pundugum Formation but not the upper part of the Karawari Conglomerate, and pebbles of microdiorite, almost certainly derived from the Maramuni Diorite, are found in the Karawari Conglomerate in places.

(4) The Karawari Conglomerate rests directly on Ambunti Metamorphics near Amboin. The Pundugum Formation is absent in the map area.

It is possible that faulting started in lower Miocene time (Pundugum Formation), and that while the Maramuni Diorite was being emplaced at depth, sedimentation of the Karawari Conglomerate continued in downfaulted areas. The conglomerate beds would have resulted from the accelerated erosion which followed uplift of the horsts. At a fairly early stage, erosion exposed the top of the Maramuni Diorite and thus provided the pebbles and boulders of microdiorite found in the upper part of the Karawari Conglomerate.

The volcanic rocks at the base of the Karawari Conglomerate could have been the surface manifestation of the intruding diorite, and certainly the volcanic rocks show the same range in composition as the Maramuni Diorite.

Burgers Formation
(new name)

The name Burgers Formation was first proposed by Dekker & Faulks (1964, unpubl.) for a thick Miocene sequence capping the eastern end of the Central Range.

Lithology. Great variety of volcanolithic sediments, water-laid tuff, greywacke, and siltstone; minor coralline limestone; basic and intermediate volcanic rocks (Tarua Volcanic Member).
Distribution. Forms crest of Central Range between Burgers Mountains and Mount Hagen.
Derivation of name. Burgers Mountains.
Type area. Burgers Mountains. No single type section; several sections, spanning most of formation, measured along north side of Central Range between Burgers Mountains and head of Sau River.
Stratigraphic relationships. Tarua Volcanic Member at base rests apparently unconformably on Pundugum Formation. Where volcanic member is absent sedimentary rocks rest apparently unconformably on Pundugum Formation. Top faulted.
Fossils and age. Impure limestone just above and at base of volcanic member contains Tertiary f_{1-2} Stage Foraminifera. Poorly preserved Foraminifera in upper part are Miocene or older; probably little younger than f_{1-2} Stage.
Thickness. 1 800 m measured in Burgers Mountains.
Definition. Where volcanic rocks are present, base at first major volcanic bed. Where volcanics are absent, gradational boundary between Pundugum and Burgers Formations placed arbitrarily at first major volcanolithic pebble conglomerate (generally massive resistant bed at least 30 m thick).

The Burgers Formation is mainly marine and is composed almost entirely of detritus derived from intermediate and basic volcanics of the Tarua Volcanic Member. It shows extreme lateral variation, and the lithology ranges from submarine (and possibly subaerial) lavas, agglomerates, and tuffs (Tarua Volcanic Member described below), to water-laid tuff and agglomerate, volcanolithic pebble, cobble, and boulder conglomerate, and calcarenite, containing much volcanic detritus. Lenses of impure coralline calcarenite are common near the base of the formation, and micaceous greywacke and siltstone are found throughout.

A typical section was measured along a gorge in the headwaters of the Maramuni River which cuts across the southeastern end of the Burgers Mountains at an altitude of about 2 400 m. The section is on the northeastern flank of an axially faulted syncline, and the formation dips consistently at a high angle to the southwest. Because the stream traversed was so rugged, a section could not be measured on the ground, but a good estimate of the thickness was obtained from the air-photographs.

The type section contains no volcanic rocks but grades laterally to the southeast into the Tarua Volcanic Member. It is about 1 800 m thick and consists mainly of well bedded to massive dark grey andesite crystal-lithic tuff, almost all of which was laid down in water. The base of the formation in this locality consists of dark andesite tuff and andesite-cobble conglomerate. A 1 800-m massive bed of andesite-cobble conglomerate, with a coarse tuffaceous matrix, occurs about 120 m from the base, and lenses of coralline limestone and thin beds of limestone, rich in indeterminate gastropods, bivalves, corals, and bryozoans, are common about 900 m above the base. Minor dark-coloured siltstone is found throughout the section, but is more common towards the top. The coarser sediments are dark tuffaceous sandstone and grit.

The crystal-lithic tuffs are all intermediate in composition, and consist of broken crystals of andesine-labradorite, hornblende, and augite, and fragments of andesite.

The major syncline is faulted along its keel so the measured section is not complete, but it is thought that only a small part of section is missing. The sequence in the southwestern limb of the syncline is also estimated from the air-photographs to be about 1 800 m thick, but the regional structure, and facings on some of the beds near the keel of the syncline, show that the limb is overturned.

Only the uppermost beds were examined on this limb of the syncline. They consist mainly of well bedded feldspathic sandstone of variable grainsize, crystal-lithic tuff, and interbedded dark-coloured siltstone—virtually indistinguishable from the uppermost sequence on the northeastern limb. There are a few thin horizons of shelly beds containing poorly preserved macrofossils.

Elsewhere the formation is similar to the section described above. There are a few small faulted outliers northwest of the Burgers Mountains in the headwaters of the Salumei River. The sequence ranges from micaceous tuffaceous sandstone, containing much carbonaceous material (plant remains and thin coaly seams are common), to pebble and cobble conglomerate, containing rounded to angular megaclasts of basalt and andesite, limestone, coral, quartz, and rare coal. Calcareous beds, ranging from marl to tuffaceous calcarenite, and coralline limestone were also seen. Volcanic rocks are prominent in the outliers, but they grade imperceptibly into the sediments and could not be mapped separately. The most common types are basalt and andesite agglomerate, agglomerate with a calcarenite matrix, and rare lava flows.

The age of the formation is given by a small lens of impure coralline limestone near the base of the sedimentary rocks about 6½ km west-southwest of Kompiam. The Foraminifera were determined by D. J. Belford; they include *Lepidocyclina* (*N.*) *ferreroi*, *Lepidocyclina* (*N.*) sp., *Miogypsina* sp., and *Elphidium* sp., which belong to the Tertiary f_{1-2} Stage (middle Miocene).

Tarua Volcanic Member (new name) (by R. W. Page)

The Tarua Volcanics of Dekker & Faulks (1964, unpubl.) grade laterally into the Burgers Formation, and we regard it as a member of the formation.

Lithology. Intermediate and basic volcanic rocks; minor conglomerate, sandstone, and siltstone.
Distribution. Volcanics crop out in northwesterly trending belt between Burgers Mountains and Kompiam.
Derivation of name. Tarua River, where volcanics attain their maximum development.
Type section. Headwaters of Tarua River (143°45′, 5°15′). Section of river from east of Keman to north of Keman.
Stratigraphic relationships. Rests apparently unconformably on Pundugum Formation; forms base of Burgers Formation, into which it grades vertically and laterally.
Fossils and age. Base contains middle Miocene (Tertiary f_{1-2} Stage) Foraminifera. As bottom of Burgers Formation is same age, Tarua Volcanic Member must lie wholly within Tertiary f_{1-2} Stage.
Thickness. Maximum of about 2 700 m in Tarua River section; generally less than 1 500 m.
Definition. Base defined at incoming of volcanic rocks resting unconformably on Pundugum Formation. Towards top of member lavas gradually give way to volcanolithic sediments of Burgers Formation.

The Tarua Volcanic Member consists of intermediate to basic submarine volcanics with minor conglomerate and finer tuffaceous sediments. The volcanic belt is about 70 km long on the northeastern limb of the Lai Syncline (Dekker & Faulks, 1964, unpubl.).

The section traversed varied considerably both in thickness and lithology. The member is approximately the same as that mapped by Dow et al. (1967, unpubl.), but mapping in 1967 has shown that the coarse tuff and tuffaceous sandstone in the Maramuni River are part of the member. The volcanic pile in the Tarua River was also found to be much thicker than indicated by photo-interpretation.

The member contains sporadic beds of conglomerate. The pebbles and cobbles are up to 15 cm across and consist of fragments of porphyritic lava and some gritty sandstone set in a feldspathic sandy matrix. The matrix is identical with the tuffaceous sandstone which forms individual beds. The sediments range from light grey to dirty green, depending on the proportion of feldspathic to ferromagnesian detritus. They consist of well sorted angular grains of andesine, pyroxene, hornblende, minor iron oxides, and rock fragments set in a carbonate-rich cement. The presence of fresh clear grains in the sandstones probably indicates rapid transport and sedimentation.

Dykes of augite microdiorite and hornblende microdiorite intrude the sediments and volcanics, particularly in the lower part of the Tarua Volcanic Member. The dykes may have acted as feeders for the volcanic rocks higher in the sequence.

The section between Kompiam and Birip (or Birap) contains widespread beds of massive agglomerate and intercalated lava flows. The agglomerate consists of unsorted blocks of lava up to about 1 m across set in a matrix of fine crystal tuff. The matrix contains abundant fragments of volcanic rock as well as grains of feldspar and ferromagnesian minerals. Pieces of devitrified glass are also present, but are generally chloritized or replaced by calcite.

The bulk of the lavas are andesites which have many affinities with the calc-alkaline suite. They are porphyritic and generally slightly altered. The phenocrysts consist of euhedral zoned crystals of diopsidic augite, plagioclase (An_{20-50}), and hornblende, up to 5 mm across. A few of the andesites from the Sau River section contain up to 15 percent olivine phenocrysts. The groundmass ranges from an intergranular mosaic of andesine, clinopyroxene, and iron oxides, and in places hornblende, to devitrified glass, which has been altered to chlorite. The alteration of the volcanics and the introduction of zeolites, calcite, and chlorite was a late-magmatic or early diagenetic process.

Foraminifera from the bottom of the Tarua Volcanic Member in the Maramuni River have been dated as Tertiary f_{1-2} Stage, and as the bottom of the overlying Burgers Formation is also of the same age, the deposition of the whole of the volcanic member must have occupied only a short period of time.

Wogamush Beds
(new name)

Lithology. Mostly dark micaceous sandstone and subgreywacke; intermediate and basic volcanic rocks or volcanolithic conglomerate at base.
Distribution. North of Frieda Fault between April River and May River Patrol Post; western limit not mapped.
Derivation of name. Wogamush River, major southern tributary of Sepik River.
Type area. Headwaters of Wogamush River.
Stratigraphic relationships. Rests unconformably on Ambunti Metamorphics and April Ultramafics; probably overlies Salumei metamorphics and intruded by Freida Porphyry.
Thickness. At least 2 400 m.
Fossils and age. Tertiary f_{1-2} Stage Foraminifera in limestone lenses near base; age of upper part not known, but unlikely to be younger than middle Miocene.

Most of the formation consists of black, dark blue, or medium grey micaceous quartz sandstone, which grades into subgreywacke with an increase in the proportion of matrix and feldspar. The rocks are almost invariably fine-grained and moderately indurated, and most of the beds grade upwards into siltstone or very fine sandstone. The sequence is generally medium-bedded to thick-bedded, though massive beds up to 2 m thick have been seen.

Volcanic rocks of unknown thickness occur at the base between the April and Wogamush Rivers. They are similar to the volcanic rocks of the Karawari Conglomerate to the east, and consist of hornblende andesite and basalt lavas and agglomerate. Some beds of andesitic crystal tuff are present.

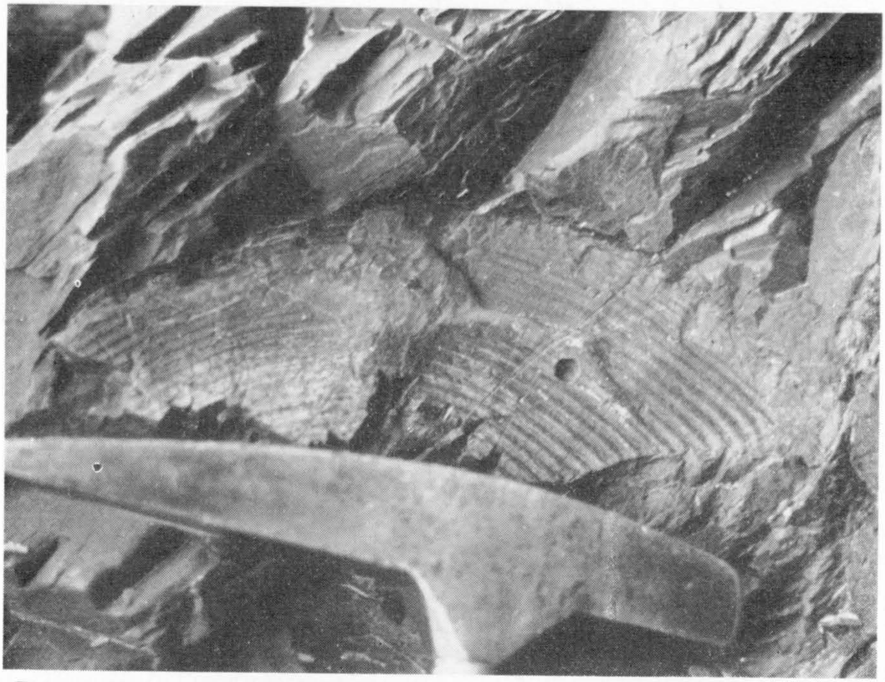

Plate 5, Figure 1. Fragment of *Sturia* sp., a discoidal ammonite of Anisian to Ladinian age, found in the Yuat Formation in Yuat Gorge.

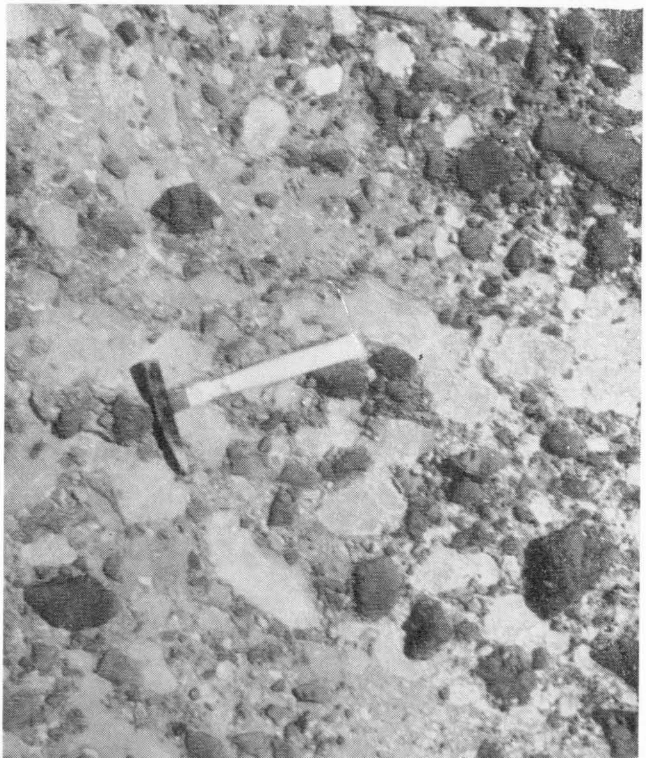

Plate 5, Figure 2. Limestone breccia in the Salumei Formation; it contains poorly ~~sorted~~ subangular fragments of basalt.

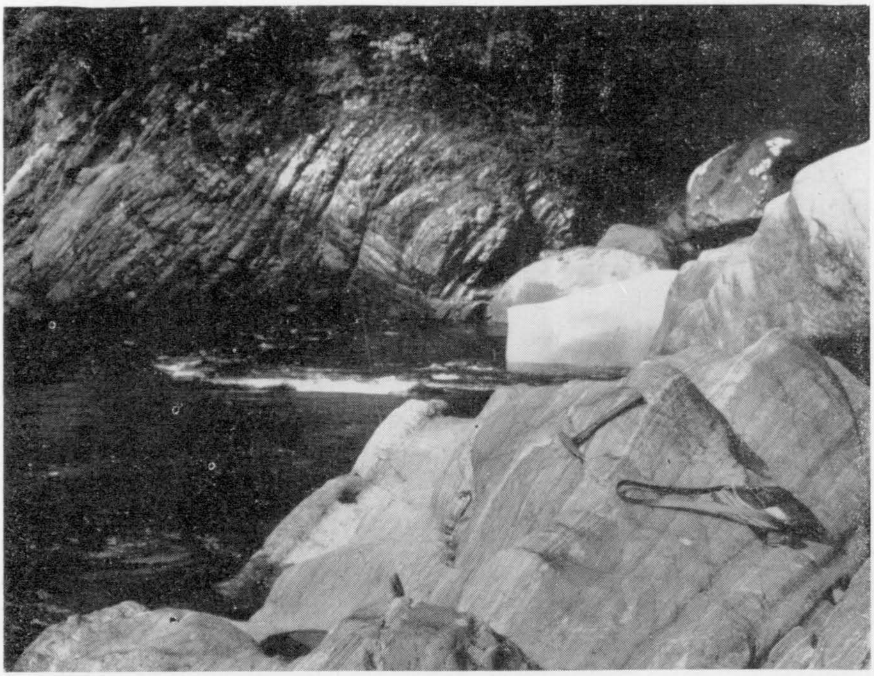

Plate 6, Figure 1. Indurated laminated to thin-bedded shale and siltstone of the Salumei Formation in the upper Karawari River.

