COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 75

THE GEOLOGY OF THE BOWUTU MOUNTAINS, NEW GUINEA

BY

D. B. DOW AND H. L. DAVIES

Issued under the Authority of Senator the Hon. Sir William Spooner,
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Minister: SENATOR THE HON. SIR WILLIAM SPOONER, K.C.M.G., M.M.

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SUMMARY

The Bowutu Mountains are in the south-eastern corner of the Territory of New Guinea, between Salamaua and the Lower Waria River. They attain a maximum elevation of about 8500 feet and are rugged, bush-covered, and unpopulated. There are no tracks in the mountains, and they offer some of the hardest travel in New Guinea.

The map area also covers part of the north-western end of the Owen Stanley Range, a lightly populated, bush-covered mountain range which rises to over 12,000 feet in the map area. The narrow Waria Rift Valley separates the two mountain ranges; it is almost flat-floored, but ranges in elevation from 1500 feet in the south to 6000 feet in the north, and supports a fairly large native population.

The Bowutu Mountains form the north-western end of the Papuan Ultrabasic Belt, which is an elongated complex of ultrabasic, basic, and acidic rocks more than 230 miles long and up to 25 miles wide, extending from the New Guinea coast near Salamaua to the Musa River in Papua. The ultrabasic rocks crop out in the north-western part of the mountains, and were mapped separately from the feldspathic rocks of the Belt, which occupy the south-eastern part.

The Belt was emplaced in fluid or near-solid state in Upper Cretaceous, Lower Tertiary, or lower Middle Tertiary time. Gravity differentiation before or during emplacement produced ultrabasic, basic, and acid rocks in turn, but tectonic movements and stress during crystallization prevented the development of orderly layering and caused the intrusion of residual magma into the already-solidified parts of the pluton.

The Owen Stanley Range is composed of Owen Stanley Metamorphics, which include the Kaindi Metamorphics (metamorphosed Palaeozoic or Lower Mesozoic shelf and trough-type sediments), and fossiliferous greywacke and sericite schist of Cretaceous age. The rocks within the Waria Rift Valley are Lower Tertiary fine-grained sediments and basic volcanics called the Nipanata Beds, and a discontinuous veneer of Recent alluvium. Altered volcanics cropping out near Salamaua are called the Lokanu Metavolcanics and can probably be correlated with the Nipanata Beds. Lower Miocene basic and intermediate volcanics which crop out along the north-eastern, coastal, flank of the Bowutu Mountains are called the Mageri Volcanics.

A small stock of trondhjemite which intrudes the Kaindi Metamorphics in the north-western part of the map area may be co-magmatic with the (?) Lower Tertiary Morobe Granodiorite. Small andesite porphyry dykes were intruded in the Upper Tertiary.

The Owen Stanley Metamorphics and the Ultrabasic Belt are separated by the Owen Stanley and Timeno Faults, which have probably been active since early Tertiary time. The main movement on the faults has been transcurrent, the Ultrabasic Belt moving north-westwards relative to the Owen Stanley Metamorphics. Where this movement was impeded by the northerly curve of the Owen Stanley Fault, the Ultrabasic Belt has been locally elevated and the basal ultramafic part of the pluton is now exposed. Vertical movement on the faults has elevated the two mountain ranges and depressed the area between.

Gold is shed from the Kaindi Metamorphics, the Ultrabasic Belt, and the Mageri Volcanics, and about 1000 fine ounces have been won, mostly from alluvial workings in the Middle Waria Valley. Platinum and osmiridium occur with the gold. Lateritic concentrations of nickel have been found in soils developed over the ultramafic rocks, but, in the two areas tested, are apparently below economic grade. Copper mineralization occurs at a number of places in the Bowutu Mountains. The writers recommend a major programme of nickel prospecting north-east of Lake Trist, and more intensive search for copper near the Timeno Fault, and in the north-eastern part of the Bowutu Mountains.

INTRODUCTION

An area of about 1500 square miles of rugged, unpopulated, and inaccessible mountain country in the south-eastern corner of the Territory of New Guinea forms the range known as the Bowutu Mountains. Previous geological work, which had been confined to the more accessible parts of the region, had shown that the Papuan Ultrabasic Belt had its greatest development in the Bowutu Mountains and the area was therefore one of economic mineral potential. It was therefore surveyed in September and October 1960.

Location

The area covered by this Report extends from Salamaua southward to the Papuan border, and lies between the Owen Stanley Range and the Morobe Coast. It is bounded by Latitudes 7°00'S and 8°07'S and Longitudes 146°48'E and 147°42'E.

Access

Garaina, in the Middle Waria Valley, has an airstrip of DC3 standard and is served by weekly flights from Port Moresby (Papuan Air Transport) and Lae (Trans-Australia Airlines). At Kipu, three miles south of Garaina, there is an airstrip suitable for light aircraft. There are emergency landing grounds at Juni and Bapi, north of Garaina, at Dona near Morobe, and Salamaua on the coast, but these have not been used since 1945 and are at present unserviceable.

Morobe is served by small motor vessels operating from Lae and Samarai at approximately fortnightly intervals. The indented coastline provides a number of good anchorages, but some of these are unsafe during the north-west monsoon.

There are no well-used tracks in the Bowutu Mountains; several minor tracks cross the range between Garaina, Morobe, and Maiama, but they are rarely used and are poorly defined. A well-kept Administration track connects Garaina and Morobe: for the most part it follows the Waria River.

Garaina and Wau are connected by a good foot-track through the Upper Waria, Biaru, Korpera, and Upper Bulolo valleys, and there is an unused track from Bapi, at the head of the Middle Waria Valley, to Lake Trist and thence Wau. South of Lake Trist the track is overgrown by fine bamboo creeper, which is difficult to penetrate.

Field Method

In the Bowutu Mountains fresh rock exposure is generally confined to the beds of watercourses, though dunite and dolerite may form residual surface boulders. Soil cover within the range is thin, so that shallow track cuttings commonly reveal weathered remnants of the underlying rock, particularly in the case of the trondhjemite. Most of the foot-tracks are situated on ridges and the geologist is often faced with the alternatives of making a quick traverse along a foot-track with limited exposure, or a slow difficult traverse along a creek bed where outcrop is generally plentiful.

During the survey the writers worked independently and employed a permanent line of fourteen native carriers. This permitted a maximum traverse of twelve days in unpopulated country, with six loads of native rations and eight loads of equipment. Movement through populated country presents few problems as good tracks connect the villages and around each village there is a network of hunting tracks which give access to the surrounding bush. However, much of the Ultrabasic Belt, particularly in the north, is unpopulated, and only the fringes are penetrated by hunting parties. In such country it may take three to four hours to cut a mile of track, and carrier trouble is likely because the natives commonly regard unknown bush with superstitious fear.

Aerial Photography

Only a small part of the area is not covered by vertical or oblique photography (see 'Airphoto Coverage', Pl. 1), and field observations were plotted on air photographs wherever possible.

The base map for Plate 2 was prepared by tracing from uncontrolled assemblies of air photographs and reducing these from the various scales to a final scale of 1:250,000. The coastline was plotted from Military One-mile Maps of Salamaua, Baden Bay, and Mageri Point. The only control is given by two points on the Buisaval and Lower Waria Rivers, which were plotted from the Salamaua and Buna 'Four-mile' sheets, published by the Administration Department of Lands, Surveys and Mines.

Because of the young topography and the forest cover, photo-interpretation is only practicable on a broad scale: Quaternary fault traces are apparent and the main rock types may be distinguished. Within the Owen Stanley Range the Kaindi Metamorphics cannot be distinguished from the Cretaceous greywacke and sericite schist, but within the Ultrabasic Belt a number of erosion and vegetation patterns may be discerned, and these, together with field observations, are the basis for the boundaries within the Belt shown on Plate 2.

Climate

The climate of the area is influenced by the following seasons (Dep.Nat.Dev., 1951).

North-West Monsoon	:	Mid-December to mid-March
South-East Monsoon	:	May to October
Doldrums	:	Mid-March to April
		November to mid-December

The average annual rainfall at Morobe is 117 inches, the wettest months being April, May, June, November, and December. At Garaina the annual rainfall is 106 inches, the wet months being November and December, and the dry months June, July, and August. Rain generally falls in the afternoon and evening.