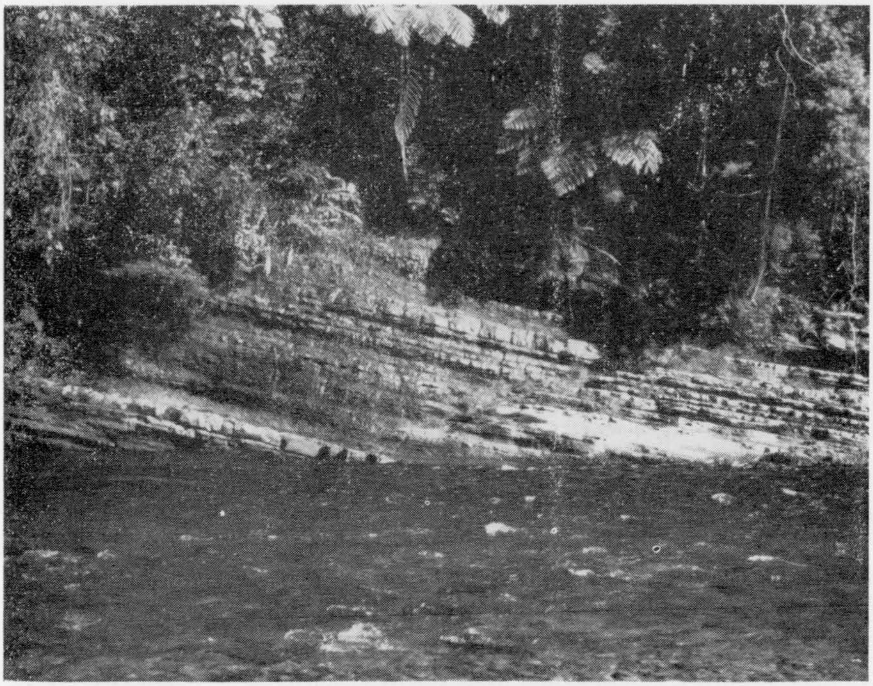

Plate 6, Figure 2. Gently dipping subgreywacke and siltstone of the Salumei Formation in the upper Karawari River.

Plate 7, Figure 1. Quartz sandstone and interbedded shale of the Lagaip Beds in the head of the Ambum River.

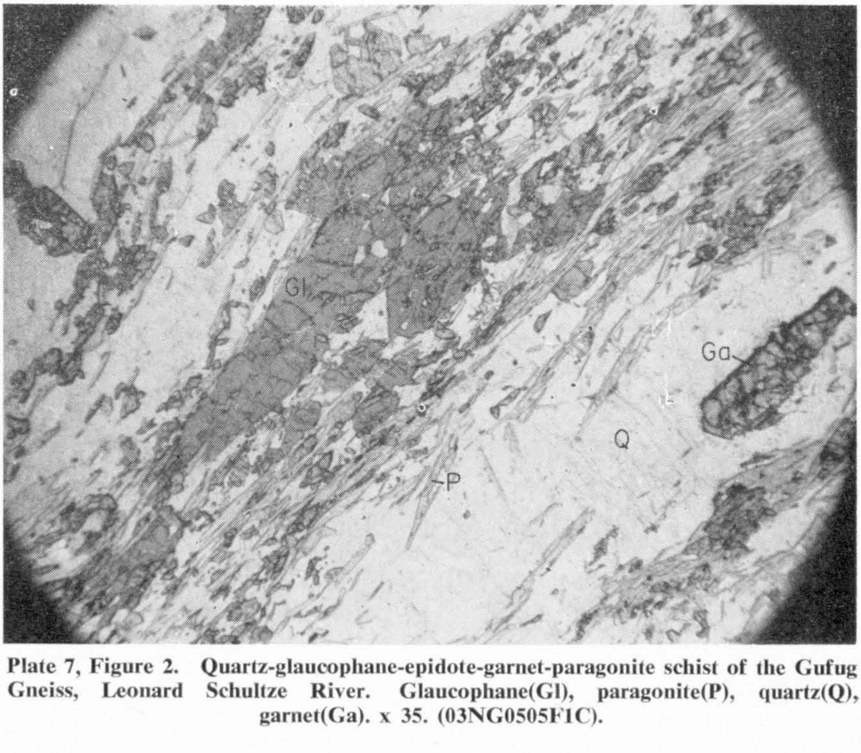

Plate 7, Figure 2. Quartz-glaucophane-epidote-garnet-paragonite schist of the Gufug Gneiss, Leonard Schultze River. Glaucophane(Gl), paragonite(P), quartz(Q), garnet(Ga). x 35. (03NG0505F1C).

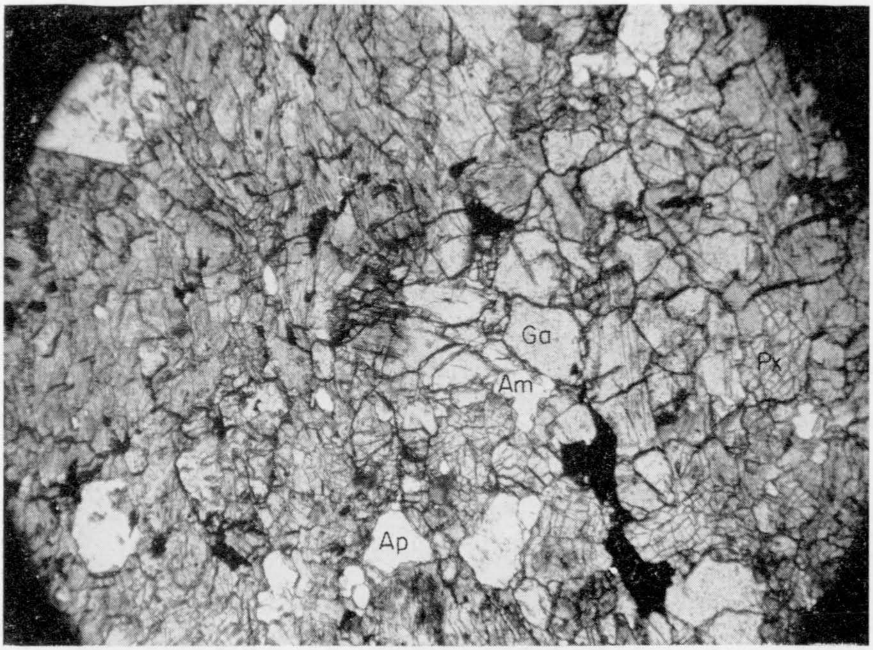

Plate 8, Figure 1. Eclogite of the Gufug Gneiss, Leonard Schultze River. The rock is composed of pyroxene(Px), garnet(Ga), amphibole(Am), and apatite(Ap). x 35. (03NG2510F).

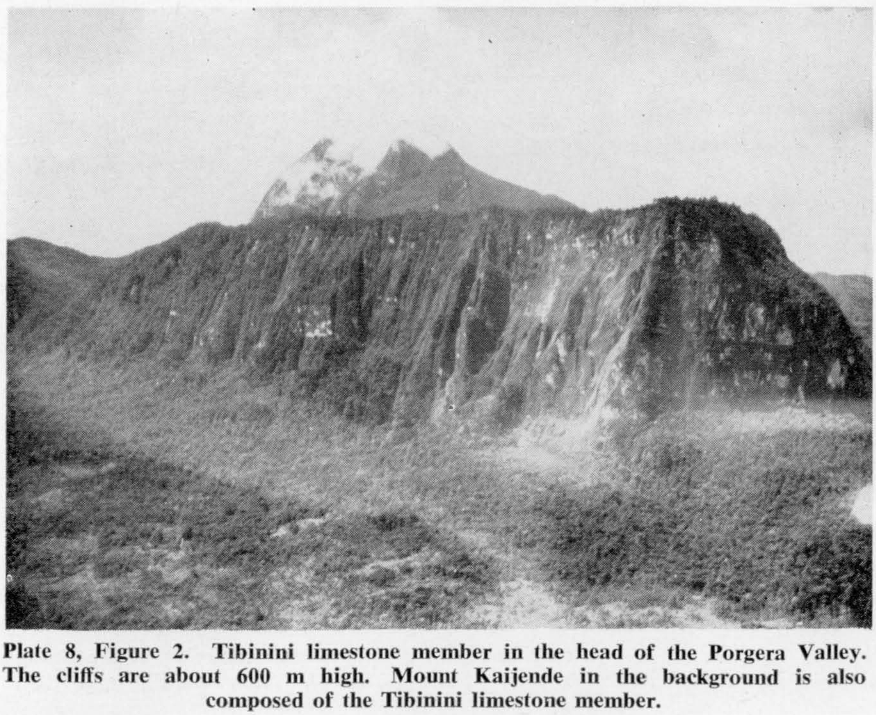

Plate 8, Figure 2. Tibinini limestone member in the head of the Porgera Valley. The cliffs are about 600 m high. Mount Kaijende in the background is also composed of the Tibinini limestone member.

The patches of vesicular and amygdaloidal basalt capping the hills north of the junction of the Sitipa and April Rivers are probably remnants of a once extensive cover of volcanic rocks of the Wogamush Beds.

As the dip of the Wogamush Beds in this locality could not be accurately determined, the thickness of the volcanic rocks is not known, but the maximum thickness is probably about 300 m.

Where the volcanic rocks are missing a conglomerate about 100 m thick is found at the base of the formation. The composition is very variable, but cobble or pebble conglomerate predominates. It consists of well rounded fragments of hornblende andesite and basalt set in a matrix of tuffaceous sandstone or crystal tuff. Rare pebbles of diorite, serpentinite, glaucophane schist, and some limestone (one containing Tertiary e Stage Foraminifera) have been found within the conglomerate.

The matrix of the conglomerate ranges from crystal tuff and tuffaceous sandstone, containing shelly material, to calcarenite and coquinite. Lenses of coaly material and some plant fragments are not uncommon.

The greatest thickness of the Wogamush Beds was traversed in a creek between the Leonhard Schultze and Frieda Rivers, where measurements on the air-photographs show the formation to be about 2 400 m thick.

The beds rest unconformably on the Ambunti Metamorphics and April Ultramafics. In the Frieda prospect area they are intruded by the Frieda Porphyry, but overlie the Frieda Porphyry farther north. In the Frieda prospect area they have been interpreted as overlying the Salumei metamorphics. Tertiary e Stage Foraminifera have been found in a pebble in the basal conglomerate.

Tertiary f_{1-2} Stage Island Arc Volcanism

The Tertiary f_{1-2} Stage volcanics and sediments of the South Sepik region are part of a belt of volcanic rocks and volcanolithic sediments, which extends from the northwestern part of the map area, southeastwards along the Highlands of New Guinea, to central Papua (Fig. 6). The formations making up the belt, from northwest to southeast, are the Wogamush Beds, Karawari Conglomerate, Burgers Formation (this Bulletin), Daulo Volcanics and Asaro Conglomerate (MacMillan & Malone, 1960), Lamari Conglomerate (Dow & Plane, 1964), and Langimar Conglomerate (Smit, in prep.). All of them except the Karawari Conglomerate have been reliably dated by the presence of limestone lenses, containing Tertiary f_{1-2} Stage Foraminifera, near the base of the sedimentary rocks.

The almost identical volcanics underlying Tertiary f_{1-2} Stage volcanolithic sediments (Yapsiei Volcanics of Paterson & Perry, 1964), cropping out near where the Sepik River crosses the West Irian border, are almost certainly a part of the same belt.

All these formations are remarkably similar, and they undoubtedly were formed by a chain of island arc volcanoes, which extended for over 500 km along the Highlands of New Guinea, from the West Irian border at least as far as the Langimar River. Similar volcanics along the north coast of Papua may represent a continuation of the belt.

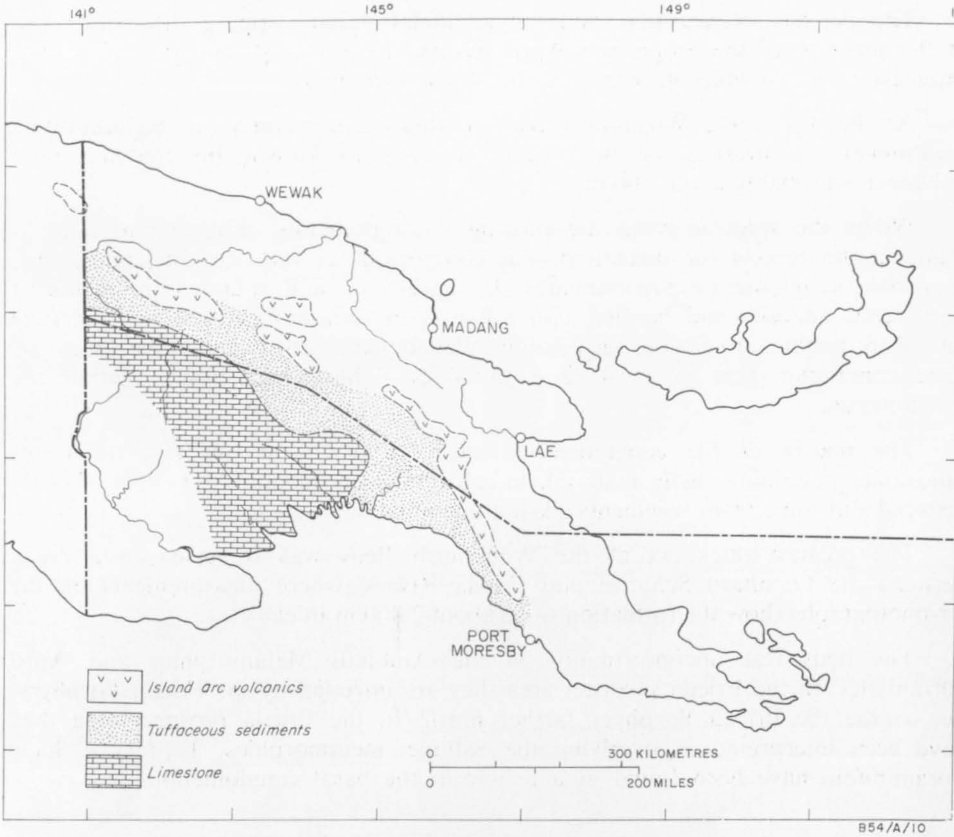

Figure 6. Tertiary f_{1-2} Stage palaeogeography

The following characteristics of the formations indicate that the belt was formed by island arc volcanism:

(1) The volcanic rocks are sporadically distributed along the belt. They are up to 700 m thick in regions of maximum development, but generally lens out within a few kilometres. The main exposure of the Tarua Volcanic Member, which is about 40 km long, is one of the largest bodies of volcanics mapped and probably represents the outpourings of a group of volcanic islands.

(2) Most of the volcanics appear to be submarine, and though subaerial volcanics must have been deposited, they probably did not survive erosion.

(3) The rocks show extreme lateral variation from lava and agglomerate to a wide range of volcanolithic sediments, of which the most striking are the great thicknesses of volcanolithic conglomerate around the volcanic centres.

(4) Patches of coralline limestone, up to several kilometres across and up to about 100 m thick, are sporadically developed throughout the belt, generally within the conglomerate. They represent coral reefs which fringed the volcanic islands when the volcanoes were active.

The sediments laid down in New Guinea at this time exhibit a remarkable change towards the southwest which shows conclusively that to the southwest of the island arc the northern extension of the Great Barrier Reef was being laid down on the stable Australian continental block in southwestern Papua. Thus, the volcanolithic sediments of the island arc grade southwestwards through a belt of tuffaceous greywacke, into the extensive platform cover of limestone and interbedded marl which extends over much of southwestern Papua (APC, 1961).

TERTIARY g STAGE (UPPER MIOCENE)

Chuingai Limestone
(new name)

The name Chuingai Limestone is given to coralline limestone forming the main mass of the Chuingai Hills of the Sepik River (143°35′E; 4°55′S) and mapped (Papp, 1930) by the Anglo-Persian Oil Co.

Lithology. Whitish and yellowish, and in places compact, coralline limestone; some thin beds of foraminiferal limestone.
Distribution. Forms rough Chuingai Hills, 16 km northeast of Timbunke village on Sepik River.
Derivation of name. Chuingai Hills.
Type area. Chuingai Hills.
Stratigraphic relationship. Unconformable on Ambunti Metamorphics.
Thickness. Not measured; probably no more than 60 m.
Age. Contains Miocene Foraminifera, but according to Chapman (*in* Papp, 1930) some of the Foraminifera are of Pliocene aspect. Probably upper Miocene (contains g Stage Foraminifera to northwest).

The Chuingai Limestone is well bedded, and some individual beds attain a thickness of 6 m. The limestone has a rough picturesque topography and several caves are known to exist in the area.

Papp (1930, p. 74) correlated the limestone at Chuingai Hills with similar limestone farther east at Marienberg and other nearby areas where they overlie Miocene strata. The age indicated by Foraminifera (Papp, 1930, p. 75) is ambiguous and the limestone could be Pliocene.

PLIOCENE TO PLEISTOCENE

There is no record of sedimentation in the map area after about the middle Miocene. At some time in the Pliocene andesitic and basaltic eruptions began, which built up huge volcanic cones throughout much of the Highlands of New Guinea. Most of the volcanoes had reached full development by the Pleistocene as the larger volcanoes were glaciated in the Pleistocene. Volcanic rocks from Mount Hagen volcano (Hagen Volcanics) occur in the southeastern corner of the map area.

Hagen Volcanics
(new name)

The pyroclastics, lavas, lahars, and associated alluvial and lake deposits, forming the large volcanic cone of Mount Hagen have been called the Hagen Volcanics. Ward (1949, unpubl.) referred to the outcrops of basalt agglomerate and volcanic ash on the Lai River as the Mount Hagen Volcanics, and Dow (1961, unpubl.) proposed the name Hagen Volcanics for the volcanic material derived from Mount Hagen volcano.

Lithology. Andesite and basalt crystal tuff, agglomerate, and lavas; lahars; and alluvial and lake deposits, laid down where the rivers were dammed by the volcanic rocks.
Distribution. Hagen volcano and environs. Remnants of the crystal tuff mantle are widespread around the volcano, and lahar deposits fill the head of the Wahgi and Nebilyer Valleys and the gorge of the Yuat River to the Sepik Plain. The upper part of the Lai Valley and the lower part of the Jimi Valley are filled with alluvium deposited when the valleys were dammed by volcanic rocks.
Derivation of name. Hagen Range.
Type area. Hagen Range.
Stratigraphic relationships. Volcanic rocks fill valleys deeply incised in marine sediments of Burgers Formation of Tertiary f_{1-2} Stage.
Thickness. Very variable; at least 2 400 m in middle reaches of Lai River.
Age. Hagen volcano is deeply dissected and was glaciated during the Ice Age; probably ranges from upper Pliocene or early Pleistocene. Well preserved cones and explosion craters testify to more recent volcanic activity (Sugarloaf Volcanics).

The Hagen Range is made up of one or more large extinct volcanic cones which were built up on a rugged land surface on the divide between the Wahgi and Lai Rivers. The volcano is well preserved on the eastern and southern sides, where it has been protected from erosion by a huge mantle of lahars which spread out many kilometres from the base of the cone.

On the north and east the volcano has been vigorously eroded by the Lai River, and most of the original cones have been removed (Pl. 9, fig. 2). Headward erosion of streams draining the flanks has resulted in the formation of a huge erosion caldera in the centre of the volcano, and has obliterated all trace of the original crater.

The range is over 3 600 m high and the well preserved cirques, some containing small lakes, testify to glacial erosion during the Ice Age.

A large proportion of the pyroclastic material was carried away from the volcano by lahars: much travelled eastwards, filling the head of the Wahgi Valley with a huge mantle of ill sorted volcanic material. The original land surface in this direction had a fairly gentle relief, and the deposits are but little dissected. Much lahar material probably also flowed to the west and north, but the deep Lai-Yuat gorge had a steep gradient which channelled the lahars 110 km to the Sepik Plain.

The headwaters of the Lai River were dammed by the volcano, and as a result, alluvial deposits fill the valley to a depth of about 100 m.

A small volcanic centre at the crest of the Lai-Sau divide spilled basalt lavas down the Sau Valley, a remnant of which forms the airstrip at Kompiam, and another underlies the village of Linganas. It is thought, because of the advanced dissection of this volcano, that it was active at the same time as Hagen volcano.

The cone of Hagen volcano is built of interbedded ash, agglomerate, and subordinate lava flows. Four thin sections of the lavas were examined by Dekker & Faulks (1964, unpubl.), and five sections of the lavas in the lahars in the Yuat Gorge.

All the lava flows are olivine basalt composed of phenocrysts of labradorite, olivine, and subordinate pyroxene (mostly augite), set in a groundmass of similar composition. Apatite and iron oxides are accessory.

Most of the volcanic fragments in the lahars consist of porphyritic andesite composed of phenocrysts of plagioclase (An_{60-65}), hornblende, and some pyroxene, set in a fine-grained groundmass of plagioclase, pyroxene, microlites, and iron oxide. Some have a strong trachytic texture. The preponderance of andesitic fragments in the lahars is probably due to the explosive nature of the andesitic eruptions.

The subaerial volcanic ash mantling much of the Wabag area (Pl. 10, fig. 1) consists mainly of shards and angular fragments ranging down to fine dust composed of volcanic glass and broken crystals of hornblende, plagioclase, and some augite.

The lahars filling the Yuat Gorge are composed of a chaotic mixture of agglomerate, volcanic breccia, conglomerate, sandstone, and lenses of basalt lava. Many of the deposits are massive and almost completely unsorted; they consist of volcanic fragments up to 2 m across randomly distributed in a tuffaceous matrix. The lahars also contain well rounded pebbles and large lenses of river gravel.

Patches of basalt lava up to about 100 m long are exposed at many places in the Yuat Gorge, and though they are almost invariably badly broken up and commonly highly contorted, it is almost inconceivable that they could have travelled 110 km from Hagen volcano. They are much more likely to have been extruded from local vents, and to have flowed down to the Yuat River where they were incorporated in the lahars. Small remnants of basalt are found capping some of the ridges west of the Yuat Gorge, and it is possible that they may have been derived from the same volcanic centre.

QUATERNARY

Sugarloaf Volcanics
(new name)

The lava field which extends northwards from the Giluwe Volcano almost to the Lai River post-dates the Giluwe volcanics, and probably the Hagen Volcanics.

The field is about 50 km long and up to 20 km wide, and is largely composed of coalescing lava domes, the more recent of which are shown on the geological map. Most are smooth cumulo-domes which do not have craters, but some are small ash cones with well marked craters. Several explosion craters are found throughout the lava field; the largest crater contains a lake and is over half a kilometre in diameter.

The volcanic rocks were examined at five localities on the northern margin of the field. They range from olivine basalt to hornblende andesite; andesitic ash and fine agglomerate were also noted.

Other small volcanic cones are found in the Lai Valley east of Wabag and at Kepilam village in the headwaters of the Lagaip River; they are referred to as the Sugarloaf Volcanics because they are of andesitic composition and are probably of the same age.

Alluvium

The Sepik Plain is composed of an unknown thickness of fine alluvium. Most of the exposures seen in the river banks consist of grey and black carbonaceous silt, but the composition of the underlying sediments is not known.

Brown tuffaceous sandy sediments form the banks of much of the Yuat River in the Sepik Plain. They are composed of clay, quartz grains, glass shards, and broken ferromagnesian minerals, most of which were apparently derived from the Hagen Volcanics. Near the mountains fine gravel and pebbly beds are predominant.

East of the Yuat River the alluvium of the Sepik Plain has been uplifted about 9 m, and is now dissected by a fine dendritic drainage. It is possible that this uplift was due to recent movement on the Jimi Fault.

INTRUSIVE ROCKS

Hunstein Complex
(new name)

Mount Hunstein, north of the junction of the April and Sitipa Rivers, is composed of a variety of basic igneous rocks ranging from unaltered gabbro, similar to the Maramuni Diorite, to plutonic and volcanic rocks which have been metamorphosed to the greenschist facies. Quartz-biotite gneiss and sheared and recrystallized serpentinite are also present.

Exposure in the Hunstein Range is poor, so the relationships of the various rock types are not known, but from the few outcrops seen the metamorphics and the gabbro seem to be intimately mixed.

The rocks belong to the greenschist facies and are of about the same grade as the nearby Ambunti Metamorphics in the lower April River near Nikaium hamlet. The complex probably consists essentially of a basic pluton, which incorporated much of the surrounding country rock near the margins, and was later affected by the same metamorphism which formed the Ambunti Metamorphics. The less altered gabbro probably belongs to the Maramuni Diorite, but it could not be mapped separately.

The lenses of uralitized gabbro cropping out along the Frieda Fault have been mapped as part of the Hunstein Complex. They are green highly altered fine-grained rocks containing irregular white patches which are probably altered feldspar. Most of them have a rudimentary foliation. They were not examined in thin section, but in hand specimen they appear to be identical with metamorphosed gabbro (03NG006C) from Mount Hunstein. The uralitized gabbros are probably fragments of deep-seated gabbro plutons which have been brought to the surface by movement on the Frieda Fault, at the same time being metamorphosed to the greenschist facies.

Petrography (by D. E. Mackenzie)

Altered gabbroic rocks. In hand specimen the altered gabbroic rocks commonly have a granular to gneissic texture with relict phenocrysts or porphyroblasts of light or dark-coloured crystals or crystal aggregates. In some specimens crude banding of light and dark minerals may be observed, whilst in others light minerals form numerous flecks and veinlets. The gabbros which exhibit evidence of shearing or have a strong gneissic texture are also the most strongly altered.

In thin section the rocks consist of granular masses of yellow-brown epidote (about 1 mm across) and clots of pale green fibrous actinolite which form a pseudogranular igneous texture. Patches of fine-grained recrystallized quartz and albite and small aggregates of pale green chlorite occur between the actinolite and epidote. Small crystals of sphene, fine dusty hematite, or aggregates of hematite, are scattered sparsely through the rock. Fine-grained crystalline aggregates of prehnite, epidote, and a little actinolite, quartz, and albite form numerous small veinlets. The actinolite appears to have replaced hornblende or pyroxene, or both, and the epidote and albite were formed by the alteration of plagioclase. However, in some specimens, notably specimen 11NG0006C, distorted partly altered relict phenocrysts of pale yellow-brown augite have been preserved.

Unaltered gabbroic rocks. The presence of phenocrysts of black hornblende up to 1 cm long set in a dark olive-green granular groundmass gives many of the unaltered gabbroic rocks a most unusual appearance.

The hornblende-pyroxene gabbro (specimen 11NG0007) contains 20 percent of hornblende. It forms large zoned phenocrysts, with brown cores and green to green-brown margins, and small (0.3-0.5 mm) brown-green crystals in the groundmass. The large subidiomorphic crystals are crowded with inclusions of colourless clinopyroxene concentrated in the outer parts of the phenocrysts. The granular groundmass is composed of clinopyroxene (70%), small hornblende crystals, and interstitial plagioclase (10%), with accessory sphene and iron oxides. The pyroxene has a 2V of 60° to 65° and is probably diopsidic augite. The plagioclase is andesine (An_{50}).

Serpentinite. The serpentinite is schistose and contains about 90 percent antigorite with subordinate magnetite forming clusters of irregular grains up to 1 mm across, and a few scattered minute grains of sphene(?). The antigorite forms a dense mass of interlocking fibres and irregular plates with strong preferred orientation due to shearing (11NG0009A).

Banded schist. The banded schist is dark greenish grey. It shows slickensiding, with very dark green-grey bands up to 1 mm thick separated by pale mottled grey and green bands. Quartz and albite are concentrated in the lighter bands as a fine mosaic speckled with crystals of epidote and actinolite. Epidote-clinozoisite forms small equant crystals scattered evenly throughout the rock, whereas actinolite is concentrated in the schistose dark bands, with patches of prehnite. Pumpellyite(?) occurs as tiny rounded grains clustered together in the quartz-albite-rich bands. The rock appears to have formed under conditions of the greenschist metamorphic facies (Turner & Verhoogen, 1960).

Chambri Diorite
(new name)

Chambri Diorite is the name given to a large body of diorite between Ambunti and Chambri Lakes.

The only specimens collected were from Aibom village, but as the diorite has a characteristic dendritic drainage pattern the outline of the intrusion can be photo-interpreted with confidence.

The diorite is coarse and even-grained, and has a crude foliation due mainly to the alignment of plagioclase prisms. The rock is composed of about 80 percent plagioclase (An_{43}), microperthitic potash feldspar (5-8%), hypersthene (about 10%), which is partly replaced by small crystals of hornblende and biotite parallel to the main cleavage set, and clusters of red-brown biotite (5%). The accessories are magnetite and apatite.

The age of the Chambri Diorite, even within broad limits, is not known; it intrudes the Ambunti Metamorphics of unknown age, and is overlain by Recent alluvium.

April Ultramafics
(new name)

Numerous bodies of ultramafic rocks, ranging from a few metres to 50 kilometres long, which intrude pre-Miocene rocks, are called the April Ultramafics. The name is derived from the headwaters of the April River where they crop out extensively.

Intrusions of April Ultramafics were found between the Maramuni River (143°45′E, 5°00′S) and the westward limit of mapping in the Frieda River (141°40′E, 4°45′S), but the main bodies occur in the middle reaches of the April, Leonhard Schultze, and Frieda Rivers. Reconnaissance in 1967 indicated that ultramafic rocks extend westward into the headwaters of the May River, and are probably related to ultramafics in the northern fall of the central ranges of West Irian.

The ultramafic bodies range from ubiquitous small sheared lenses of serpentinite, mainly in fault zones, to large irregular masses of dunite and peridotite, the largest of which is 50 km long by 10 km wide at its widest point in the Leonhard Schultze and Frieda Rivers. The bodies are typically elongated to the west-northwest, parallel to the regional structural trend.

The margins of the larger bodies are characteristically sheared and serpentinized, and in many cases they are bounded by faults. Although it is difficult to determine the dip of the contacts most structural features adjacent to and within the margins point to subvertical or steeply dipping contacts. However, the contacts of the ultramafic bodies within the Lagaip Fault Zone at the head of Bamali River are thought to dip moderately to the southwest, and the bodies to be tabular sheets incorporated within the Lagaip Fault Zone (see map, cross-section A-B-C).

The larger intrusions are composed mainly of massive crystalline peridotite and dunite, much of which appears to be fresh in hand specimen. Serpentinization is apparent in varying degrees in many areas within the larger bodies, but principally in the peripheral zones and along internal shear zones. The smaller bodies tend to be completely serpentinized, though relict pyroxenes (bastite) are commonly visible in the serpentinites. Layering, although not common, was seen at some localities and within loose boulders. It generally takes the form of alternating pyroxene-rich and olivine-rich layers. Pyroxenites are subordinate but widespread; they generally occur as cross-cutting dykes, but also form layers in dunite or peridotite. The dykes may have been formed by the alteration of the peridotite along fissures by hot silica-saturated vapour (Turner & Verhoogen, 1960, p. 316). A similar explanation may account for the light-coloured veins and dykes of hydrogarnet, tremolite, sericite, and carbonate minerals which are common in the margins of some bodies.

Small bodies and blocks of gabbro and hydrothermally altered sediments are commonly enclosed by sheared serpentinite, particularly along the margins of many of the ultramafics. They are apparently of tectonic origin and were derived from the surrounding rock during emplacement. Some streams draining the ultramafics are choked with large boulders from the tectonic inclusions.

Dunite. The dunite is greenish grey and coarsely crystalline, and contains visible crystal of pyroxene and chrome spinel. It consists principally of granular magnesian olivine showing varying degrees of strain and cataclasis. Some of the intensely crushed rocks can be classified as dunite cataclasite (e.g. specimen 03NG009). Most of the rocks are partly serpentinized, although they may appear to be unaltered in hand specimen (e.g. specimen 03NG0002A). The pyroxene (less than 10%) is generally enstatite or bronzite, although clinopyroxene appears as exsolution lamellae within some of the orthopyroxene. The accessory chrome spinel ranges from reddish brown picotite to virtually opaque chromite.

Peridotite. Apart from their higher pyroxene content the peridotites are similar in texture and mineralogy to the dunites. Most of the peridotite specimens examined contain enstatite or bronzite as well as olivine and may be classed as harzburgite. The proportion of pyroxene rarely exceeds 30 percent and the average composition of the bulk of the April Ultramafics appears to be close to the boundary between orthopyroxene-rich dunite and olivine-rich harzburgite. Some specimens contain appreciable amounts of clinopyroxene, and in specimens 03NG0014 and 03NG2627A it is roughly equal to the orthopyroxene, placing them in the lherzolite range. Specimen 03NG006 contains about 20 percent clinopyroxene and 5 percent orthopyroxene and may be called a wehrlite.

Serpentinite. The sheared serpentinites consist mainly of a felted mass of antigorite which commonly has a preferred orientation. Some small serpentinite lenses in the metamorphic phase of the Salumei Formation contain a hard form of serpentinite known as bowenite which consists of a mass of coarse-grained interlocking plates of antigorite (03NG2510A). In unsheared serpentinites relict crystals of serpentinized pyroxene (bastite) are common

Pyroxenite. Only two pyroxenite specimens were examined. Specimen 11NG2036A consists of 60 percent clinopyroxene, with exsolution lamellae of orthopyroxene, 35 percent olivine, and 5 percent chrome spinel. Specimen 11NG2630 is a very coarse-grained pyroxenite consisting mainly of clinopyroxene with some enstatite and serpentinized olivine. One boulder from the Frieda River (03NG0533C) consists of serpentinized banded peridotite, composed of layers of diallage and olivine-rich layers which have been completely serpentinized.

Age of emplacement. As the April ultramafics intrude the Salumei Formation they must have been emplaced after the Eocene. They are unconformably overlain by the middle Miocene (f_{1-2} Stage) Karawari Conglomerate in the Maramuni River and by the Wogamush Beds of the same age in the April, Leonhard Schultze, and Frieda Rivers. Ultramafic pebbles were found in the base of the Wogamush Beds.

The relationship with the upper Oligocene to lower Miocene (Tertiary e Stage) Pundugum Formation is uncertain, and the only contacts seen are apparently faulted.

The relationship of the April Ultramafics to the Maramuni Diorite is also in doubt. Nowhere were the ultramafic rocks seen to be intruded by diorite, but hydrothermal alteration of ultramafic rock along the boundary between adjacent diorite and ultramafic bodies in the Yokopos River (143°05'E, 4°50'S) may have been caused by intrusion of the diorite.

As in other orogenic belts the emplacement of the ultramafics apparently coincided with the folding and faulting of the geosynclinal pile.

Mode of emplacement. The lack of contact metamorphism and the sheared nature of the margins suggest that the ultramafic bodies were emplaced at low temperatures, and in an essentially solid state (c.f. Turner & Verhoogen, 1960, p. 321). Semi-rigid masses of peridotite probably forced their way up through the incompetent geosynclinal sediments by a process of faulting aided by the lubricating nature of the serpentinite margins (Raleigh & Paterson, 1965). The universal straining and cataclasis of the peridotite and dunite, which is clearly visible in all thin sections, lends weight to emplacement in the crystalline state.

The alpine ultramafics are commonly believed to have been derived from the upper mantle (e.g. Hess, 1960), and the April Ultramafics appear to have originated in the same way. Thompson (1957, unpubl.) and Davies (1971) reached a similar conclusion regarding the origin of the Papuan Ultramafic Belt.