The coastal belt can be unpleasantly hot and humid, but the climate in the Middle Waria Valley is quite equable. The mountain country is often blanketed with cloud and can be very bleak.

Flora

Three main types of vegetation were observed: rain forest, grasslands, and stunted hardwoods. Rain forest covers most of the mountainous country. Over metamorphic rocks the forest has little undergrowth and is not difficult to penetrate. Over the Ultrabasic Belt the undergrowth is denser, and is at its worst south and east of Lake Trist, where fine bamboo creeper forms a dense springy mass from five to twenty feet high.

Kunai and other long-leafed grasses cover the flats of the Middle Waria Valley, and the flanks of the Bubu, Ono, and Upper Waria valleys. There are also extensive alpine grasslands between 9000 and 10,000 feet in the valleys of Kau and Diu Creeks, and small patches of alpine grass on the divide east of Lake Trist.

Gnarled and stunted hardwoods grow on the divide (elevation 7000 - 8500 feet), east and south-east of Lake Trist, and on exposed points at slightly lower altitudes. The transition between rain forest and stunted hardwoods is quite clear on the air photographs, but does not indicate a geological boundary.

Fauna

Game is plentiful near the coast, and rations can be supplemented with cassowaries, pigeons, ducks, and a variety of other birds. Eels in the larger streams draining the Bowutu Mountains were another useful addition to our diet. In the mountain country game is scarce: there are no fish in the Middle and Upper Waria River, birds are rare, and the only game caught by the carriers was tree-climbing kangaroos and opossums, and an occasional cassowary.

Mosquitos are generally not a nuisance, except in the coastal belt. In the Saia River and the area around Lake Trist, we were plagued by a large stinging fly not unlike the Australian march fly.

Population and Industry

About 12,000 natives inhabit the area; of these 5400 live on the coast and in the Lower Waria Valley, the remainder in the Middle and Upper Waria, Ono, and Bubu valleys. The coastal natives have a reputation for indolence, but the inland natives are generally good workers. There is little available labour in the Middle Waria Valley as many of the able-bodied men have been recruited by plantations and the Administration departments.

Europeans number between 15 and 20, and there are settlements at Morobe Patrol Post, Garaina (Department of Agriculture), Sumu, Kipu, Sawet, and Zaka (mission stations).

Most of the natives live by subsistence agriculture, but cash crops, such as coffee and cocoa, are being introduced. Natives produce some copra on the coast, and a little alluvial gold is won on the Ono, Waria, Wiwo, and Wuwu Rivers.

The Department of Agriculture has an experimental tea plantation at Garaina.

Previous Investigations

In September 1939, N.H. Fisher, then Government Geologist for New Guinea, traversed from Wau to Garaina via the Biaru, Upper Waria, and Ono valleys. En route he examined alluvial gold workings at Timanagosa and Juni (Fisher, 1939).

J.E. Thompson, Senior Resident Geologist, Port Moresby, first visited the Waria Valley in 1951 to investigate a reported gold find near Sako. He mapped the Garaina - Koreppa area and recognized nickel silicate minerals at Koreppa. In 1957 he returned to Koreppa to make a more detailed examination of the nickel mineralization and carried out some pitting and augering. In 1958 he traversed the Morobe Coast by small motor vessel and noted zoning within the Bowutu Mountains which has been broadly verified by this survey (Thompson, maps, unpublished reports, and pers. comm.).

Bulolo Gold Dredging Ltd has made a brief geological reconnaissance of the southern part of the area (Gibson, 1957) and has carried out programmes of pitting and augering at Koreppa and near Lake Trist (Campbell, 1958).

D.B. Dow and G. Siedner, Resident Geologists at Wau, mapped the area north of Lake Trist in August-September 1958 (Dow & Siedner, 1958), and their results have been incorporated in this Report.

Petrography

Petrographic descriptions are by Davies unless otherwise indicated. Time did not permit the use of the universal stage and refractive index methods for detailed mineral identification.

TOPOGRAPHY

Four physiographic units are recognized in the area mapped: the Owen Stanley Range, the Waria Rift Valley, the Bowutu Mountains, and the Coastal Region (see Fig. 1).

Owen Stanley Range

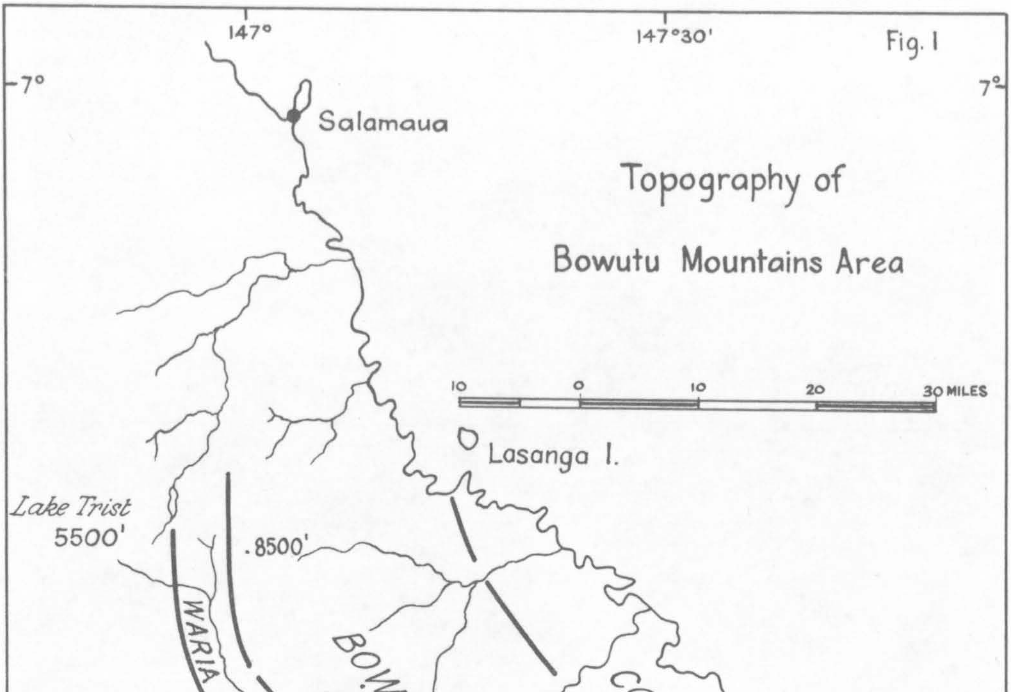
In the south-western part of the map area, a broad massif, the north-western extension of the Owen Stanley Range, rises more than 12,000 feet above sea-level. The massif has the appearance of a dissected plateau and consists of broad undulating interfluves separated by deep river valleys, such as the Upper Waria, Ono, and Bubu rivers.

The massif is bounded on the north-east by a straight, steep, fault scarp. The larger rivers have cut through the scarp and join the Waria River with accordant junctions, but many of the smaller streams form cascades and waterfalls where they cross the scarp.

Waria Rift Valley

A slightly curved trough, the Waria Rift Valley, extends from Lake Trist south-eastwards to the Eia River. It is bounded by the steep front of the Owen Stanley Range to the west and by the Bowutu Mountains to the east. The floor of the valley has only low relief in the northern and central parts, and ranges in the elevation from 6000 feet near Lake Trist, to 1500 feet near Motetei. South-east of Motetei the floor rises and becomes hilly.

The Waria River enters the Rift Valley near Bapi and flows south-eastwards along its eastern margin except near Timanagosa and Motetei, where the river enters the Bowutu Mountains. From near Upupuru the river swings away from the Rift Valley and flows north-eastwards to the coast.



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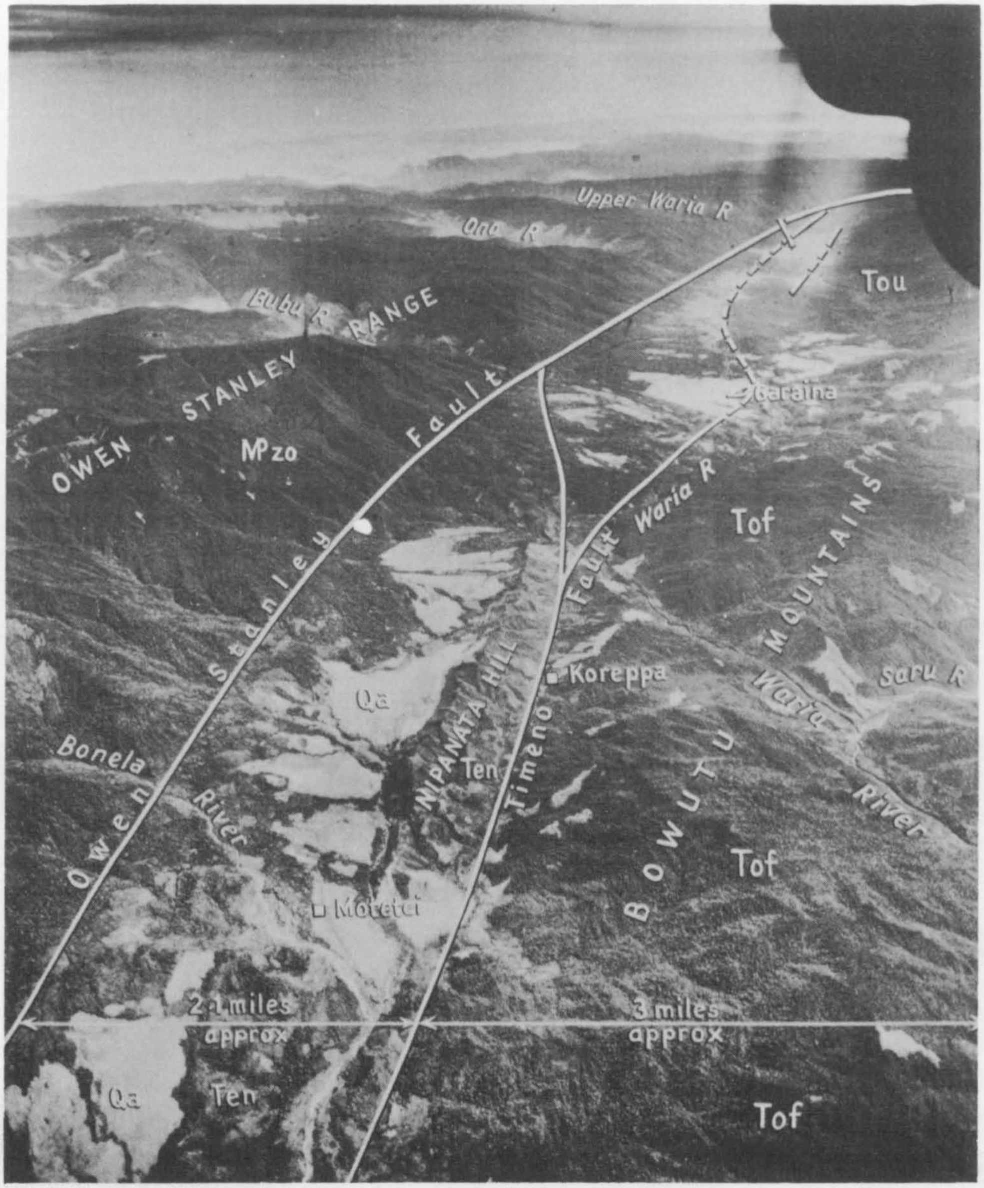

Fig 2: The Middle Waria Valley, part of the Waria Rift Valley, flanked by the Owen Stanley Range and the Bowutu Mountains. (Photograph made available by the Commonwealth Department of Air).

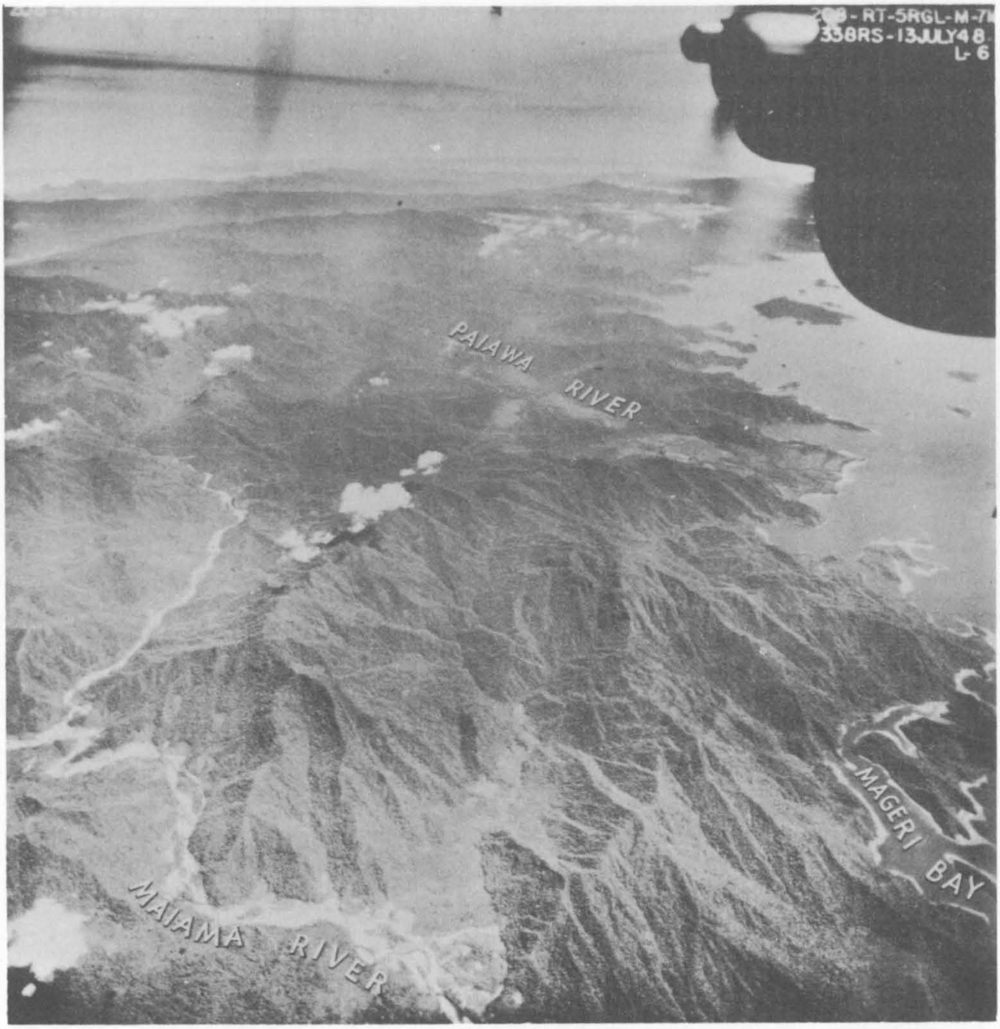

Fig 3: Coast north-west of Morobe showing the embayed coastline and sharp ridges characteristic of the Coastal Region. (Photograph made available by the Commonwealth Department of Air).

In their lower reaches the Ono and Superua Rivers flow south-eastwards along the valley before joining the Waria River.

Bowutu Mountains

The Bowutu Mountains form a fairly well-defined mountain chain between the Waria Rift Valley and the coast. The divide is nearer the Waria valley and hence the coastal streams are larger and more deeply incised than the inland streams. The range has a maximum elevation of 8500 feet; the rivers are deeply incised, and the drainage is generally dendritic. Different topographic patterns within the range are discussed below under Geomorphology.

Coastal Region

The coastal belt from Lasanga Island to Morobe is characterized by razor-backed ridges of moderate elevation. Recent depression of this belt has caused a sharply indented coastline with many off-shore islands. In their lower reaches the larger rivers flow sluggishly across wide alluvial flats which are swampy in places.