Maramuni Diorite
(new name)

The Maramuni Diorite consists of a number of intrusive bodies, ranging from batholiths to small dykes, which occupy much of the eastern part of the South Sepik region. Similar rocks of uncertain affinities occur in the headwaters of the April River.

Most of the rocks are dioritic, although many of the bodies range from ultrabasic to acid (see Table 1). The changes in composition are gradational, and are probably the result of differentiation and contamination.

TABLE 1: ESTIMATED MODES OF MARAMUNI DIORITE

Rock Type (Locality, Spec. No.)	Plagioclase (%) (* = zoned)	Potash Feldspar (%)	Quartz (%)	Hornblende (%)	Biotite (%)	Notes
Yuat Intrusives						
Hornblende-biotite microgranodiorite. L. Maramuni R. (11NGO578A)	43*	12	22	21	—	1% opaque minerals, epidote (pseudomorphs after biotite), sphene
Hornblende-biotite microgranodiorite. L. Maramuni R. (11NGO566)	48 (An_{54})	23	16	11	—	2% sphene, epidote, opaque minerals, and zircon
Hornblende-biotite microgranodiorite. L. Maramuni R. (11NGO582)	51*	12	14	20	—	1% sphene and epidote
Hornblende-biotite microtonalite. Lamant R. (11NGO514)	70 (An_{38})*	—	18-20	8	1-2	2% opaque minerals
Microdiorite. Lamant R. (12NGO512)	80 (An_{42})*	—	1-2	20	2-5	3-5% opaque minerals and epidote; numerous small gabbroic xenoliths
Karawari Intrusives						
Quartz diorite. Wogupmeri R. (11NGO115C)	65-70 (An_{50-26})*	—	5-10	20-25	—	5% opaque minerals, epidote, and apatite
Hornblende tonalite. Wogupmeri R. (11NGO115E)	55-60*	—	15-20	20-25	—	2-3% opaque minerals
Biotite granodiorite. U. Maramuni R. (11NG1190)	40*	20	30	—	10	Very minor opaque minerals and apatite
Pyroxene-quartz diorite. Karawari R. (11NGO609)	75 (An_{62})*	5-10	5-7	—	—	2-5% accessories; 10% clinopyroxene
Anorthite gabbro. Karawari R. (11NGO605)	65-70 (An_{95-100})	—	—	25-30	—	5% magnetite
Anorthite gabbro. Wogupmeri R. (11NGO102)	50	—	—	45	—	1-2% magnetite; 5% olivine
Porphyry phase						
Porphyritic diorite. Wogupmeri R. (11NGO112)	35-40 (An_{40})*	—	—	15	—	10% clinopyroxene, 5-10% accessories; 30-35% groundmass (altered feldspar)
Altered porphyritic microdiorite. Korosameri R. (11NGO117)	30*	—	5	—	—	5% chlorite; 60% groundmass (fine feldspar and chlorite)
Porphyritic quartz microgabbro. Yuat R. (11NGO556)	45	—	—	—	—	2-5% clinopyroxene; 50% groundmass (plagioclase, with granules of pyroxene, hornblende, and accessories)
Porphyritic leucomicrodiorite. U. Maramuni R. (11NG1187)	40*	—	—	—	—	60% groundmass (finely divided feldspar and chlorite, with small granules of quartz, pyroxene, hornblende, biotite, and accessories)

These rocks have been subdivided into the Yuat intrusives (mainly granodiorite), comprising two batholiths and numerous small apophyses, in the east; the Karawari intrusives (mainly diorite), consisting of a larger body and many apophyses, in the west; and a number of smaller porphyritic bodies associated with the main intrusions and at Porgera in the southwest (Porgera intrusives).

The Yuat intrusives crop out in a northwesterly trending horst of Mesozoic sediments, and the Karawari intrusives in a more westerly trending fault block of Tertiary sediments. The Porgera intrusives occur as small stocks and dykes in late Mesozoic/early Tertiary sediments.

Yuat intrusives

The northernmost batholith of the Yuat intrusives was systematically sampled at 400 m intervals across the body, and a representative collection was made of the southern body.

The two bodies are composed predominantly of microgranodiorite with minor diorite phases, small remnants of crystal tuff (found within the northern body), and some small aplitic veins and dykes. Almost all the apophyses consist of porphyry of intermediate composition. The hornblende-biotite microgranodiorite is fairly uniform and has a plagidiomorphic texture (Pl. 10, fig. 2). It contains quartz (20%), plagioclase (45%), potash feldspar (14%), hornblende and biotite (20%), and accessory iron oxide, sphene, zircon, and apatite (1%).

The quartz is mostly unstrained allotriomorphic and to some extent interstitial. Graphic intergrowths of quartz and potash feldspar occur in some specimens. Raguin (1965) calls this texture micropegmatite and suggests that it is due to corrosion of the feldspar by quartz. Plagioclase occurs mainly as idiomorphic tabular zoned crystals of labradorite (An_{50-54}). Most of the crystals are crazed and slightly sericitized from the core outward. The potash feldspar is predominantly orthoclase with minor microcline, and occurs mostly as irregular grains moulded on plagioclase. The orthoclase has been partly kaolinized, but the microcline is less altered. The mafic minerals include partly and completely chloritized and epidotized hornblende and biotite crystals. The accessory minerals are iron oxide and small discrete grains of sphene, zircon, and apatite. The margins of the batholiths are noticeably finer in grain, and tend to be somewhat porphyritic.

The abundance of strongly zoned plagioclase crystals and the presence of quartz-feldspar intergrowths suggest rapid cooling of the magma and high-level emplacement.

Karawari intrusives

The Karawari intrusives are much more variable than the Yuat intrusives, and although the most of them range from tonalite to diorite, many are more basic. Some dacite crystal tuff occurs in the western extremity of the batholith. The massif was not examined in detail because of the rugged topography, and many of the rock types were seen only as boulders in streams.

Pyroxene-quartz gabbro is common. It consists of tabular crystals of labradorite (An_{60-64}), irregular grains of clinopyroxene, and a little interstitial quartz and kaolinized feldspar. Opaque minerals form 2 to 5 percent of the rock. The gabbro has a hypidiomorphic granular texture, similar to the finer-grained Yuat intrusives. Compared with the microgranodiorite of the Yuat intrusives, hornblende and biotite are generally present in small amounts only, or are absent, pyroxene is commonly predominant, and the plagioclase is much more basic.

The pyroxene-quartz gabbro grades into porphyritic quartz diorite composed of phenocrysts of zoned plagioclase (An_{45-15}) in a groundmass of quartz, ferromagnesian minerals, and small granules of opaque minerals. Hornblende and pyroxene are almost invariably present, and there is generally a little biotite. In rare cases biotite is predominant.

The basic phases of the complex have a wide range in composition and are intimately mixed. Hornblende gabbro, hornblendite, pyroxenite, and anorthite gabbro are common. The anorthite gabbro is almost identical with the gabbro associated with the April Ultramafics and has a distinctive gabbroid or granulitic texture. It is composed of clear fresh subhedral laths and rounded grains of anorthite (An_{95-100}), clinopyroxene partly or wholly altered to green-brown hornblende, rounded and embayed blebs and aggregates of magnetite, and small discrete grains of sphene, apatite, and epidote. Some varieties are pegmatitic and contain hornblende crystals up to 4 cm long. The wide variety of rock types within the batholith suggests that they have been formed by differentiation of basic magma.

Yuat and Karawari porphyries. Microporphyritic varieties occur in the border zones of the larger bodies and as numerous small stocks and dykes. The porphyritic marginal zones are up to about 100 m wide with a gradual transition from porphyritic microdiorite to normal granodiorite. The majority of the porphyritic apophyses are found within the Salumei sediments surrounding the northern Yuat batholith and Karawari batholith. Most are small bodies about 100 m across and many were seen only as boulders in streams. The presence of numerous small intrusions is revealed by the persistence over large distances of boulders in the streams.

The leucocratic porphyritic microdiorite generally contains up to 5 percent quartz and 40 percent plagioclase (An_{50-55}) as phenocrysts with 30 to 70 percent of altered feldspathic groundmass. The phenocrysts, especially the quartz, are commonly embayed or corroded, and the groundmass is finely crystalline. The plagioclase is generally twinned, zoned, and strongly sericitized. The melanocratic types contain pyroxene and hornblende, but lack quartz. Some hornblende phenocrysts show ironstained reaction rims and most are corroded and chloritized. Many of the porphyritic bodies contain 5 percent (and some as much as 10%) disseminated pyrite.

The texture of the rocks and the nature of the phenocrysts clearly indicate that the porphyries crystallized under subvolcanic conditions, and they are indistinguishable from many of the nearby volcanic rocks of the Tarua Volcanic Member.

Comparison of Yuat and Karawari intrusives. The Karawari and Yuat intrusives show fairly consistent differences. They may have been formed from different magmas, but as each intrudes different rock types (Tertiary Salumei Formation in the case of Karawari intrusives and mainly Mesozoic Kana Formation and Maril Shale in the case of Yuat intrusives) the differences may be due to contamination. Contamination may also explain the atypical Yuat intrusive in the northwestern part of the northern batholith where it intrudes the Salumei Formation. The contaminated rocks closely resemble the Karawari intrusives, and both contain pyroxene and olivine (11NG1170A,E,D; Pl. 11, figs 1 & 2). Alternatively they could be hybrids formed by the mixing of granodioritic and basic magma.

A recent geochemical survey of the area by W. J. Atkinson of C.R.A. Exploration Pty Ltd (1967, unpubl.) has revealed differences in the trace metal content of the Yuat and Karawari intrusives that can be related to the composition of the adjacent sediments. The mean copper content of the intrusives reflects these differences: the Yuat intrusives contain 31 to 32 ppm copper; the Karawari intrusives contain 56 ppm. The mean copper content of Mesozoic sediments intruded by the Yuat intrusives is significantly lower (28 ppm) than that of the Salumei Formation (45 ppm) intruded by the Karawari intrusives.

The Karawari intrusives also have a correspondingly higher concentration of nickel and silver. Some gold production is associated with these rocks of higher silver content (e.g. Timun River).

Porgera intrusives

The Porgera intrusives consist of a number of small irregular stocks and dykes of porphyritic microdiorite with minor monzonite and soda trachyte.

The microdiorite contains phenocrysts of sericitized andesine, with subordinate chloritized and sericitized granules of augite and pale yellow-brown anhedral chloritized hornblende. The groundmass is composed of highly altered finely crystalline plagioclase, augite, hornblende, iron oxide, and apatite. Although a small amount of quartz occurs as anhedral granules it is thought to have been formed by deuteric alteration of the primary constituents. Much carbonate material and other alteration products are present.*

In the vicinity of Porgera the porphyry has presumably mineralized the Lagaip Beds and gold is being shed from stockworks of quartz veins in the country rock.

Petrogenesis and mode of emplacement of the Maramuni Diorite. In a differentiated intrusion an early basic phase is commonly formed along the roof or borders of the batholith. The abundance of fine-grained basic rocks in the Maramuni Diorite, especially in the Karawari intrusives, probably indicates that only the top of the body has been exposed. 'The rocks which follow constitute a more acidic phase and may dislocate and partially modify the portions first crystallised' (Raguin, 1965, p. 132). This is clearly illustrated in large boulders in the upper Karawari River, where multiple injection and brecciation of several rock types can

* Petrographic determination by AMDL (Dekker & Faulks, 1964, unpubl.).

be seen. Similarly, tonalite and gabbro at the head of a small tributary of the Lamant River have been dislocated and cemented by granodiorite and porphyritic pyroxene leucodiorite. It is thus assumed that most of the rocks in the Maramuni Diorite were formed by differentiation, probably from a granodioritic magma. However, the effects of assimilation can be seen at many places along the border of the batholith. The border zone is rich in xenoliths and veined with aplite, and has a heterogeneous porphyritic texture. Orbicular structures have been observed in the granodiorite in the Lamant River (Pl. 12, fig. 1). It is generally considered (Raguin, 1965; Johannsen, 1941; Palmer, Bradley, & Prebble, 1967) that the orbs are due to the partial assimilation and recrystallization of foreign inclusions or the segregation from the same magma (Johannsen, 1941). Assuming the nucleii to be small inclusions, Eskola (1938) explained the orbicular facies as a metasomatic process with crystallization directed outwards from the centre of the orbicules (i.e., centrifugal migration of more basic material into the surrounding granite).

The inclusions are commonly ringed with mafic minerals, especially biotite, followed by a fringe enriched in feldspar. However, where the inclusions are abundant the fringes are diffuse and discontinuous. According to Raguin (1965, p. 79) biotite fringes do not necessarily imply important migration of material, although Walton (1952) describes biotite fringes derived from hornblende by potash diffusion from the surrounding granite. Such a transformation appears to be the case in many inclusions in the Maramuni Diorite (e.g. 12NG0512). The inclusions are mostly small (5-10 cm), but many larger angular blocks and rounded 'pillows' up to several metres in diameter occur. The basic 'pillows' are similar to those described by Blake (1966), but not nearly so numerous.

The many dykes and apophyses that accompany the main intrusive bodies appear to have crystallized under conditions similar to volcanic rocks. A period of volcanism commenced at a late stage of the emplacement and crystallization of the plutonic rocks, and the andesitic and dacitic tuffs and lavas in the overlying Tarua Volcanic Member of the Burgers Formation represent a continuation of this volcanic episode.

The Salumei Formation around the Karawari massif has been slightly domed by the Karawari intrusives. The volume of the intrusive rocks, however, is much larger than the space provided by the updoming, and the intrusion was probably emplaced by faulting and stoping. Most of the contacts are faulted.

The nature of intruded sediments of the Salumei Formation away from the narrow metamorphic aureole, and the petrographic evidence of rapid cooling, suggest that the Maramuni Diorite may have been emplaced at a depth of 1 500 to 3 000 m.

Age of intrusion. All the intrusive bodies constituting the Maramuni Diorite, with the possible exception of the Porgera intrusives, are probably middle Miocene in age.

Karawari intrusives have intruded the Pundugum Formation (upper Oligocene to lower Miocene, Tertiary e Stage), but are not known to have intruded younger rocks. Very soon after intrusion, the diorite must have been faulted up about 1 000 m, thereby becoming exposed to erosion, since pebbles of the diorite are found in increasing quantities towards the top of the Karawari Conglomerate (Tertiary f_{1-2} Stage). The presence of interbedded lavas and diorite-pebble conglomerite in the lowermost part of the Karawari Conglomerate suggests that some volcanic activity connected with the pluton continued throughout the period of erosion.

The Yuat intrusives could possibly be older, because over most of the region they intrude only Mesozoic rocks. The northwestern part of the northern batholith, and part of the southern batholith in the Lamant River area, intrude the Salumei Formation, but these rocks are not typical of the Yuat intrusives, and more closely resemble the Karawari intrusives. However, the slight difference in composition in these restricted areas is more likely to be due to assimilation of the Salumei Formation or another magma.

Although the Porgera intrusives intrude the Upper Cretaceous Lagaip Beds they show a marked similarity to the middle Miocene Frieda Porphyry and it is possible that they are not related to the Maramuni Diorite.

Frieda Porphyry
(new name)

Frieda Porphyry is the name proposed for a number of predominantly porphyritic intrusive bodies, ranging from small stocks and dykes to bodies 10 km across, in an area about 30 km south of the May River Patrol Post (Fig. 10). Although these rocks are similar to the Maramuni Diorite mapped farther east, they are separated from them by an area of metamorphic rocks and ultramafic intrusions.

Most of the smaller bodies are composed of hydrothermally altered hornblende andesite porphyry (P. 12, fig. 2) and tuff. The large bodies to the north of the Frieda Fault consist predominantly of microdiorite, microgranodiorite, and micromonzonite, and have a subporphyritic texture. Some of the intrusions have a granular texture (03NG0038). Hydrothermal alteration has resulted in the formation of alunite, sericite, chlorite, albite, quartz, kaolinite, and epidote in varying amounts and combinations. The tuffs have been altered to a distinctive white iron-stained (limonite after pyrite) rock (03NG2537) containing about 70 percent alunite, 20 percent quartz, and 10 percent finely disseminated pyrite. The hydrothermal alteration in both the andesite tuff and porphyries appears to be intimately linked with the sulphide mineralization which is particularly widespread in these intrusive bodies (see p. 00).

There is conflicting evidence as to the age of the Frieda Porphyry, and it may consist of intrusives of two different ages.

The smaller more porphyritic stocks south of the Frieda Fault intrude Tertiary f_{1-2} Stage sediments. The volcanic rocks associated with the porphyry are interbedded with marine sediments which appear to be overlain conformably by Tertiary f_{1-2} Stage limestone. Thus it appears that the southern bodies were intruded during the early part of the Tertiary f_{1-2} Stage, that is, at the same time as the Maramuni Diorite.