STRATIGRAPHY

The stratigraphy of the area is summarized in the following table:

Quarternary		Alluvium
Tertiary	?Pliocene	Andesite porphyry intrusions
	Miocene	Mageri Volcanics
	?Oligocene	Papuan Ultrabasic Belt
	?Eocene	Nipanata Beds / Lokanu Metavolcanics
	?Lower Tertiary	Morobe Granodiorite
Mesozoic	Cretaceous	Greywacke and sericite schist
Lower Mesozoic or Palaeozoic		Kaindi Metamorphics

The Owen Stanley Metamorphics comprises two units, the Kaindi Metamorphics and the Cretaceous sediments, both of which are regionally metamorphosed. The Nipanata Beds and the Lokanu Metavolcanics, which are thought to be correlatives, are only weakly metamorphosed. The Mageri Volcanics are slightly altered and are probably a part of the Iauga Formation (Paterson & Kicinski, 1956).

Definite evidence of age is lacking except in the Cretaceous greywacke and the Iauga Formation, in both of which diagnostic fossils have been found.

?PALAEOZOIC TO CRETACEOUS

Owen Stanley Metamorphics

The metamorphic rocks which constitute the bulk of the Owen Stanley Range were named the Owen Stanley Series by E.R. Stanley (1923). We prefer the name Owen Stanley Metamorphics, and in the northern part of the map area we have divided them into two units: the Kaindi Metamorphics and the less metamorphosed Cretaceous sericite schist and greywacke. The Kaindi Metamorphics are of higher grade than the Cretaceous rocks and the two units are probably separated by an unconformity. We mapped in less detail in the Owen Stanley Range and the rocks have been mapped as undifferentiated Owen Stanley Metamorphics.

Kaindi Metamorphics

The Kaindi Metamorphics (Fisher, 1944), take their name from Mount Kaindi near Wau. In the map area they crop out from the coast near Salamaua to the headwaters of the Buiawim River. They almost certainly occur to the south-east in the Owen Stanley Range, but they have been mapped as undifferentiated Owen Stanley Metamorphics. North of the Bitoi River, the Kaindi Metamorphics are generally fine-grained, but to the south they are medium and coarse-grained.

North of the Bitoi River the predominant rock type is dark, fine-grained quartz-biotite schist. Calcareous schist and thin marble beds are common in this area and travertine has formed at seepages on the sides of many of the streams. Green, silicified, medium-grained biotite schist also occurs. In all these rocks schistosity has almost completely obliterated the bedding, and only in Buipal Creek, west of Mubo, was bedding seen. There the rock is a laminated and thin-bedded grey and black schist in which the bedding is roughly parallel to the schistosity.

South of the Bitoi River the rocks are coarser-grained, and consist mainly of medium-grained to coarse-grained quartz-biotite schist with subordinate fine-grained schist, marble, calcareous schist, and stretched conglomerate. The most common rock type is a green to grey coarse-grained silicified quartz-biotite schist in which bedding is rarely seen. Dark-coloured fine-grained schist occurs with this coarse-grained schist and was originally interbedded with it, but regional metamorphism has obliterated the bedding and the fine-grained rock now occurs as irregular streaked-out lenses. Another common rock type is a 'streaky schist' which consists of streaked-out lenses and plates (up to 1/4 inch thick and 6 inches long) of light green medium- grained silicified schist alternating with dark fine-grained mica schist. The development of these lenses is discussed below.

Sheared and stretched conglomerate was seen as boulders in the Buisaval River. It consists of pebbles of quartz, silicified greywacke, and feldspathic igneous rocks in a matrix of coarse-grained quartz-biotite schist. The less competent pebbles, such as greywacke and siltstone, are streaked out into lenses.

The marble occurs in the map area as small lenses, generally about 50 feet thick and several hundred yards long. It is generally grey, and contains thin lenses (about

1/8 inch thick, and several inches long) of brown mica schist, which have been derived from original argillaceous impurities in the limestone. Some pure white marble was seen, but it is not common. One large lens of marble, several hundred feet thick, was seen at the head of Kiname Creek, but was not visited.

Fisher (1939) noted green schist in the Upper Ono valley; he suggested that it was originally a tuff.

The regional metamorphism of the Kaindi Metamorphics is not high-grade, and falls within the biotite zone. However, the sediments have reacted to stress by intense shearing and plastic flow. Transition from schist in which bedding can still be seen to the 'streaky schist' was seen two miles to the west of the map area in the headwaters of the Bulolo River. The schist was derived from laminated and thin-bedded quartz greywacke containing thin shale and siltstone interbeds. In the first stage of the transformation it was folded into tight symmetrical folds and completely recrystallized; the coarse beds were silicified and the finer-grained beds became biotite schist with the schistosity roughly parallel to the axial plane of the folds. Further stress caused the limbs of the folds to stretch. Then the limbs parted and the fold-noses were streaked out into lenses and plates to give the 'streaky schist'. In the extreme case, lenses were so stretched out that the schistosity, which is parallel to the axial plane of the folds, can easily be mistaken for laminated bedding.

The Kaindi Metamorphics, which are probably overlain unconformably by the Cretaceous Snake River Greywacke north of Wau (Dow, 1961), may be of Palaeozoic or Lower Mesozoic age.

Greywacke and Sericite Schist

Fossiliferous greywacke and sericite schist crop out in Sampa Creek, a tributary of the Buiawim River, seven miles west of Lake Trist. The rocks were only cursorily examined, and the area warrants more detailed mapping.

The greywacke is known only as boulders shedding from the head of Sampa Creek. It is dark-coloured, medium to fine-grained, indurated rock consisting of rounded to subangular grains of feldspar, quartz, ferromagnesian minerals, and rock fragments. The finer-grained greywacke is sub-schistose. It appears to overlie the sericite schist, but in the absence of continuous exposure this could not be verified.

Black and grey fine-grained sericite schist crops out in the stream bed, but its relationship to the greywacke is not known. Thin bedding can generally be distinguished, and where seen it dips more steeply than the schistosity.

Fossils collected from greywacke boulders in Sampa Creek were identified by Skwarko (1960) as follows:

Pelecypoda: *Glycimeris* sp.
Ashcroftia distorta Glaessner, 1949
Pinna sp. nov.
Trigonia sp. nov.
Nototrigonia sp. nov.
Cardium sp.
Panopea sp. nov.

Gastropoda: *Tibia (?) morobica* Glaessner, 1949

The assemblage is similar to one described by Glaessner (1949), from the Snake River area 35 miles to the north-west. Glaessner suggests an Aptian, Albian, or Cenomanian age for the Snake River assemblage, and Skwarko assigns the same age to the Sampa Creek fossils.

Undifferentiated Owen Stanley Metamorphics

South-east of the Buiawim River, only short traverses were made into the Metamorphics, and rocks in this area have been mapped as Undifferentiated Owen Stanley Metamorphics. The rocks seen were laminated green and black phyllite and sericite schist. Marble which crops out at Garawaria on the Ono River (Fisher, 1939) is probably a member of the Kaindi Metamorphics.

?EOCENE

Lokanu Metavolcanics

We propose the name Lokanu Metavolcanics for altered volcanic rocks which crop out between Salamaua and the Bitoi River. The rocks are best exposed in small streams to the south-south-west of Lokanu Village, from which the name is derived. Dow & Siedner (1958) referred to the rocks as Salamaua Metavolcanics, and the following account is taken from their report:

'Both the volcanics and the intrusives are dark green massive rocks, well jointed and containing irregular thin chlorite veins up to 1/4 inch thick. The volcanic rocks are fine-grained holocrystalline and are classed as altered prehnite-bearing basalt. The intrusive rocks, classed as kaolinized dolerite, have a coarser groundmass and contain pyroxene phenocrysts.

'Most streams near Buansing carry boulders of red silicified siltstone which grade by increasing calcite content to red marble. Boulders of grey and white massive marble were also found near Buansing. These rocks could not be traced to their source so that their exact relationship to the Salamaua Metavolcanics is unknown. However, one boulder showed that the dolerite is intrusive into the siltstone. It is probable that the Salamaua Metavolcanics consist of a sequence of altered basalts with minor interbeds of siltstone and marble, the whole having been intruded by dolerite.

'The Salamaua Metavolcanics are faulted against the Papuan Ultrabasic Belt to the east and probably against the Kaindi Metamorphics to the west. The only evidence of their age is a poor exposure near the contact with Kaindi Metamorphics in a stream east of Komiatum. Here dolerite has intruded the Kaindi schist and one exposure shows a xenolith of schist in dolerite. Thus ..... the Salamaua Metavolcanics are younger than the Kaindi Metamorphics'.

The Lokanu Metavolcanics are tentatively correlated with the ?Eocene Nipanata Beds. The marble and siltstone are not unlike the Nipanata sediments, and the two sequences are similarly disposed, being bounded on the west by the Owen Stanley Fault and on the east by the Ultrabasic Belt.

Nipanata Beds

The Nipanata Beds were named in 1951 by J.E. Thompson (unpublished reports) who observed them on Nipanata Hill, west of Koreppa. They crop out as a long wedge, up to three miles wide, between the Owen Stanley and Timeno Faults, and consist of fine-grained greywacke, black, green, and red siltstone and mudstone, impure marble, and altered basic volcanics. Calcite veining is common and may be derived from original lime content of the sediments.

Tightly folded green and black sericite schist was observed near the Owen Stanley Fault, west of Timanagosa and Motetei. This is probably the dynamically metamorphosed equivalent of green and black mudstone observed elsewhere in the Nipanata Beds. Pyritic metadolerite, which may be intrusive (see under Igneous Intrusives, p.16), crops out near the Owen Stanley Fault and forms boulders in a shear zone north of Bapi. Within 60 feet of the Timeno Fault the sediments have been crushed to form fault gouge; farther from the fault they have been hardened by heat from the fault or from the igneous rocks of the Ultrabasic Belt, possibly the younger trondhjemite and diorite.

Thompson (unpublished reports) suggests a Cretaceous age for the Beds, as Cretaceous sedimentation is known on the southern flank of the Owen Stanley Range (Kemp Welch Beds, east of Port Moresby) and thus might be expected on the northern flank. However, the Nipanata Beds differ from the Cretaceous rocks in Sampa Creek and the Snake River Greywacke both in lithology and degree of metamorphism, and are more likely to be Lower Tertiary. The Nipanata Beds may be correlatives of the Lokanu Metavolcanics (see p.22), the Lasa Creek sediments in the Yodda Valley (Davies, 1959), and possibly the Urere Metamorphics in the Musa River area (Smith & Green, 1961).

MIOCENE

Mageri Volcanics

The Mageri Volcanics take their name from Mageri Bay, 15 miles north-west of Morobe. They crop out between the Ultrabasic Belt and the coast, and consist of intrusive and extrusive rocks of basic, intermediate, and possibly acid composition; the more common types are basalt, dolerite, andesite, and microdiorite. More acid rocks are exposed near the top of the sequence.

Magnificent pillow lavas are exposed on the Mo, Wiwo, and Lower Waria Rivers, interbedded with massive lavas up to 20 feet thick. Agglomerate and tuff crop out to the east of the pillow lavas, on the coast north and south of Morobe, and in the lower reaches of the Mo and Waria Rivers. These are probably higher in the sequence than the pillow lavas, which are thought to be basal. Much of the dolerite and andesite shows no extrusive characteristics and was probably emplaced as shallow intrusions. The dolerite near the western margin may have intruded along the inferred fault which separates the Ultrabasic Belt from the Volcanics.

Primary minerals in the thin sections examined are partly obscured by alteration to saussurite, epidote, and chlorite. Epidotization is best seen in the massive microdiorite on Bigo Creek, which has been altered along joints to epidosite, a rock consisting solely of anhedra of quartz and epidote up to 0.5 mm. across. The original rock in this case was probably a melanocratic quartz-bearing pigeonite microdiorite.

Greenish pillow lava which crops out on the Mo River has been identified as chloritized and epidotized vesicular and amygdaloidal porphyritic basalt.

The Mageri Volcanics are probably a part of the Iauga Formation (Paterson & Kicinski, 1956), which crops out 15 miles south-east of the map area. The Iauga Formation is 'predominantly basaltic, ranging from olivine and augite andesites to quartz-microdiorite. These are accompanied by agglomerates, andesitic tuffs and tuffaceous sandstones'. The Formation is conformably overlain by Miocene (f_{1-2} Stage) limestone, and is thus probably lower Miocene.

RECENT

Alluvium

The main areas of alluvium are in the Middle Waria Valley, and on the flats of the coastal rivers. The alluvium of the Middle Waria Valley consists of gravel and sand, mostly derived from the metamorphics. Near Garaina it is 450 feet thick, but a few miles to the south it forms only a thin cover over the Nipanata Beds. No lacustrine sediments were seen.

Tumbled blocks of well cemented peridotite conglomerate were seen in the bed of the gorge on lower East Iwiri Creek, and the upper Iwiri River cuts through similar conglomerate, three miles to the north-west. The conglomerate may occur as valley fill or a thin cover over much of the low-relief country in the vicinity of Lake Trist.

Most of the coastal rivers flow through broad alluvial flats which in places extend twelve miles inland. As the rivers are not deeply incised the depth of alluvium is not known, but it may be of the order of 2000 feet. The upper part of the Saia River flows through a gorge cut in valley-fill material which consists of chaotically deposited angular and subrounded ultramafic boulders.

Most of the beaches at the mouths of the major rivers are composed of sand derived from the basic and ultrabasic rocks; for instance the beach sand at the mouth of the Saia River is predominantly olivine. In contrast, the alluvial fan of the Buiawim and Bitoi Rivers is composed largely of metamorphic detritus. Though these two rivers flow through ultramafic rocks near the coast, their headwaters are in rapidly eroding metamorphics. Away from the river mouths the beaches are made up of coral and shell fragments.

INTRUSIVE ROCKS

?LOWER TERTIARY

Morobe Granodiorite

The Morobe Granodiorite (Fisher, 1944) intrudes the Kaindi Metamorphics and Snake River Greywacke as a major batholith and many apophyses, some of which are within five miles of the Papuan Ultrabasic Belt. The intrusion has not been studied in detail; Noakes (1938) states that the overall composition is between granite and granodiorite, with more basic rock types produced by local differentiation, e.g.

Sandy Creek	:	Granodiorite
Upper Bitoi River	:	Quartz monzonite, granodiorite, tonalite, and hornblendite.

Constituent minerals are quartz, potash feldspar, andesine, biotite, hornblende, and (in the tonalite) a little augite. Two specimens from an apophysis in the headwaters of the Buisaval River were examined in thin section: both are trondhjemite, consisting of andesine, quartz, hornblende, epidote, and biotite.

The Morobe Granodiorite intrudes Cretaceous Snake River Greywacke (Dow, 1961) and is unconformably overlain by Miocene sediments (Fisher, 1944); thus it was intruded in Upper Cretaceous or Lower Tertiary time.

Trondhjemite of the Papuan Ultrabasic Belt (see p. 21)

Trondhjemite which intrudes the Papuan Ultrabasic Belt may be comagmatic with the Morobe Granodiorite. This relationship is suggested by their similar composition (see below), and the fact, first noted by Fisher (1944), that gold shed by the Morobe Granodiorite (860 to 880 fine) is very similar to that shed by the trondhjemite in the Juni area north of Garaina (854 to 866 fine). The trondhjemite is intruded by dolerite dykes which are probably related to the Miocene Mageri Volcanics: and it is therefore probably of Lower Tertiary age.

?OLIGOCENE

Papuan Ultrabasic Belt

The major igneous intrusion in the map area is the Papuan Ultrabasic Belt, an elongated complex of ultrabasic, basic, intermediate, and acid rocks which was emplaced, in solid or fluid state, in late Cretaceous or Tertiary time. It forms the western and central part of the Bowutu Mountains and is discussed in detail under a separate heading.

?MIOCENE

Dolerite

Metadolerite intruding the Kaindi Metamorphics, Nipanata Beds, and Lokanu Metavolcanics appears to be associated with the extrusion and deposition of volcanic members of the Nipanata Beds and Lokanu Metavolcanics, and is thus probably of Lower Tertiary age. Slightly altered dolerite and andesite which intrudes the Papuan Ultrabasic Belt and the Mageri Volcanics is probably associated with the extrusion and deposition of the Mageri Volcanics and is thus probably of lower Miocene age.