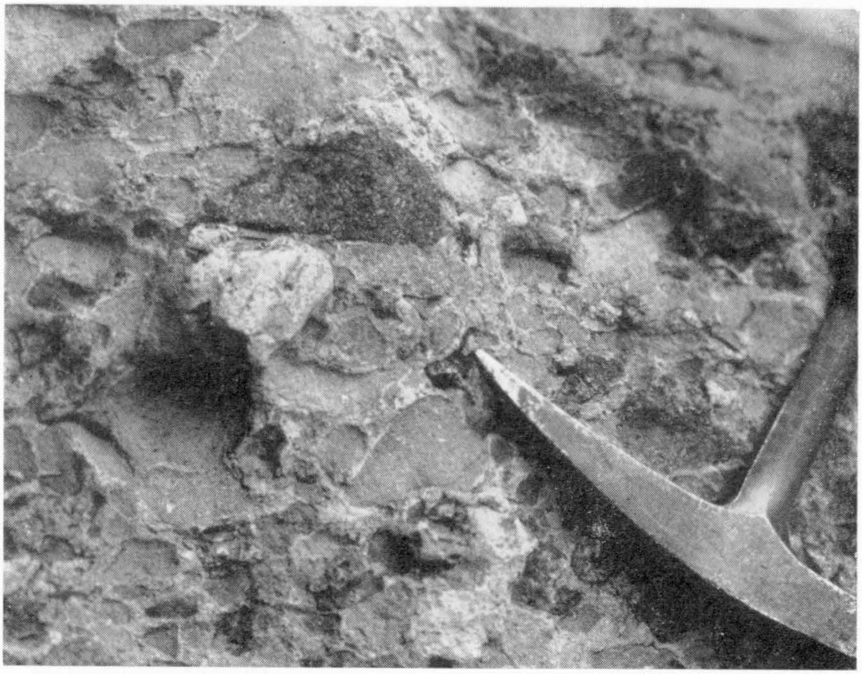

Plate 9, Figure 1. Basaltic to andesitic agglomerate near the base of the Karawari Conglomerate on the eastern side of the Arafundi River.

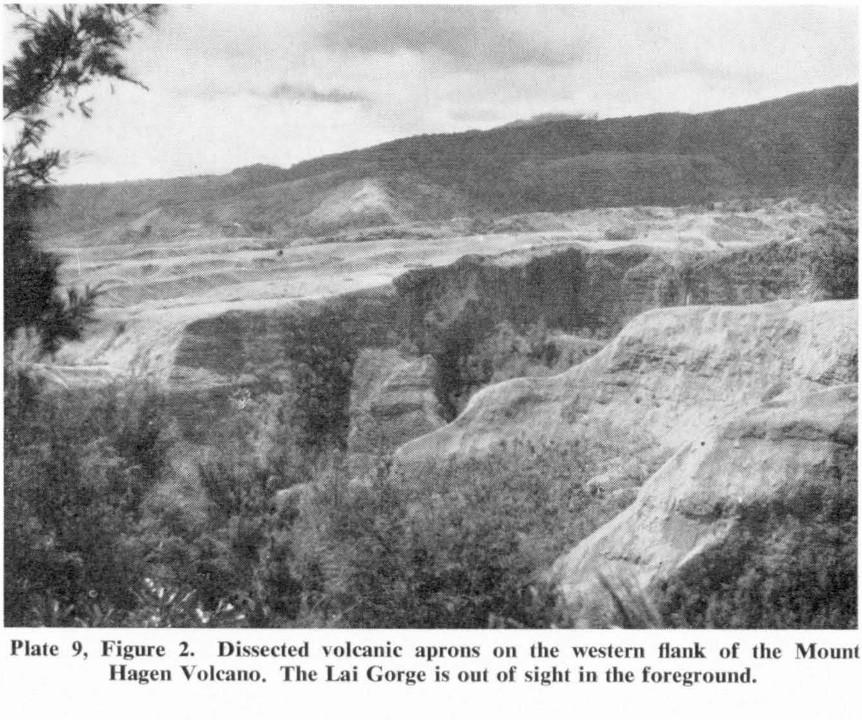

Plate 9, Figure 2. Dissected volcanic aprons on the western flank of the Mount Hagen Volcano. The Lai Gorge is out of sight in the foreground.

Plate 10, Figure 1. Subaerial volcanic ash in road cutting between Wapenamanda and Wabag. The beds belong to either the Mount Hagen Volcanics or the Sugarloaf Volcanics.

Plate 10, Figure 2. Hornblende-biotite microgranodiorite of the Maramuni Diorite in the lower Maramuni River. The rock consists of quartz(Q) and potash feldspar(KF) moulded on tabular crystals of plagioclase(P), with discrete crystals of hornblende(H) and biotite(Bi). x 35. (11NG1150).

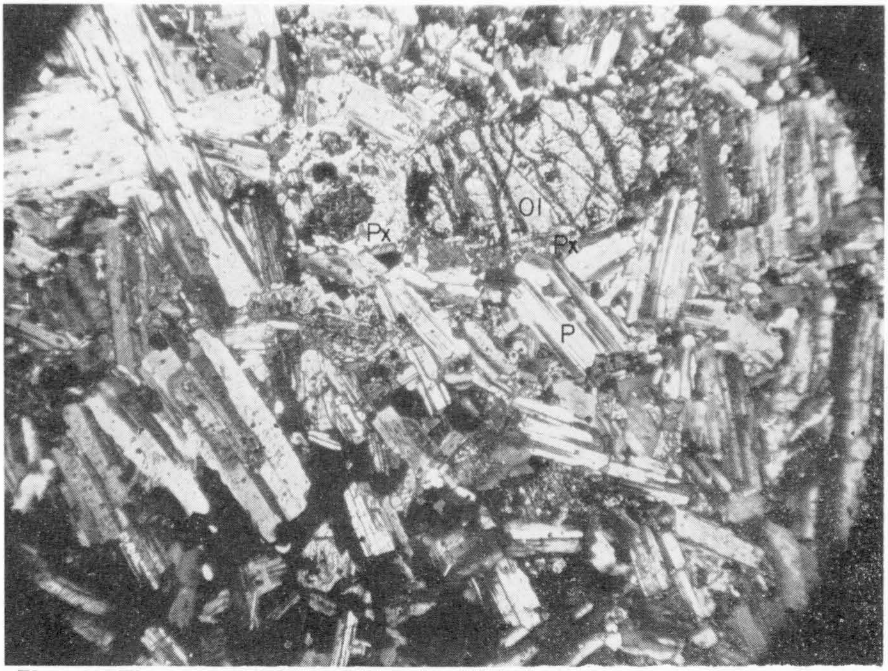

Plate 11, Figure 1. Olivine-bearing pyroxene diorite of the Maramuni Diorite in the lower Arafundi River area. Note the granular pyroxene(Px) mantling the olivine(Ol) phenocryst and filling the interstices between the interlocking plagioclase crystals(P). x 35. (11NG1170).

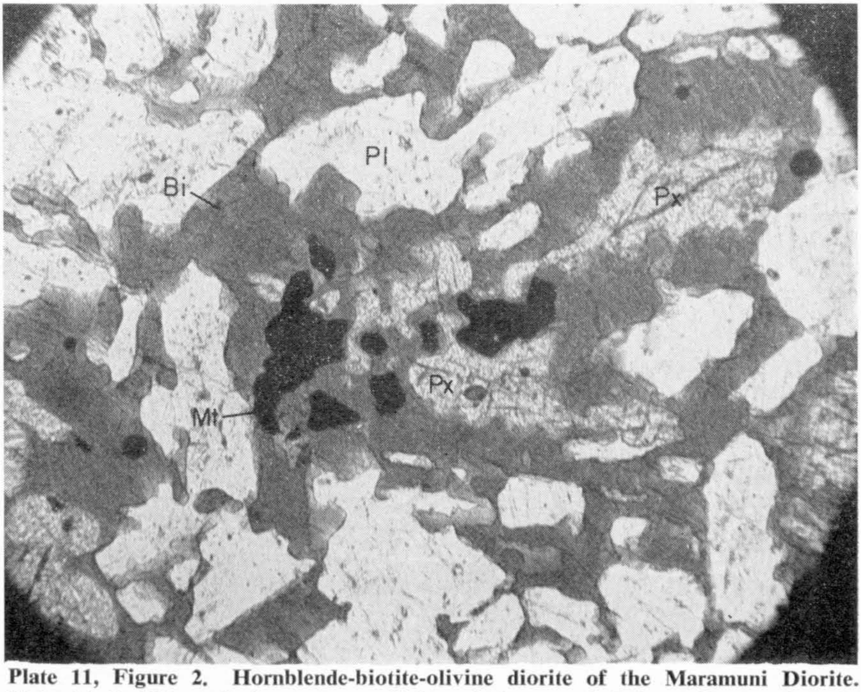

Plate 11, Figure 2. Hornblende-biotite-olivine diorite of the Maramuni Diorite. Note biotite(Bi) replacing pyroxene(Px) and the rounded 'granulite type' grain boundaries revealed under high magnification. x 80. (11NG1170E).

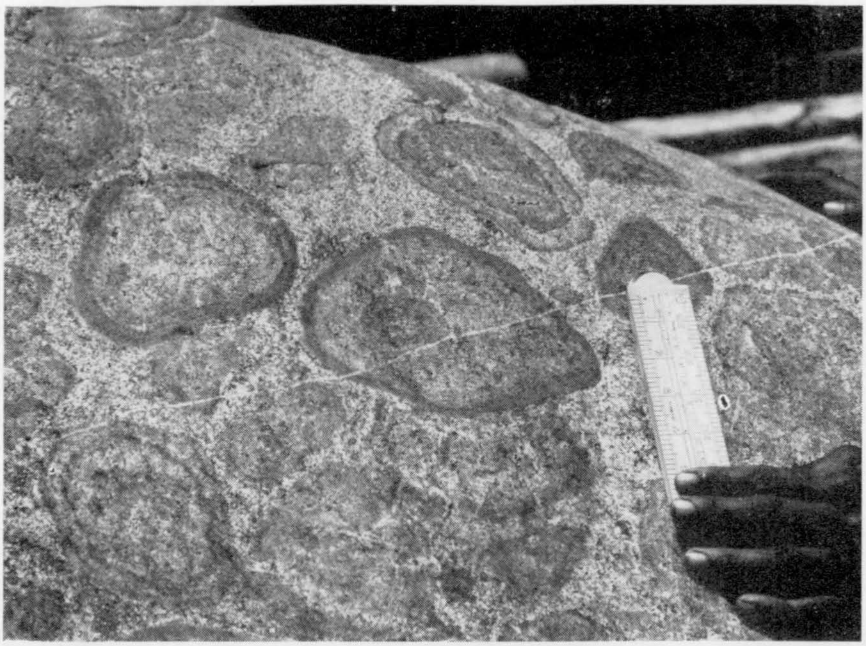

Plate 12, Figure 1. Boulder of orbicular granodiorite/diorite from the Lamant River, a tributary of the Tarua River. The orbicules have an outer mafic shell and well defined boundaries. (12NG0508).

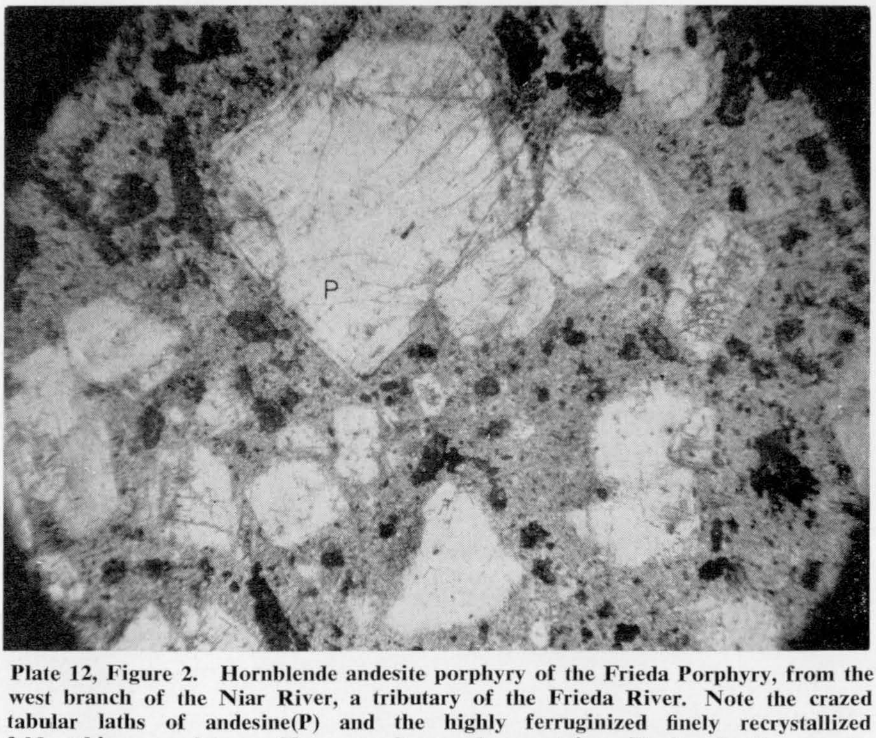

Plate 12, Figure 2. Hornblende andesite porphyry of the Frieda Porphyry, from the west branch of the Niar River, a tributary of the Frieda River. Note the crazed tabular laths of andesine(P) and the highly ferruginized finely recrystallized feldspathic groundmass. The groundmass also contains chlorite, kaolin, quartz, sericite, and disseminated granules of pyrite. x 35. (03NG2513C).

The larger bodies north of the Frieda Fault are overlain unconformably by the f_{1-2} Stage Wogamush Beds and could be the same age as the Maramuni Diorite; but they could be older, as they intrude the Ambunti Metamorphics.

Mackenzie & Bain (1968, unpubl.) have shown that the porphyritic bodies can be divided into three groups:

Hornblende andesite porphyry composed of phenocrysts of plagioclase (30-65%) and phenocrysts of hornblende and pyroxene (10-20%) set in an altered feldspathic groundmass (25-60%) containing 2 to 5 percent of disseminated iron oxides.

TABLE 2. ESTIMATED MODES OF FRIEDA PORPHYRY

Rock Type (Locality, Spec. No.)	**Plagioclase (%)** (* = zoned)	**Quartz (%)**	**Hornblende (%)**	**Opaque Minerals (%)**	**Chlorite (%)**	**Sericite (%)**	**Alunite (%)**	**Notes**
Hornblende-andesite porphyry								
Discovery Cr. (03NG1053)	50 (An_{42})	5-10	—	3	15	10	—	Extensively altered; hornblende replaced by chlorite. 10% calcite
Nena R. (03NG2536)	40 (An_{34})	—	20	—	—	—	—	Extensively altered; kaolinized granular groundmass; contains epidote
Nena R. (03NG2540)	65*	—	5-10	5	—	—	—	Strongly ferruginized glassy groundmass containing kaolinite, chlorite, and disseminated pyrite; plagioclase strongly fractured and incipiently sericitized
Discovery Cr. (03NG3070)	70 (An_{35})*	5	1	2	5	5	—	Strongly altered; many replacement minerals; 5% biotite
Quartz diorite/monzonite porphyries								
Hornblende diorite. Nena R. (03NG1046)	62 (An_{44})*	8	15	1	—	—	—	Potash feldspar, 10%; sphene, tr.
Porphyritic hornblende-biotite diorite. Discovery Cr. (03NG3077)	65 (An_{37})*	5	10	5	3	5	—	Partially altered; 5% biotite, 1% apatite, and 1% epidote
Hornblende monzonite. Nena R. (03NG3101A)	(An_{44})*							Potash feldspar, 10%; sphene, 1%
Altered tuffs and lavas								
Alunitized andesitic tuff. Discovery Cr. (03NG0031A)	5-10 (albite?)	40	—	5	—	—	45	
Alunitized andesitic tuff. Nena R. (03NG2535)	3 (albite?)	15	—	7	—	—	75	
Alunitized andesitic lava/tuff(?). Nena R. (03NG2537)	5 (albite?)	65	—	5-10 (limonite)	—	—	20-25	Zircon, 1-3%

The plagioclase consists mainly of strongly zoned idiomorphic fractured crystals of andesine, showing signs of incipient sericitization. Many of the crystals are short and stumpy, and have rounded ends. In some of the rocks the plagioclase crystals are extensively fractured and the fragments slightly displaced. The chief mafic mineral is ironstained brown corroded euhedral hornblende much of which has been partly or completely chloritized. Some clear relatively unaltered euhedral pyroxene crystals may be present.

The groundmass commonly consists of highly ferruginized finely recrystallized glassy feldspathic material. It is generally strongly kaolinized with patches of chlorite, calcite, quartz, sericite, and iron oxide. In many specimens the groundmass contains plagioclase microlites which tend to be aligned parallel to the crystal faces of the phenocrysts. The opaque minerals consist of clusters and finely disseminated granules of pyrite, much of which has been altered to limonite.

Altered tuffs and lavas (?), so extensively altered that their original composition and texture are indecipherable. Some have been altered to sericite, quartz, albite, and chlorite; others have been almost completely altered to an irregular mosaic of alunite and quartz. Numerous small angular fragments of zircon(?) and apatite(?) occur throughout many of the specimens (especially 03NG2537). Finely disseminated pyrite, with some chalcopyrite and chalcocite, commonly forms up to 10 percent of the rock. In places it is altered to reddish brown limonite.

Quartz diorite and monzonitic porphyries containing 50 to 75 percent of zoned twinned idiomorphic crystals of andesine (An_{43}) and 5 to 10 percent interstitial quartz. Up to 25 percent potash feldspar may be present as large poikilitic plates moulded on plagioclase. The remainder of the rock consists mostly of subhedral greenish brown hornblende (12-25%) and accessory sphene and apatite. Opaque minerals form 2 to 3 percent of the rocks. Some of the hornblende is partly altered to chlorite and some of the plagioclase is sericitized.

STRUCTURE

New Guinea Mobile Belt

Broadly speaking the region south of the Lagaip Fault Zone is structurally part of the stable Australian continent (Fig. 7), whereas the northern region is a small segment of a tectonically unstable belt called here the New Guinea Mobile Belt. The Mobile Belt wraps round the northern margin of the Australian continent and forms the transition from continental to oceanic crust.