A distinctive topographic pattern is evident on the southern fringe of the map area, south of Kote Creek. The pattern is quite unlike that developed over the adjacent Nipanata Beds, and exotic dolerite boulders in Jaga Creek suggest that it may represent dolerite.

?PLIOCENE

Andesite Porphyry

Hornblende andesite porphyry intrudes undifferentiated Owen Stanley Metamorphics on the Ono River (Fisher, 1939), Kaindi Metamorphics in the Buiawim River (Dow & Siedner, 1958), and Lokanu Metavolcanics in Buansing Creek. This porphyry may be comagmatic with andesite porphyry which crops out in the Wau area, about seventeen miles to the west. The latter is thought to be Pliocene, but definite evidence of age is lacking.

A fine-grained green andesite porphyry intrusion on the Buiawim River cuts across part of the shear zone of the Owen Stanley Fault without being displaced (Dow & Siedner, op.cit.). This indicates that the fault existed before intrusion of the porphyry, but does not preclude the possibility that it was active after the intrusion, as subsequent movement might simply have by-passed that part of the fault zone.

PAPUAN ULTRABASIC BELT

The Papuan Ultrabasic Belt is a linear complex of ultrabasic, basic, and acid rocks, more than 230 miles long and up to 25 miles wide, which extends from the New Guinea coast near Salamaua to the Musa River in Papua (Pl.1). The belt has a north-westerly trend and is parallel to the faulted front of the Owen Stanley Range. For the greater part of its length, the south-western margin of the belt is bounded by faulting; the north-eastern margin is everywhere concealed by volcanics and sediments of Middle Tertiary age, or younger.

Thompson (1957) was the first to define the complex, to which he gave the name Papuan Ultrabasic Belt. Smith & Green (1961) preferred the name Papuan Basic and Ultrabasic Belt. In conference with Thompson, we have retained the briefer name Papuan Ultrabasic Belt, and have assumed that the presence of basic rocks might be taken as understood. 'Belt' is preferred to 'pluton' or 'complex' as it accentuates the elongated nature of the body.

The Ultrabasic Belt may have been derived from a gabbroic pluton magmatically emplaced in Mesozoic or Tertiary time. Gravity differentiation produced ultramafic, basic, intermediate, and acid rocks, but the process was interrupted by tectonic movements which culminated in the tilting and buckling of the body. The sum effect was to raise the south-western side of the pluton, where erosion has subsequently exposed the ultramafic rocks.

An alternative hypothesis (J. E. Thompson, pers. comm.) is that the Belt is a segment of the Pacific simatic crust which has reached its present position through relative lateral and vertical movements of the Pacific crust and the Owen Stanley metamorphic block. The boundary between ultramafic and feldspathic rocks may, under the conditions of high temperature and pressure prevailing at depth, have corresponded to the Mohorovicic Discontinuity. The vertical movement required to expose the Mohorovicic Discontinuity is probably of the order of ten miles. Recent lateral and vertical movement of nearly three miles on the Owen Stanley fault has been shown by the present survey (p.21), and horizontal displacements of between ten and eleven miles along Quarternary faults have been postulated in the D'Entrecasteaux Islands (Davies & Ives, 1961). With tectonic activity on this scale it is not difficult to envisage elevation of a segment of oceanic crust through a distance of ten miles.

PAPUAN ULTRABASIC BELT IN THE BOWUTU MOUNTAINS

In the Bowutu Mountains, the Papuan Ultrabasic Belt is bounded on the west by the Timeno and Owen Stanley Faults, and on the east is overlain by the Mageri Volcanics. On the accompanying map (Pl. 2), it has been divided into Ultramafic and Feldspathic Zones; the contact between these Zones has not been sharply defined by field mapping except in the Paiawa River area, where large tongues of intrusive gabbro extend into, and enclose parts of, the Ultramafic Zone.

Ultramafic Zone

The ultramafic rocks crop out in a northerly-trending belt more than 75 miles long and up to 18 miles wide; they are best developed in the northern part of the range between

Buansing and Sou Creek. South of Sou Creek they are intruded by gabbroic rocks and in the area south-east of Garaina they are generally restricted to a narrow belt about half a mile across. They are bounded on the west and south-west by the Timeno Fault, and on the east and south they merge with the Feldspathic Zone.

The ultramafic rocks are dunite, peridotite, pyroxenite, serpentinite, and actinolite schist. Anorthosite, basic pegmatite, and gabbro occur as rare dykes throughout most of the Ultramafic Zone, except in the extreme north, where mafic and ultramafic rocks are intermixed in roughly equal proportions.

The dunite is green to dark brown and consists of forsterite and accessory chromite and picotite. It is generally partly serpentinized, but some rocks from the Saia and Paiawa Rivers are remarkably fresh. The degree of serpentinization is apparantly related to proximity to faults and to younger feldspathic intrusive rocks. Thus samples from near fault zones and from the vicinity of gabbro intrusions are completely serpentinized, and where the Timeno and Owen Stanley Faults converge there is a zone, up to half a mile wide, of serpentinite pug (identified spectroscopically by W. M. B. Roberts, Bureau of Mineral Resources).

Faulting has produced peridotite and serpentinite breccias on Iwiri River near the Owen Stanley Fault and on East Iwiri Creek, and serpentinous pug at several points on the Owen Stanley Fault. Ultramafic landslip breccia covers parts of the Iwiri Valley and Ultramafic conglomerate covers some of the low-lying country south of Lake Trist.

The peridotite is harzburgite, consisting of forsterite and enstatite. Some exposures show rhythmic layering caused by segregation of orthopyroxene, but mostly the rocks are massive. Subordinate clinopyroxene in some samples may be augite or diopside.

Actinolite schist, which occurs with black serpentinite in the shear zone of the Timeno Fault, is probably derived from pyroxenite, though no pyroxene remnants were seen in the thin section examined. The rock consists of actinolite with accessory chromite and narrow stringers of calcite.

Very coarse-grained (up to 12 mm.) yellow-green and greyish pyroxenite commonly intrudes the peridotite as irregular veins and blebs. A similar rock collected by Dow & Siedner (1958), south of Salamaua, has been identified as enstatite pyroxenite.

Feldspathic Zone

The Feldspathic Zone in the Bowutu Mountains consists of gabbroic, noritic, and minor ultramafic rocks intruded and partly altered by trondhjemite, minor granodiorite, and younger doleritic dykes. The Zone has a maximum width of 18 miles in the central area north-east of Garaina. It extends north of the Paiawa River as a narrow coastal belt averaging about three miles wide, and southwards it narrows gradually to a width of about six miles at the south-eastern end of the range. The Feldspathic Zone is bounded on the south-west by the Timeno Fault, and on the east by a straight and probably faulted contact with the Mageri Volcanics. To the north the boundary with the Ultramafic Zone is undefined except in the Paiawa River, where basic rocks intrude the Ultramafic Zone.

The rocks making up the Feldspathic Zone may be broadly divided into three groups: basic rocks, acid rocks, and dolerite dykes.

Basic Rocks: Gabbro and norite constitute about 80 percent of the Feldspathic Zone. The other basic rock types are altered gabbro, and rare ultrabasic rocks, including orthopyroxene peridotite and clinopyroxene peridotite.

The mineral composition of the basic rocks generally differs sharply from that of the Ultramafic Zone: whereas the latter consists almost wholly of olivine and orthopyroxene, the basic rocks are mostly about 50 percent plagioclase, and generally contain clinopyroxene in excess of orthopyroxene. Few of the basic rocks have mineral compositions suggesting transition from ultramafic rocks except, perhaps, some dark norites found in the Feldspathic Zone which differ from pyroxenite in that they contain 12 to 18 percent plagioclase. In these, the orthopyroxene is generally considerably more iron-rich than any found in the Ultramafic Zone (En_{70-73} as opposed to En_{85-88}). Olivine-rich rocks are rare.

Because of the sparsity lack of field data and of outcrop between streams, it is difficult to define any pattern in the distribution of the original basic rock types. The distribution of the rocks within the Zone appears to be haphazard with the exception of the 'noritic zone' and the altered gabbro, which are discussed below.