The Mobile Belt has been broken into a great many long narrow wedges by a complex system of great faults or fault zones, most of which have vertical displacements exceeding 1 500 m; displacements of the order of 6 000 m are not uncommon. Where seen the faults are mainly subvertical, are of great length (some have been traced with reasonable certainty for 800 km), and have straight or gently curved traces. The possibility of transcurrent displacement cannot be discounted.

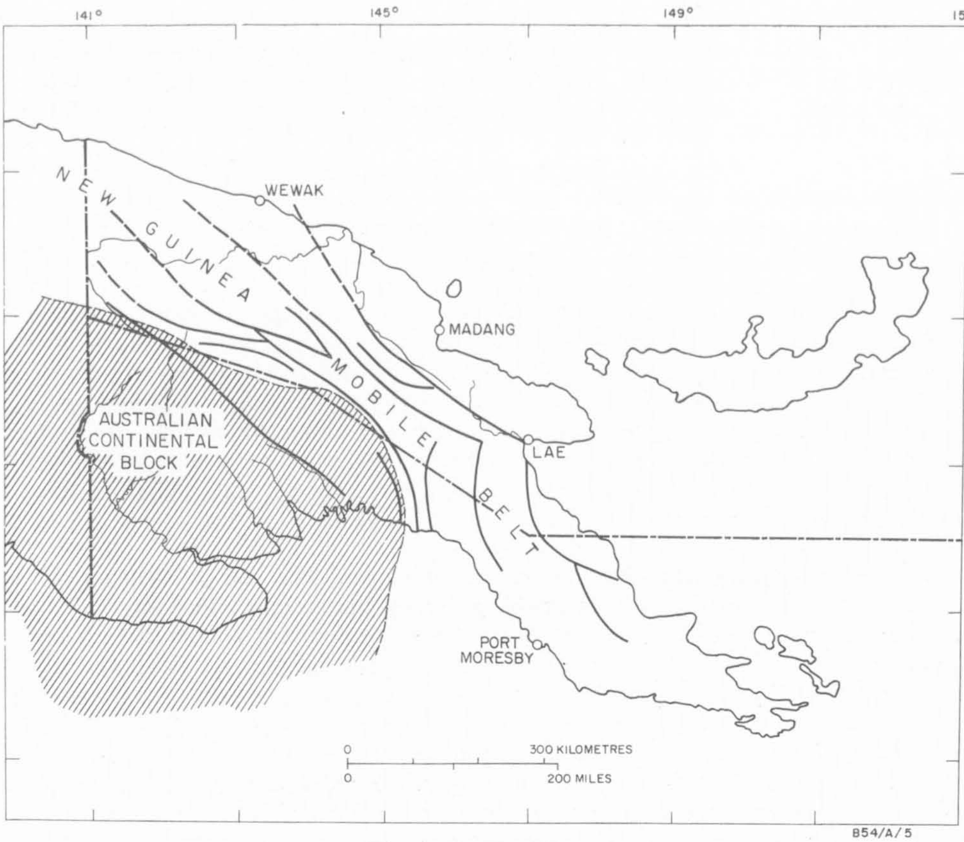

Figure 7. Post-Mesozoic structure

Most of the folds trend west-northwest parallel to major faults. In the eastern half of the area on the northern fall of the Central Range, the Cretaceous to Tertiary strata are broadly and simply folded, although steep dips are common near major fault zones. Farther west, deformation of the Cretaceous and lower Tertiary rocks (principally the Salumei Formation) becomes more intense: cleavage and small folds on outcrop scale testify to the presence of major folds, the nature of which is largely unknown. In the headwaters of the Leonard Schultze River folding and faulting combine to produce a virtual melange of low-grade metamorphics, coarse glaucophanitic schists (Gufug Gneiss), eclogite, and ultramafics.

Along the foot of the mountains to the south of the Sepik Plains, the middle Miocene sediments (Wogamush Beds, Karawari Conglomerate) form broad basin-like structures. In the Burgers Mountains, however, the Burgers Formation of equivalent age is folded into an almost isoclinal syncline, the southern limb of which is overturned.

South of the Lagaip Fault Zone in the Porgera area the Tertiary sediments are complexly folded.

Faults

The faults of the South Sepik region are concentrated in zones, several kilometres wide, which consist of several major shears (Fig. 8). They trend generally west-northwest, though local flexures occur, such as the change to an east-west trend shown by both the Lagaip Fault Zone and the Frieda Fault in the western part of the map area. The Bismarck Fault Zone and the Jimi Fault also trend at an angle to the regional trend in the map area, though on a regional scale this is also seen as only a local flexure. The zones form part of an anastomosing pattern which is characteristic of the New Guinea Mobile Belt.

The faults generally show up on the air-photographs as discontinuous lineaments defined by straight stream courses, straight escarpments, or narrow trenches. The fault zones are susceptible to erosion, and good exposures are rare, but wherever seen they consist of zones of mylonitization and shearing up to 400 m wide. Sheared and plastically deformed horsts about 100 m long are commonly incorporated in the zones, and lenses over 1 000 m long are not uncommon. The faults almost invariably dip within a few degrees of vertical, and their trace is little affected by topography.

The total displacement on the faults is not known. The vertical displacement can generally be calculated with reasonable accuracy, but there is almost no evidence showing the magnitude, or even the sense, of any transcurrent component, though the general characteristics of the faults strongly suggest that they are predominantly transcurrent.

The *Jimi Fault* is exposed at several places in the Yuat Gorge, where it is marked by zones about 100 m wide of cataclasite, mylonite, and sheared dacite porphyry. The shear zones, where seen, are subvertical, but there are no indications of the total displacement. The eastern block has been downthrown by at least 4 500 m since Upper Cretaceous time, but it is not known when the movement took place.

The *Bismarck Fault Zone* in the map area is about 6 km wide and consists of several steeply dipping and anastomosing faults. It has brought the Salumei Formation and Karawari Conglomerate in contact with Mesozoic rocks—a downthrow to the west of at least 3 000 m.

Some of the major faults of the zone are crossed by the Maramuni Diorite, which is apparently little affected, and it seems that most of the displacement occurred before the intrusion of the diorite in the Tertiary f_{1-2} Stage. This could explain the weak topographic expression of the fault over most of its length.

The *Karawari Fault Zone* has downthrown Tertiary f_{1-2} Stage rocks to the north by about 4 500 m. As would be expected of a fault with such a large amount of recent displacement, it has a very prominent topographic expression over most of its length: it is bounded to the south by the steep northern face of the Burgers Mountains, and is marked by the straight valley of the upper Karawari River.

The Karawari Fault Zone could not be traced in the Sepik Plains, but a fault mapped in the middle reaches of the April River is almost certainly part of its northwestern extension.

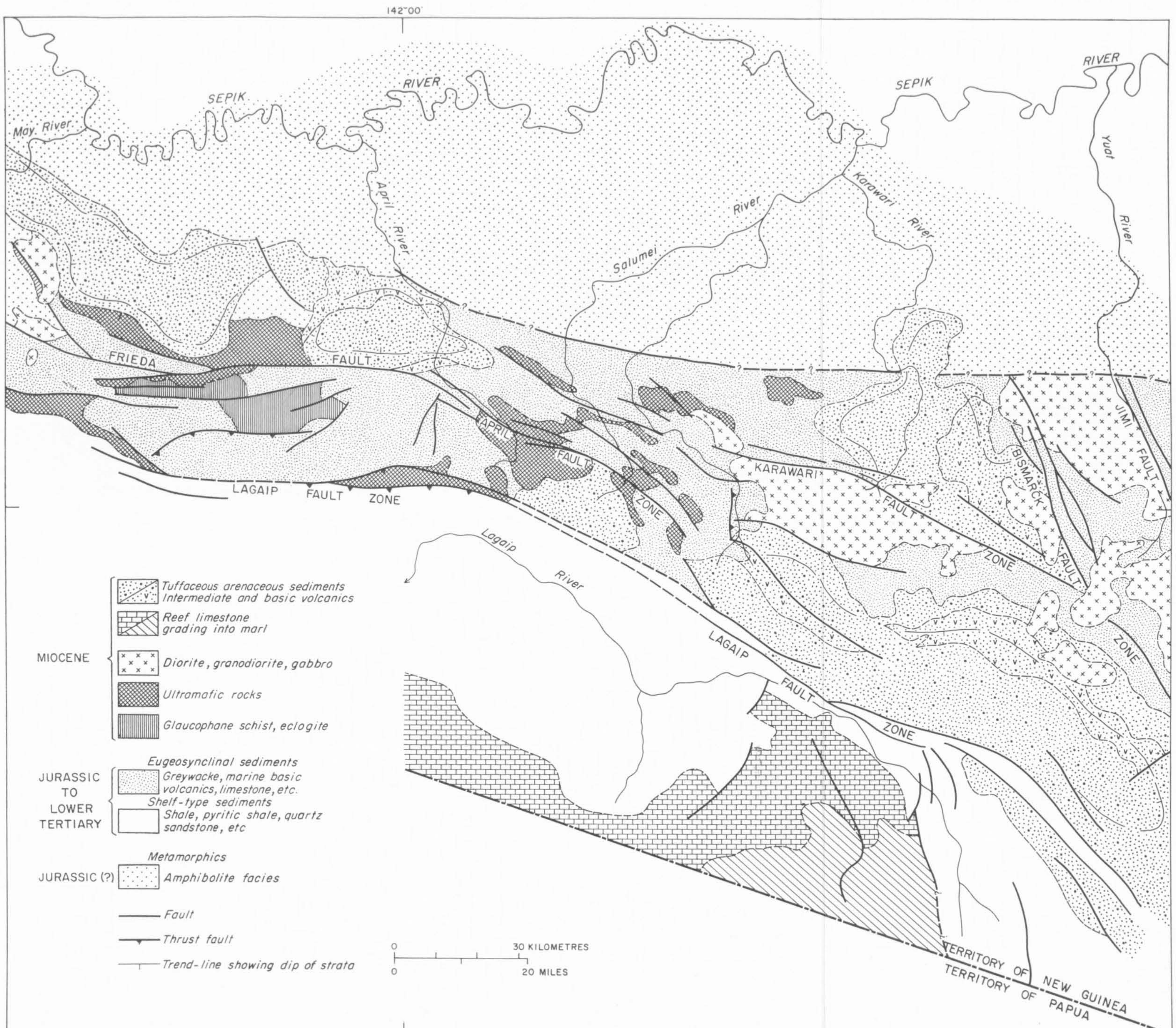

Figure 8. Structural map

The *April Fault Zone* is roughly parallel with the Karawari Fault Zone and has similar characteristics. Its southeastern and northwestern extremities have not been traced—to the southeast it was lost in the rugged mountains of the main range, and it is overlain by Wogamush Beds to the northwest.

As fault wedges of the Burgers Formation have been incorporated into the fault zone in the southeast some post-f_{1-2} Stage movement has taken place, but most of the movement is older, because the main faults do not displace the Wogamush Beds.

The *Frieda Fault* trends roughly east-west and has a profound influence on the topography of the South Sepik region. It is marked by a narrow trench over its whole length, and the dramatic change in course of the main rivers where they cross the fault suggests that considerable transcurrent movement has taken place recently. The northwestern extension of the fault was not mapped, but a strong topographic break can be seen from the air trending west-northwest across the May River into the unmapped country of the West Range.

The Frieda Fault has been seen in outcrop only along the Leonhard Schultze River, where it consists of a steeply dipping shear zone, at least 30 m wide, in the Salumei Formation and serpentinite. In places highly altered gabbro is incorporated in the shear zone.

The only proven displacement on the Frieda Fault occurred after the Tertiary f_{1-2} Stage, when the Wogamush Beds were downthrown about 1 000 m to the north.

The *Lagaip Fault Zone* marks the boundary between the moderately deformed Mesozoic and Tertiary rocks to the south, and the New Guinea Mobile Belt to the north. It also marks the change from pyritic black shale in the south to eugeosynclinal sediments containing basic marine volcanics in the north. It has little topographic expression and can seldom be confidently traced on the air-photographs. Some of the other fault zones in the region have little topographic expression because there has been little movement on them since the Tertiary f_{1-2} Stage, but the Lagaip Fault Zone has been active until Recent time. For instance, Lake Iviva was formed by warpings associated with recent movement on one of the faults of the zone, and the extrusion of the Sugarloaf Volcanics appears to have been controlled by the southeastern extension of the fault zone. Thus the lack of topographic expression must have some other explanation: it is possibly due to the relatively small amount of vertical displacement, which rarely exceeds 600 m.

The fault zone has been mapped with varying reliability for 290 km from Mount Giluwe to the western margin of the map area. To the southeast the fault zone is obscured by the Pliocene and Pleistocene volcanics of Mount Giluwe, and in the west it probably extends into West Irian.

Inferred fault bounding the Sepik Plains. Between the April and Karawari Rivers the Salumei Formation makes a straight contact with the Ambunti Metamorphics. Exposures are poor in this region of low weathered hills, but it is thought that the contact is an east-west fault which joins with the April Fault Zone in the middle reaches of the April River. The Karawari Conglomerate is not affected where it crosses the fault in the Karawari River, so any movement must have taken place before the Tertiary f_{1-2} Stage; this would explain the weak topographic expression of the fault.

The throw on the fault is not known, but the juxtaposition of high-grade metamorphics and unaltered Salumei Formation suggests that the southern block has been downthrown thousands of metres.

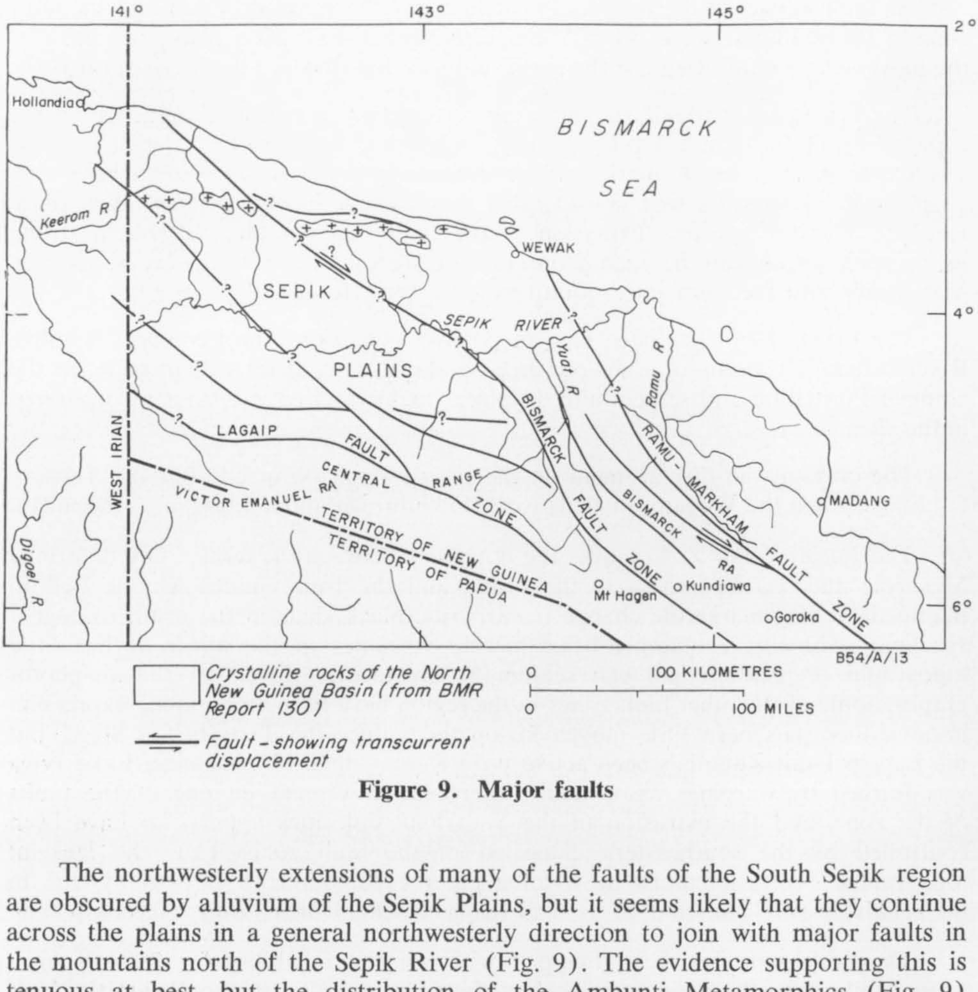

Figure 9. Major faults

The northwesterly extensions of many of the faults of the South Sepik region are obscured by alluvium of the Sepik Plains, but it seems likely that they continue across the plains in a general northwesterly direction to join with major faults in the mountains north of the Sepik River (Fig. 9). The evidence supporting this is tenuous at best, but the distribution of the Ambunti Metamorphics (Fig. 9) suggests that they occur in two fault blocks bounded on the northeast by these faults: the first fault is an extension of the Bismarck Fault Zone which passes northeast of Ambunti; and the second is an extension of the Karawari Fault Zone which passes northeast of the May River Patrol Post. Both these postulated extensions coincide with marked changes in the course of the Sepik River which may owe their origin to recent vertical movement on the faults.

If it is accepted that the fault zones cross the Sepik Plains, it can be seen that they join with major faults which displace the crystalline rocks of the North New Guinea Basin (Marchant, 1968).

Transcurrent displacements on the faults. Though it cannot be proved, we suspect that the fault zones of the South Sepik region are predominantly transcurrent.