The noritic zone lies east of Garaina. It appears to trend north-westwards, is up to 15 miles long and five miles wide, and is probably bounded by altered gabbro on all sides except to the north-west, where it may abut against the Ultramafic Zone. The rocks are hypersthene gabbro and norite in which the hypersthene is En_{70-73}, and the plagioclase ranges in composition from labradorite to anorthite. The association of norite and orthopyroxene-rich gabbro is seen again in a tongue of basic rock intruding the Ultramafic Zone on Sou Creek, a tributary of Paiawa River. Pyroxene in specimens from this locality is more magnesian (En_{84-88}), and has a similar composition to pyroxene in nearby pyroxenite. The only other known occurrence of hypersthene gabbro is near the Morobe trondhjemite body.

Altered gabbro occurs near the Timeno Fault, to the east of the noritic zone, and around the trondhjemite bodies at Piawaria, Kui, Morobe River, and the Sakia River. The largest area of altered gabbro is that around the Piawaria trondhjemite body; it extends across the full width of the Feldspathic Zone.

Alteration takes the form of partial or complete replacement of the gabbro, by minerals which are in equilibrium with trondhjemite, namely andesine, hornblende, and quartz. The resultant rock types are hornblende gabbro, hornblende diorite, uralitized gabbro, and, in one instance, augite diorite. In some exposures the new minerals, particularly hornblende, are porphyroblastic.

Gabbro and hypersthene gabbro are found only east of the noritic zone, suggesting that there may once have been a zone of pyroxene-rich gabbroic rocks east of the noritic zone. In these rocks the plagioclase is labradorite or bytownite, the clinopyroxene is augite, and the orthopyroxene is hypersthene.

Layered olivine gabbro crops out on the Saru-Morobe watershed, and olivine norite in Teperu Creek. The plagioclase is bytownite, An_{77-78}.

Acid rocks: Trondhjemite intrudes the basic rocks of the Feldspathic Zone as four main bosses and many minor intrusions. The four main intrusions, which crop out near Kui, Sakia, Piawaria, and in the Morobe River, cover areas of between four and fifteen square miles, and are roughly aligned north-south. Minor intrusions are most common near the four main bodies, but also occur at scattered locatities throughout the Zone, for instance near the Ono-Waria confluence and on upper Orupu Creek.

The trondhjemite has fairly uniform composition and consists of andesine (or rarely, oligoclase) 41-63 percent, quartz 20-39 percent, and green hornblende 5-19 percent or, rarely, 32-35 percent (probably contaminated). One sample, from the upper Orupu Creek, has unusual composition and texture: it is cataclastic granodiorite consisting of granulated quartz, albite, and unidentified potash feldspar.

Dolerite dykes: Doleritic dykes were noted in the eastern part of the Feldspathic Zone on the upper reaches of the Morobe River. The dykes are probably related to the Mageri Volcanics as they are more common near the contact with the volcanics and are of similar rock types. They intrude both gabbroic rocks and trondhjemite. Specimens examined in thin section are porphyritic leucocratic dolerite, altered porphyritic basalt, and albitized microdiorite or dolerite.

Alteration and Mineralization

Serpentinization has affected olivine and pyroxene in the peridotites (see under Ultramafic Zone above). Water required for serpentinization may have been introduced by the younger basic, intermediate, and acid rocks, or squeezed out of the Nipanata Beds, or be meteoric in origin (cf. Worst, 1958). The pyroxenes have been altered to actinolite, amphiboles to chlorite, and femic minerals and feldspars to epidote. The calcic cores of zoned plagioclase in the acid rocks are saussuritized.

Quartz veins intrude trondhjemite west of Piawaria, pyroxenite or gabbro east of Tida-ura, and dolerite of the Mageri Volcanics at Enoto Point; one such vein on the Waria River east of Tida-ura contains gold and chalcopyrite and the vein at Enoto Point contains chalcopyrite. Thin quartz veins in dolerite or trondhjemite south-west of Kui contain pyrite and minor chalcopyrite. The quartz probably derives from the trondhjemite. Calcite stringers occur in sheared and jointed ultramafic rocks near the Timeno Fault, and on the lower Waria River, south-east of Upupuru; these contain pyrite and pyrrhotite.

Lime metasomatism of ultramafic rocks from Bakewa Hill near the Timeno Fault has been described by Edwards (1957). The specimen consisted of 'finely microcrystalline grossularite enclosing patches of serpentine, and occasional blades of a tremolite-amphibole'. This specimen, which was collected by Gibson (1957), also contained chalcocite and ?chrysocolla (see below under Economic Geology).

STRUCTURE

Two separate orogenies, one pre-Cretaceous and one late Cretaceous, have folded and regionally metamorphosed rocks of the Owen Stanley Metamorphics. Faulting, probably largely transcurrent, with minor folding, has continued into Recent times.

The Kaindi Metamorphics were subjected to pre-Cretaceous regional metamorphism which has generally obliterated the bedding. Where bedding is discernible, the rocks are seen to be very tightly folded, and the schistosity is parallel to the axial plane of the folds. The present attitude of the schistosity is a result of later folding and faulting; for instance, near Wau (15 miles west of the map area), the schistosity dips gently and strikes between north and north-west as a result of late folding. Near the Owen Stanley Fault, the schistosity strikes parallel to the fault and dips towards it at progressively steeper angles, till, at the fault, the schistosity is nearly vertical; this is interpreted as a result of vertical movement along the Owen Stanley Fault.

In the Cretaceous rocks the dips and strikes of bedding planes suggest a tight north-easterly-trending syncline, the limbs of which dip at between 40^{o} and 90^{o}. However, schistosity generally dips at a shallower angle than the bedding, which is at variance with this simple structural interpretation, and more detailed mapping is required.

Faulting

Major transcurrent faults have been active along the Waria Rift Valley since Tertiary time. Of these, the Owen Stanley and Timeno Faults are the most important.

The Owen Stanley Fault forms the south-western boundary of the Waria Rift Valley; it brings the Owen Stanley Metamorphics against the younger Nipanata Beds and the Papuan Ultrabasic Belt. The fault is marked by a zone, up to half a mile wide, of intensely sheared rocks of the Papuan Ultrabasic Belt, the Owen Stanley Metamorphics, and the Nipanata Beds. North of Lake Trist the fault zone is 300 feet wide and consists of greenish-grey clay containing many rafted fragments of unaltered dunite up to six feet across. Between Lake Trist and the Iwiri - Waria junction, the zone consists of serpentinite and serpentinite pug, but farther south and south-east it is concealed by alluvium. The fault plane is probably vertical throughout its length, because the fault trace is relatively straight and unaffected by topography, and shear planes in the fault zone are approximately vertical.

The Owen Stanley Fault has been active in Recent times and the Bitoi, Buiawim, and Buisaval Rivers have been displaced anti-clockwise by about 14,000 feet where they cross it. Similarly, the Fault has displaced a small tributary of the Buiawim River and has blocked one of its branches, which is now filled with alluvium. The stream draining Lake Trist is displaced by only 8000 feet, but this discrepancy would be explained if Lake Trist were formed after the start of the transcurrent movement. To the south-east, in the Middle Waria Valley, the deposition of alluvial fans has obliterated most evidence of transcurrent movement, but such movement has probably caused the suspected diversion of the lower reaches of the Ono River (Fisher, 1939).

Along the middle Waria Valley, the elevation of the Owen Stanley Range suggests that the Fault has a vertical component of about 10,000 feet, though the high relief could be partly due to differential erosion along the fault trace. Outwash fans resulting from this uplift show that part of this movement has been comparatively recent. North of Mubo the Owen Stanley Fault splits, one branch trending north-eastwards to Buansing, and the other trending northwards to a point on the coast west of Salamaua. These two faults enclose a wedge of Lokanu Metavolcanics between the Kaindi Metamorphics and the Ultrabasic Belt.