In common with faults of known transcurrent displacement in New Zealand (Wellman, 1952; Suggate, 1963) the major faults are characterized by their great length, steeply dipping fault planes near the surface, and straight or gently curved traces. Many streams change direction abruptly where they cross those faults showing recent displacement, but only rarely is the change in direction a reliable indication of the direction of the transcurrent movement. A major fault in the Bismarck Range northwest of Goroka (Fig. 9) has been shown fairly conclusively (Dow & Dekker, 1964, unpubl.) to have undergone right-lateral movement of at least 2 100 m since the major river valleys were formed.

The only indication of transcurrent movement on the faults in the Sepik region is the apparent 25 km right-lateral displacement of the crystalline core of the mountains north of the Sepik River, by the extension of the Bismarck Fault Zone.

If this picture of right-lateral transcurrent faulting is accepted, then the local development of the Salumei metamorphics between the April and Frieda Rivers is explained. The major faults in this region trend roughly east-west (Fig. 5), and the area between the Lagaip and Frieda Faults is therefore one of maximum compression where low-grade metamorphism would be expected. One would also expect the faults to have an overthrust component where they trend east-west: this appears to be the case with the Lagaip Fault Zone, for the ultramafic rocks in this area are bounded by faults which dip between 30° and 50° to the south. The Frieda Fault however is steeply dipping in the locality where its attitude could be determined (i.e., in the Leonhard Schultze River). The Gufug Gneiss is restricted to the same area, and it is conceivable that in such a compressive environment, tectonic overpressures could be produced to form the high-pressure metamorphics characteristic of the gneiss.

It is also considered significant that the Maramuni Diorite is absent from this zone (Fig. 8), because the less compressive areas to the east and west would be a more favourable environment for these intrusions.

Previously it has been assumed that the lowlands of the Sepik Plains were caused by faults trending roughly east-west (e.g. Krause, 1965), but the distribution of the Sepik swamps shown in Figure 9 suggests that they were probably controlled by the Bismarck and Karawari Fault Zones where they cross the Sepik Plains. It is postulated that the swamps are areas of downwarping resulting from recent compressive forces acting in a roughly northwesterly direction—the same forces that produced the transcurrent displacements on the faults.

ECONOMIC GEOLOGY

Almost all the South Sepik region is inaccessible, but in several areas the geological environment is favourable for the occurrence of large-tonnage low-grade orebodies, and despite the handicaps imposed by the remoteness of the area, it is recommended that further prospecting work be carried out.

The most promising is the Frieda River copper prospect, which is an area of several square kilometres in which disseminated copper mineralization is associated with hydrothermally altered stocks and dykes of andesite porphyry. Also promising are the large areas of dunite and peridotite exposed over about 1 000 km^2 of the South Sepik region, some of which may contain lateritic concentrations of nickel and cobalt.

Alluvial gold and platinum are found in many of the streams draining the Central Range, but only in the April River are prospects thought to be worth further investigation. No testing for gold was done on the alluvials in the western tributaries of the Frieda River, but it is possible that economic deposits may be present.

Regional Geochemistry

To aid in the location of mineralized zones, samples of stream sediment were collected from the main streams and small tributaries throughout the area and analysed in the Bureau of Mineral Resources laboratory at Canberra. Wet samples of sediment from the stream beds were sieved in the field through 80-mesh nylon screens into small plastic bags. Excess water was poured off, and the bags sealed. Analysis was made at the end of the field season by an atomic absorption spectrophotometer.

The locations of the 246 samples analysed and the results are given by Dow et al. (1968).

Two areas of anomalously high copper values were delineated. In the Frieda prospect area maximum values (980 ppm) are as much as 24 times background (40 ppm), whilst a lesser anomaly of 120 ppm (3 times background) is revealed in the headwaters of the April River. Anomalously high nickel values (up to 1 760 ppm) are found on and around the ultramafic rocks, especially along the April River.

The anomalous areas are discussed in more detail in the sections on copper and nickel. When the report on the Bureau's 1966 field season was released (Dow et al., 1967, unpubl.), C.R.A. Exploration Pty Ltd carried out a reconnaissance geochemical survey of the area covered in that report as well as part of the Schrader Range and Hunstein Mountains. Numerous samples of stream sediment were collected and analysed for Cu, Pb, Zn, Ni, Co, and Ag by T. Langman and C. J. Reddell using an atomic absorption spectrophotometer (Atkinson, 1967, unpubl.).

No anomalous values that could not be explained as variations in local background metal content were detected. However, the analyses revealed regional differences in metal content which are characteristic of the various bedrock units (Table 3). In fact Atkinson notes that several formations are 'characterized by significantly high or low Cu contents and this is reflected in well marked regional Cu patterns'. He goes on to say that:

TABLE 3. DISTRIBUTION OF TRACE ELEMENTS IN THE PRINCIPAL ROCK UNITS*

Rock Type		No. of Samples		Copper	Lead	Zinc	Nickel	Cobalt	Silver	Cx Copper†	Molybdenum
Tarua Volcanic Member		2	M	107	32	90	45	45	3.0	5.5	<1
			R	100-115	30-35	85-95	35-55	45	3.0	3.5-7.5	<1
Maramuni Diorite	Yuat R. (N)	13	M	31	47	90	34	31	1.0	2.3(5)‡	<1(5)
			R	25-45	30-85	35-165	10-55	15-50	<1-2	1.0-3.5	<1
	Yuat R. (S)	22	M	32	38	62	26	25	1.3	2.0	<1
			R	20-75	15-90	20-110	10-50	10-60	<1-3	1.0-6.0	<1
	Tarua R/Timun R.	17	M	62	48	112	48	30	2.1	3.7	<1
			R	50-75	30-65	85-150	25-70	10-55	<1-4	2.5-6.0	<1
	Karawari R./ Korosameri R.	27	M	53	40	72	49	35	1.4	3.4 (17)	<1
			R	35-90	25-50	35-140	25-85	25-50	<1-3	1.0-6.0	<1-1
		79	M	45	42	81	40	30	1.4	3.1	<1
			R	20-90	15-90	20-165	10-85	10-60	<1-4	1.0-6.0	<1-1
April Ultramafics		30	M	39	32	79	336	38	1.4	3.4	<1
			R	12-55	15-50	30-135	110-1650	25-85	<1-3	1.0-5.0	<1
Lagaip Beds		54	M	45	38	107	58	33	1.3	2.6(42)	<1
			R	25-65	15-70	45-235	15-135	15-115	<1-4	0.5-6.0	<1
Keram Beds		30	M	58	32	87	59	28	1.3	3.1	<1
			R	35-75	15-45	55-255	30-130	10-55	<1-3	1.5-5.0	<1
'South Schrader' Black Shales*		8	M	44	34	96	95	31	<1	2.9	<1
			R	30-60	30-40	80-110	40-180	25-40	<1-1	2.5-3.0	<1
Jurassic-Triassic		12	M	28	35	62	32	25	<1	2.2	<1
			R	15-50	30-50	35-85	10-75	15-30	<1-3	1.0-5.0	<1
'Hunstein' Beds*		13	M	29	17	35	66	24	<1	2.3	<1
			R	12-45	<10-40	15-90	25-125	15-30	<1.1	1.0-6.0	<1
Asai Beds		11	M	26	20	53	36	18	<1	1.7	<1
			R	15-40	15-30	35-75	20-40	10-25	<1	1.0-3.0	<1-1

*After Atkinson (1967, unpubl.)
Results in ppm, on -80 mesh wet-sieved stream sediment.

M = arithmetic mean; R = range of values;
‡(5) = No. of samples when fewer analysed for CxCu and Mo.
† Cold extractable copper.

'The areas occupied by the Jurassic-Triassic sediments can be readily discarded as being of no interest because of the extremely low (20-29 ppm) mean background copper value. When considering the dioritic bodies, the Yuat Intrusives, which carry mean values of only 31 and 32 ppm would also seem to indicate environments not particularly conducive to porphyry copper mineralization. On the other hand, it appears from one erratically high value of 75 ppm copper from a diorite porphyry apophysis at the northern end of Yuat South batholith, that the marginal, more basic phases, may be more favourable as target areas.

'Of particular significance is the difference in mean copper content of the Karawari Intrusives (56 ppm) compared with the Yuat Intrusives (31-32 ppm), both included by Dow in the Maramuni Diorite. Dow has already pointed out lithological variations between these rocks, and although he accepts that they may have formed from separate magmas he favours the possibility that chemical variations in the rocks assimilated during intrusion may account for these differences. Geochemical evidence points to the latter process as the copper content of the Triassic-Jurassic sediments intruded by the Yuat Intrusives is significantly lower (28 ppm) than that of the Lagaip Beds (Salumei Formation) (45 ppm) assimilated by the Karawari Intrusives. It would appear from this that the Karawari Diorite and in particular the smaller intrusives in the Tarua-Timun Rivers (mean copper content 62 ppm) constitute far more favourable environments for the concentration of copper than the batholiths adjacent to the Yuat River. Although the higher copper values representative of the Karawari Intrusives have not resulted in the detection of anomalous levels they do emphasise the fact that in the search for porphyry copper type deposits areas of intruded host rocks with significantly higher copper backgrounds should be favoured as target areas for investigation. At this stage it can be pointed out that the Karawari Intrusives also carry higher concentrations of nickel and silver than the Yuat Intrusives and that this feature is reflected in the composition of the intruded sediments.'

Copper

Frieda prospect

During the initial reconnaissance of the Frieda River area, boulders of highly altered andesite porphyry containing abundant disseminated pyrite and some scattered chalcopyrite were noted in a tributary of the Frieda River about 20 km south of May River Patrol Post (Fig. 10). Some boulders with sparse stockworks of quartz veins containing patches of chalcopyrite were also seen.

Subsequent traverses up the major side streams showed that the source of the boulders was an area of several square kilometres of Wogamush Beds intruded by high-level stocks and dykes of andesite porphyry, all of which are hydrothermally altered. The alteration of the rocks has obscured most of the original textures, but petrographic studies have shown that some of them are subvolcanic.

A zone of highly mineralized porphyry about 100 m wide containing some chalcocite and chalcopyrite was found in one of the tributaries, but because the exposure is so poor it could not be adequately sampled and the grade of the deposit is unknown.

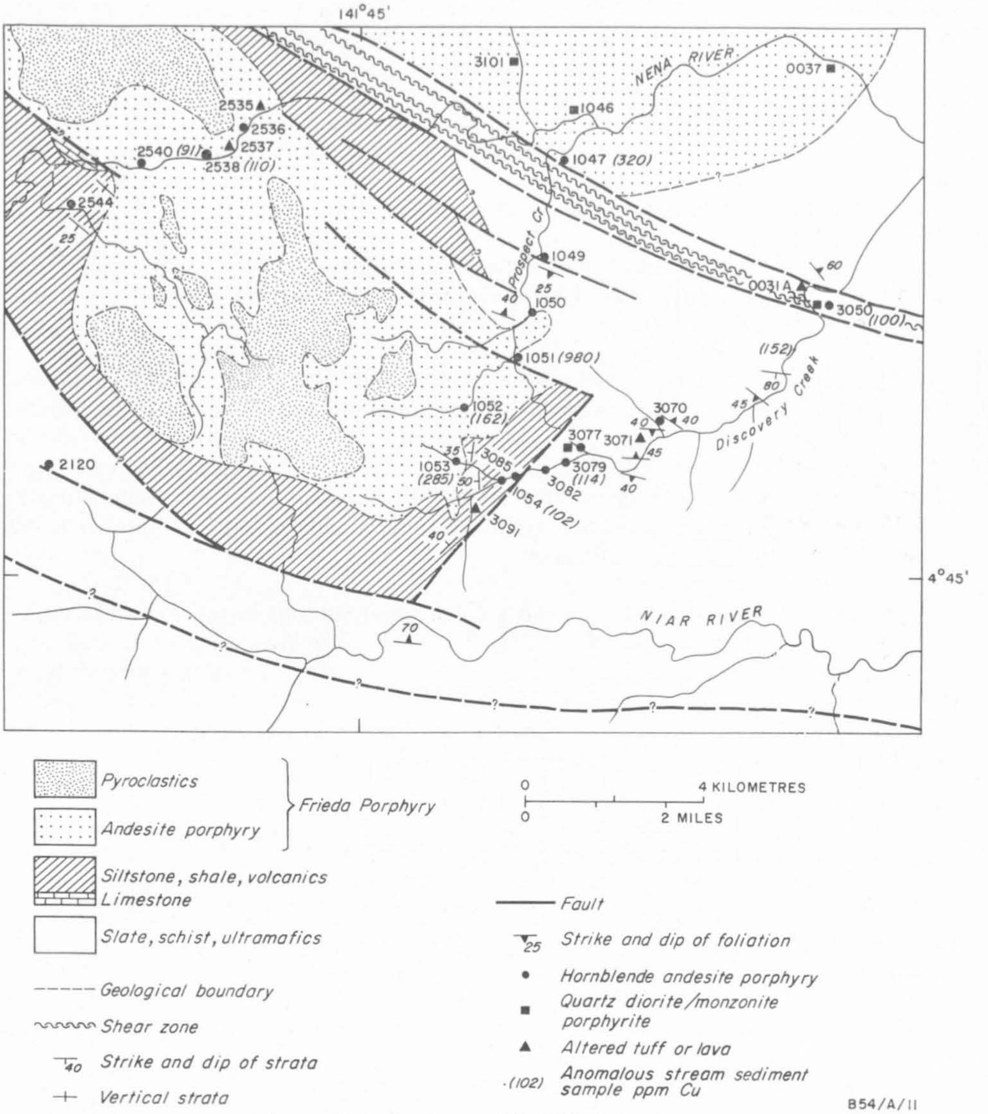

Figure 10. Geology of the Frieda prospect

The stream sediment samples collected in the prospect area contain average copper values 6 times above background, and ranging up to 24 times background; the streams drain an area of more than 20 km^2. Thus mineralization of the porphyry copper type (Titley & Hicks, 1966) is indicated.

In the prospect area fine-grained Wogamush Beds are intruded by numerous stocks and dykes of Frieda Porphyry. The rocks are faulted and poorly exposed and it is difficult to be certain of the field relationships. The fine-grained sediments are composed mainly of light to dark grey micaceous siltstone, which is indurated but shows little sign of recrystallization. It is generally massive, but in places contains thin interbeds of coarser-grained siltstone and fine sandstone. Graded bedding and slump structures were observed in some of the coarser beds.

Minor interbeds of andesite tuff, green intermediate lavas, and fine to coarse tuffaceous greywacke are found in places; they appear to grade into massive andesite welded tuff and red and green volcanic agglomerate and volcanic breccia which are similar in thin section to the porphyry intrusions.

The sediments in the prospect area are intruded by many stocks and dykes of andesite porphyry called the Frieda Porphyry. The porphyry and the volcanic rocks are closely related.

The Frieda porphyry consists of hydrothermally altered hornblende andesite porphyry and tuff. The alteration products are alunite, sericite, chlorite, albite, quartz, kaolinite, and epidote in varying amounts and combinations. Many of the tuffs have been almost completely alterated to a distinctive white partly ironstained (limonite after pyrite) rock containing about 70 percent alunite, 20 percent quartz, and 10 percent finely disseminated pyrite. Alunite is widespread and appears to be linked with the sulphide mineralization.

Pyrite is by far the most common sulphide mineral and in places forms up to 50 percent of the altered rocks; it is finely disseminated throughout all the porphyries and volcanic rocks. Chalcopyrite forms only a small proportion of the sulphides, but is widespread; it occurs mainly as finely disseminated grains, but boulders of porphyry with stockworks of quartz veins containing chalcopyrite were found in streams draining the prospect.

Minor copper occurrences

Minor occurrences of chalcopyrite were found at several localities, but only in the headwaters of the Clay River, just off the map area to the east (Dow et al., 1967, unpubl.), is the geological setting sufficiently favourable to warrant geochemical prospecting. In the Clay River area the chalcopyrite was found as rare scattered grains in basic igneous rocks of the Kumbruf Volcanics. The rocks have been metasomatically altered, possibly by an acid or intermediate pluton, the presence of which is suggested by an area of dendritic drainage on the airphotographs 6 km east of the Clay River.

Dekker & Faulks (1964, unpubl.) have reported small nodules of bornite in reddish marl of the Lagaip Beds between Laiagam and Muriaga, a selected sample of which assayed 2.95 percent copper. Sparse secondary copper minerals can be found lining small joints over a fairly large area, but it seems unlikely that the occurrence is of economic importance. Streams draining the area do not contain sediments with anomalous copper values.

Stream sediments in small tributaries draining the main range in the head of the April River contain anomalous copper values. The area is composed of strongly faulted Salumei Formation intruded by altered gabbro and ultramafic rocks. The region is extremely rugged, and as the anomalies are not of great magnitude, it is thought that the chances of finding economic copper mineralization are poor.

Gold, Silver, and Platinum

Gold, silver, and platinum are the only minerals produced in the map area.

Porgera Valley. Alluvial gold was first reported in the Porgera Valley in 1938, and it has been mined spasmodically ever since, mostly by indigenous miners (see Table 4 for production figures).

TABLE 4. GOLD PRODUCTION, PORGERA AREA

Year Ended	Production (fine oz) Gold	Silver	Value ($) Gold	Silver
1949	134	22	2 875	8
1950	427	67	11 905	34
1951	153	24	4 750	16
1952	84	14	2 614	10
1953	277	42	8 576	27
1954	177	47	5 983	29
1955	336	56	10 493	40
1956	151	24	4 707	18
1957	346	54	10 804	40
1958	146	7	4 577	5
1959	363	54	11 341	40
1960	363	56	11 349	42
1961	439	95	13 714	66
1962	732	115	22 884	101
1963	654	109	20 447	102
1964	1 302	279	40 679	278
1965	1 042	293	32 562	279
1966	613	202	19 169	219
1967	1 281	330	40 021	349
1968	1 019	191	31 851	307
Total	10 039	2 081	311 301	2 010

The area was visited in 1948 by Ward (1949, unpubl.) and subsequently by officers of the Mines Division. Department of Lands, Survey, and Mines, who traced the gold to its source. Horne (1967, unpubl.) visited the area in 1963 and mapped the main lodes, and later the Bulolo Gold Dredging Co. Ltd and Carpentaria Exploration Pty Ltd tested the lodes by diamond drilling. The results were apparently unfavourable, for no further work has been done.

The gold, which is alloyed with considerable silver, is shed from stockworks of quartz veins in the Lagaip Beds near the margins of small dioritic intrusions (Porgera intrusives). Sphalerite, pyrite, galena, and some chalcopyrite are commonly associated with the gold mineralization. Some of the porphyry stocks are covered with soil containing residual concentrations of very finely divided gold.

Timun River. Gold and platinum were discovered in the Timun River near Kompiam by N. Rowlands in 1948, and were later worked by the brothers L. and M. Wilson until the 1960s. The total recorded production is small (see Table 5). Ward (1949, unpubl.) visited the area in 1948, and Dow (1961, unpubl.) described the prospect. During the course of a geological reconnaissance Dow found promising gold prospects in the Lamant River, which the Wilson brothers later visited and worked for some years.

TABLE 5. GOLD PRODUCTION, TIMUN RIVER AREA

Year Ended	Production (fine oz) Gold	Platinum	Silver	Value ($) Gold	Platinum	Silver
1950	79	5	18	2 438	276	10
1951	—	—	—	—	—	—
1952	201	11	44	6 218	695	28
1953	3	1	1	109	60	1
1954	50	5	12	1 540	376	7
1955	69	4	8	2 155	272	5
1956	105	8	23	3 272	580	15
1957	72	11	19	2 262	835	13
1958	247	31	62	7 710	1 710	43
1959	123	15	25	3 831	450	19
1960	47	3	12	1 461	52	8
1961	18	2	4	578	112	3
1962	58	5	16	1 802	236	11
1963	66	5	18	2 056	261	15
1964	38	2	9	1 201	104	8
1965	27	4	6	830	284	6
1966	8	—	2	259	20	2
1967	4	—	1	120	—	1
1968	1	—	—	34	—	—
Total	1 216	112	280	37 876	6 323	195

In the Timun River the gold and platinum apparently originated in the Maramuni Diorite, which in this area is a composite body of diorite, gabbro, and serpentinite. Only small concentrations of the precious metals were shed directly by the Maramuni Diorite, but by a fortuitous set of circumstances, they accumulated in thin rather restricted lake beds near the head of the Timun River. These beds are not prospective, but the concentrating action of the Timun River and its tributaries has made the recent river gravels worth working.

In the Lamant River the gold originated in stocks of highly propylitized andesite porphyry which are now shedding considerable fine gold. The river immediately below the porphyry stocks has a low gradient and gold has been concentrated both in the stream channel and in the low terraces flanking the river.

Gold is carried by almost all the streams draining the Maramuni Diorite, but the deposits are not economic because the amount of gold being shed is very small and the streams are almost invariably steep. Before World War II a gold strike was reported in the lower Yuat River, and several prospectors visited the area, but no mining was done. Probably as a result of the rumours, the alluvium of the Maramuni River above its junction with the Yuat River was tested by percussion drilling (L. Schmidt, pers. comm.), but very little gold was found.

During a brief reconnaissance up the April River in 1966 the Sepik party discovered alluvial gold and platinum in the main river above the junction with Bamali River. Prospects are regarded as reasonably good, and despite the difficulties of access the area is worthy of further prospecting to test the terraces flanking the main river.

The platinum is shed from the April Ultramafics, which make up a large proportion of the rocks of the region, but the origin of the gold is not known. The gravels of the April River contain a small proportion of boulders of hornblende andesite porphyry which contain much pyrite. These porphyries are probably the source of the gold, but they were not found in place during the present survey.

Nickel

Under favourable circumstances, of which low relief and intense tropical weathering are probably the most important, economic concentrations of nickel may be found in the soils overlying peridotite and dunite. These conditions prevail in some areas of the South Sepik region, and despite the problems of access the ultramafic rocks are worthy of more detailed investigation than was possible during the present survey.

All the ultramafic rocks examined were either dunite or peridotite, or serpentinite derived from them, and preliminary assays by A. D. Haldane indicate that the fresh rocks contain about 0.2 percent nickel (see table VIII, Dow et al., 1968). The sediments from streams draining these rocks contain high nickel values, generally between 800 and 2 000 ppm. Random soil and sediment samples taken in the headwaters of small tributaries between the April and Sitipa Rivers contain from 2 000 to 4 000 ppm nickel. These results are significant in that they show the high average nickel content of the ultramafic rocks and also that some concentration of nickel has taken place in the soils.

The most favourable areas are those in which the ultramafic rocks have low relief, and the hills near the Sepik Plain therefore offer the most promise. Hand-augering has proved the most satisfactory method of preliminary testing of the soils on ultramafic rocks in other parts of New Guinea, and it is recommended that the ultramafic bodies at the head of Sikipas Creek and in the middle reaches of the Sitipa River are worthy of more detailed investigation.

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APPENDIX

Kana Volcanics
(name amended)

Name. Originally named the Kana Formation by Dow & Dekker (1964, p.12). As the formation is now known to contain a predominance of volcanic rocks the name has been amended to Kana Volcanics.

Derivation of name. Kana River (144°55′, 5°40′), a tributary of the Jimi River draining the western flank of Mount Herbert in the Bismarck Range.

Lithology. Dacitic, rhyolitic, and andesitic tuff and lava; tuffaceous sandstone, volcanic pebble conglomerate, and red tuffaceous siltstone.

Distribution. Crops out in a belt 160 km long, between the lower Maramuni River and the Chimbu River, northeast of Kundiawa.

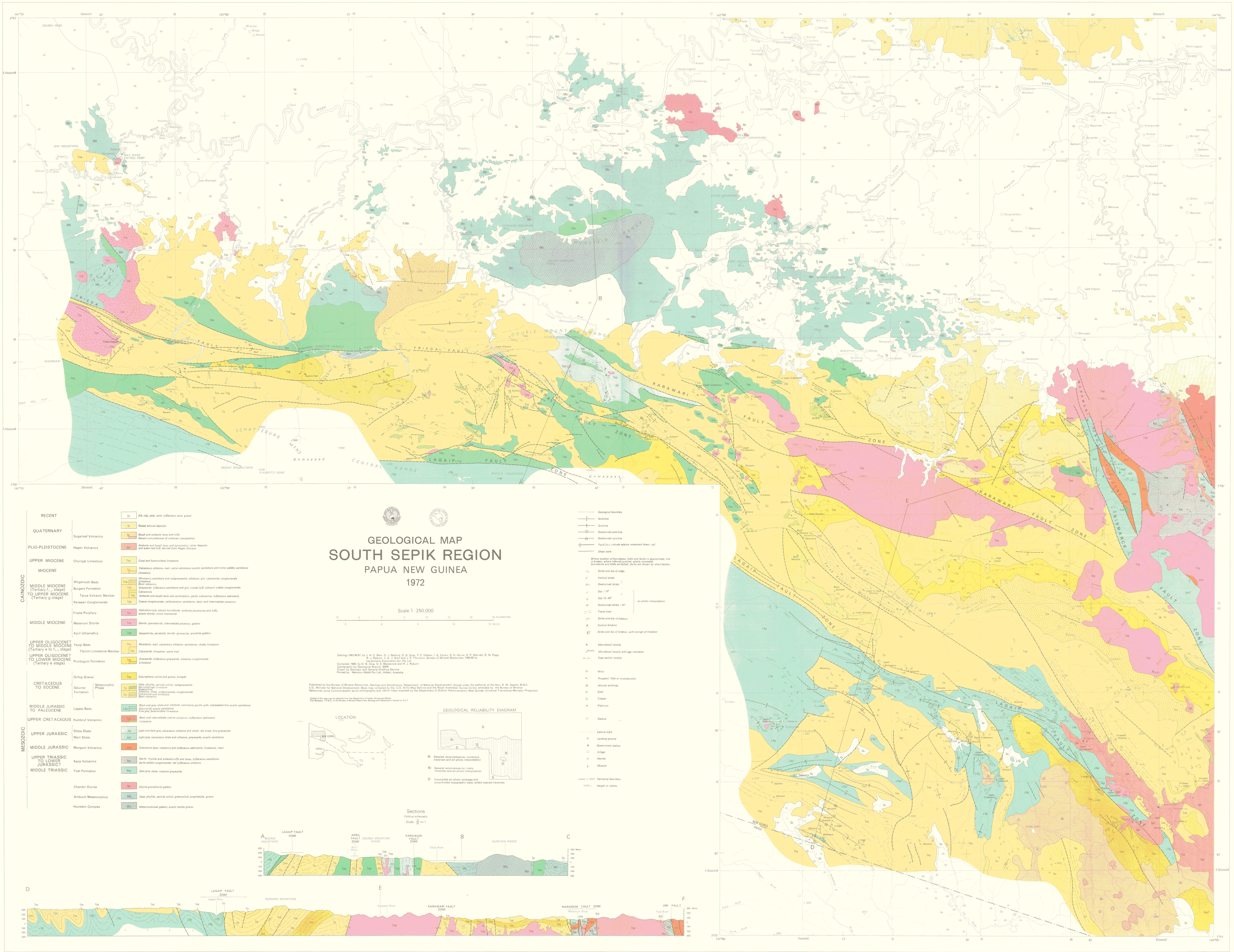
Type section. The Kana River was originally nominated as the type area (Dow & Dekker, 1964, p.12). The section exposed downstream from Gembogl Patrol Post in the Chimbu River (Chimbu District) is here nominated as the type section. The best exposure is along the road. The section is overturned. The basal part of the formation may not be represented as the base of the sequence (northeast) is an intrusive contact with the Bismarck Intrusive Complex.

Thickness (m)	
Top	Fault or faulted unconformity.
600	Pebble conglomerate beds up to 2.5 m thick interbedded with red siltstone and fine tuffaceous sandstone. Conglomerate consists of well rounded cobbles and pebbles and rare boulders of dacitic rocks in reddish purple tuffaceous matrix. Some rare basaltic pebbles. Grades into green and reddish purple feldspathic sandstone containing rounded pebbles of porphyritic andesite and some calcareous nodules. Medium-bedded. Contains some beds of red tuffaceous siltstone and dacite-pebble conglomerate similar to underlying beds. Top probably faulted against Balimbu Greywacke.
180	Red tuffaceous siltstone and shale. Small quartz and feldspar grains can generally be distinguished in coarser varieties. Massive jointed unbedded band of dark grey sheared phyllite near top.
180	Green basaltic agglomerate and interbedded basalt-pebble and cobble conglomerate. Basalt green and highly epidotized in places.
1 820	Mostly well bedded crystal tuff and tuffaceous sandstone consisting of graded beds 5 to 60 cm thick grading into light-coloured shale and siltstone. Appear to be mostly acidic. Some dacitic lavas and agglomerate, and rare dacite pebble conglomerate. Intruded by dolerite and gabbro.
750	Poorly exposed and intruded by many dykes of altered dolerite and gabbro, so original rock type not readily apparent. Some green highly altered fine-grained basic rocks which are probably basaltic lava flows. Only other rock seen is bedded andesitic crystal tuff similar to overlying volcanics.
Bottom	Intrusive contact with Bismarck Intrusive Complex.

Stratigraphic relationships. Overlies the Jimi Greywacke, probably unconformably, and is overlain unconformably by the Lower Jurassic Balimbu Greywacke. Overlies the Yuat Formations in the Yuat River.

Thickness. 3 500 m in the Chimbu River type section, 600 m in Kana River, and about 600 m in the Yuat River area.

Fossils and age. Macrofossils from several localities date the formation as Upper Triassic.


GEOLOGICAL MAP
SOUTH SEPIK REGION
PAPUA NEW GUINEA
1972
Scale 1 : 250,000
KILOMETRES
MILES
Geology, 1963,66,67, by J. H. C. Bain, D. J. Belford, D. B. Dow, F. E. Dekker, I. G. Faulks, R. G. Horne, R. P. Macnab, R. W. Page, R. J. Ryburn, J. A. J. Smit and J. E. Thomson, Bureau of Mineral Resources; 1968,69 by Carpentaria Exploration Co. Pty Ltd
Compiled, 1968, by D. B. Dow, D. E. Mackenzie and R. J. Ryburn
Cartography by Geological Branch, BMR
Drawn by Geologic and General Drafting Service
Printed by: Mercury–Walch Pty Ltd., Hobart, Australia
Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Issued under the authority of the Hon. R. W. Swartz, M.B.E., E.D., Minister for National Development. Base map compiled by the U.S. Army Map Service and the Royal Australian Survey Corps; amended by the Bureau of Mineral Resources using Commonwealth aerial photography and patrol maps supplied by the Department of District Administration, New Guinea. Universal Transverse Mercator Projection
Copies of this map may be obtained from the Department of Lands, Survey and Mines, Port Moresby, T.P.N.G., or the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T.
LOCATION
GEOLOGICAL RELIABILITY DIAGRAM
CAINOZOIC
MESOZOIC
RECENT
Qa Silt, clay, peat, sand, tuffaceous sand, gravel
QUATERNARY
Qr Raised alluvial deposits
Sugarloaf Volcanics
Qs Basalt and andesite lavas and tuffs
Recent cumulodomes of unknown composition
PLIO-PLEISTOCENE
Hagen Volcanics
Qph Andesite and basalt lavas and pyroclastics, lahar deposits and water-laid tuff, derived from Hagen Volcano
UPPER MIOCENE
Chuingai Limestone
Tmc Coral and foraminiferal limestone
MIOCENE
Tm Calcareous siltstone, marl, some calcareous quartz sandstone and minor pebbly sandstone
Limestone
MIDDLE MIOCENE (Tertiary f1-2 stage) TO UPPER MIOCENE (Tertiary g stage)
Wogamush Beds
Tmw Micaceous sandstone and subgreywacke, siltstone, grit, calcarenite, conglomerate
Limestone
Basic volcanics
Burgers Formation
Tmb Greywacke, tuffaceous sandstone and grit, crystal tuff, volcanic cobble conglomerate
Calcarenite
Tarua Volcanic Member
Tmv Andesite and basalt lavas and pyroclastics, partly submarine; tuffaceous sediments
Karawari Conglomerate
Tmk Coarse conglomerate, carbonaceous sandstone, basic and intermediate volcanics
MIDDLE MIOCENE
Frieda Porphyry
Tmx Hydrothermally altered hornblende andesite porphyries and tuffs, quartz diorite, minor monzonite
Maramuni Diorite
Tmp Diorite, granodiorite, intermediate porphyry, gabbro
April Ultramafics
Tma Serpentinite, peridotite, dunite, pyroxenite, anorthite gabbro
UPPER OLIGOCENE? TO MIDDLE MIOCENE (Tertiary e to f1-2 stage)
Yangi Beds
Tmy Mudstone, marl, calcareous siltstone, sandstone, chalky limestone
Tibinini Limestone Member
Tmt Calcarenite, limestone, some marl
UPPER OLIGOCENE? TO LOWER MIOCENE (Tertiary e stage)
Pundugum Formation
Tms Greywacke, tuffaceous greywacke, siltstone, conglomerate
Limestone
CRETACEOUS TO EOCENE
Gufug Gneiss
Tmg Glaucophane schist and gneiss, eclogite
Salumei Formation
Metamorphic Phase
Tls Slate, phyllite, sericite schist, metagreywacke
Recrystallized limestone
Greenschist
Tls Siltstone, shale, subgreywacke, conglomerate
Calcarenite and limestone
Basic volcanics
MIDDLE JURASSIC TO PALEOCENE
Lagaip Beds
J-Kp Black and grey shale and siltstone, commonly pyritic with interbedded fine quartz sandstone
Glauconitic quartz sandstone
Fine grey foraminiferal limestone
UPPER CRETACEOUS
Kumbruf Volcanics
Kuk Basic and intermediate marine volcanics, tuffaceous sediments
Limestone
UPPER JURASSIC
Sitipa Shale
Jus Light and dark grey calcareous siltstone and shale, red shale, fine greywacke
Maril Shale
Jum Light grey calcareous shale and siltstone, greywacke, quartz sandstone
MIDDLE JURASSIC
Mongum Volcanics
Jmm Submarine basic volcanics and tuffaceous sediments, limestone, chert
UPPER TRIASSIC TO LOWER JURASSIC?
Kana Volcanics
Ruk Dacite, rhyolite and andesite tuffs and lavas, tuffaceous sandstone, dacite pebble conglomerate, red tuffaceous siltstone
MIDDLE TRIASSIC
Yuat Formation
Rmy Dark grey shale, massive greywacke
Chambri Diorite
Mc Diorite, granodiorite, gabbro
Ambunti Metamorphics
Mbt Slate, phyllite, sericite schist, greenschist, amphibolite, gneiss
Hunstein Complex
Mhs Metamorphosed gabbro, quartz biotite gneiss
Sections
FRIEDA FAULT
LAGAIP FAULT ZONE
KARAWARI FAULT ZONE
SCHATTEBURG RANGE
CENTRAL RANGE
BUCKLE MOUNTAINS
DOUBLE MOUNTAIN RANGE
Unmapped
BISMARCK FAULT ZONE
WARAMUNI FAULT ZONE
SEPIK RIVER