The eastern side of the Middle Waria Valley is bounded by the Timeno Fault (Thompson, unpublished reports and maps). This fault is marked by a zone of serpentinite and actinolite schist up to quarter of a mile wide, and shows no evidence of recent movement. Apparent displacement of the Nipanata Beds, seen in the air photographs, suggests a north-westerly-trending branch fault which connects the Timeno and Owen Stanley Faults south of Garaina.

North of Bapi, the Owen Stanley and Timeno Faults are displaced anti-clockwise about 2000 feet by a fault trending 280^{o}. This displacement post-dates transcurrent movement on the Owen Stanley Fault and is probably Recent. Definite evidence for the fault was not seen; it is concealed by alluvium in the Middle Waria Valley and has probably been masked by rapid erosion in the Upper Waria Gorge. East of the Timeno Fault, near Bapi, air photographs reveal a fault which appears to have displaced Recent alluvium.

The preponderance of ultramafic rocks in the northern part of the Bowutu Mountains (see Ultramafic Zone, Plate 2) might be attributed to curvature of the Owen Stanley Fault. The Ultrabasic Belt has moved generally north-westward along the Timeno and Owen Stanley Faults. Where the latter curves from north-west to north, this north-westerly movement was probably partly arrested and translated into vertical movement, which might have elevated the ultramafic basal part of the pluton, subsequently exposed by erosion as the Ultramafic Zone. Photo-interpreted Recent faults near Lake Trist indicate vertical fault movements in this area. Of these faults, the westernmost show upthrow to the east. They displace Recent topographical features such as ridges and streams, and have caused the development of many small lakes and swamps, including Lake Trist. Campbell (1958) observed an 'old fault reopened by very recent movement' about two miles north of Lake Trist.

The contact between the Papuan Ultrabasic Belt and the Mageri Volcanics is probably fault-controlled as it is straight and the basal volcanic strata strike at right-angles to it. There is no evidence of faulting at the contact, probably because later dolerite and andesite were intruded along the fault zone.

GEOLOGICAL HISTORY

The oldest rocks are the metamorphosed sediments of the Owen Stanley Metamorphics: these include the Kaindi Metamorphics and the younger Cretaceous rocks. The Kaindi Metamorphics are geosynclinal sediments of Palaeozoic or Mesozoic age. The limits of the area of deposition are not known, but it is thought that marble lenses and associated coarse-grained metamorphics, which crop out between the Snake and Ono Rivers (see Pl. 1), were originally the marginal sediments (limestone reefs, conglomerate, quartz greywacke, and greywacke) of the western flank. The Kaindi sediments emerged and were probably folded and metamorphosed before deposition of the Cretaceous rocks, which are not older than Middle Jurassic nor younger than Middle Cretaceous (see p. 12). The folding of the Cretaceous rocks may have been contemporaneous with the emplacement of the Morobe Granodiorite, which was intruded as several major plutons and a number of stocks and bosses, probably in Lower Tertiary time.

The Nipanata Beds and Lokanu Metavolcanics were probably deposited in Lower Tertiary time on the eastern and north-eastern flank of the metamorphic block. The sediments of these two formations are fine-grained (e.g. marble, siltstone, mudstone); this indicates a deep-sea environment or deposition offshore from a land mass of low relief. The volcanic members are altered and have not been examined in sufficient detail to determine whether extrusion was sub-aerial or submarine.

The Papuan Ultrabasic Belt was probably magmatically emplaced in lower Middle Tertiary time. The evidence for both magmatic emplacement and age is very meagre as contacts with supposed older rocks are almost invariably sheared. The only evidence of age is the fact that the Belt is overlain by volcanics of the Iauga Formation, which are conformably overlain by Miocene (f_{1-2} stage) limestone (Paterson & Kicinski, 1956).

The Belt may have been emplaced in the fluid, near-solid, or solid state. Thompson (see under Papuan Ultrabasic Belt) thinks it more likely that the Belt was emplaced in near-solid state by faulting, and was originally a segment of the Pacific simatic crust. Green (1961), working separately, has reached a similar conclusion and, in support of this hypothesis, cites the difficulty of envisaging a magma chamber of appropriate dimensions undergoing prolonged differentiation in the active orogenic environment in which the Belt occurs.

We suggest that the pluton was emplaced in a fluid state, intruding either the sub-oceanic simatic crust or the Nipanata Beds. Subsequent gravity differentiation was disturbed by tectonic stresses which accompanied the faulting of the pluton into its present position. The sequence of crystallization and stress could have been as follows:-

1. Crystallization and gravity-induced settling of the mafic minerals, olivine and pyroxene, resulting in a basal layer of peridotite and pyroxenite.
2. Crystallization of calcic plagioclase, pyroxene, and minor olivine resulting in a layer composed of gabbro, norite, pyroxenite (minor), and anorthosite (minor), and leaving a residual magma of trondhjemite composition.
3. Stress and tectonic movements contemporaneous with stage 2, resulting in the intrusion of gabbro, norite (some pegmatitic), and anorthosite into joints and brecciated zones in the ultramafic layer.
4. Crystallization of trondhjemite, granodiorite, and residual quartz.
5. Stress and tectonic movements contemporaneous with stage 4, resulting in the intrusion of intermediate and acid rocks into the basic rocks and the intrusion of quartz into both types.
6. Intrusion of dykes of basalt, dolerite.
7. Extrusion of the Mageri Volcanics, probably accompanying stage 6.

The contact between the Mageri Volcanics and the plutonic rocks of the Papuan Ultrabasic Belt is sharp and linear, but with no sign of either an old erosion surface or faulting. The linearity of the contact suggests that it is faulted; the lack of field evidence for faulting might be due to late-stage intrusions of dolerite along the fault zone.

Andesite porphyry intruded the Kaindi Metamorphics, the Lokanu Metavolcanics, and the shear zone of the Owen Stanley Fault, probably in Upper Tertiary time.

Major faulting may have commenced in Upper Cretaceous or Lower Tertiary time and has continued until the Recent; the most recent fault movements have been predominantly transcurrent and anti-clockwise. The Ultrabasic Belt has moved north-westward relative to the Owen Stanley Metamorphics. Where this north-westerly movement was impeded by curvature of the Owen Stanley Fault, the Ultrabasic Belt has been elevated, and in these areas erosion has exposed the ultramafic basal part of the pluton.

Both the metamorphic and igneous blocks have been elevated by faulting; uplift of the metamorphics has probably continued into the Recent. Elevation of the western side of the igneous block was apparently accompanied by depression of the eastern (Volcanics) side. The intervening wedge of Nipanata Beds was probably folded by the faulting and may have been depressed relative to the igneous and metamorphic blocks.

Quarternary sediments include piedmont deposits of angular rock fragments in a clay matrix, alluvium, coral reefs, and beaches of coral and shell fragments.

GEOMORPHOLOGY

Uplift and tilting by Plio-Pleistocene and Recent faulting have formed the two mountain ranges, the intermontane depression, and the sunken coastline. These topographical units correspond to the major geological units.

The prominence of the Owen Stanley Range is due to uplift on the Owen Stanley Fault and to the resistance to erosion of the crystalline metamorphic rocks of the Owen Stanley Metamorphics. The Owen Stanley Fault is expressed by the steep linear front of the range. The major streams which drain the range are consequent and flow into the Waria Rift Valley at right angles to the fault. The tributaries of these streams are mostly subsequent and follow the regional north-westerly strike of the Metamorphics. The Buiawim, Buisaval, and Bitoi Rivers have been displaced by anti-clockwise transcurrent movement along the Owen Stanley Fault.

The central and southern part of the Waria Rift Valley is bounded by the Owen Stanley and Timeno Faults. To the north there is no evidence that the Rift Valley originated from down-faulting and it may have been formed merely by rapid erosion of rocks imbricated by movement on the Owen Stanley Fault. The Iwiri River flows southward through this zone of imbrication. Minor Recent faulting in this area has formed lakes and swamps. The Middle Waria River flows through the Rift Valley and has been deflected to the north-eastern margin by alluvium shed from the rapidly eroding Owen Stanley Range.

The Bowutu Mountains have been formed by elevation of the Papuan Ultrabasic Belt on the Timeno and Owen Stanley Faults. Topographical patterns within the range reflect the different rock types. The most distinctive is the fine dendritic drainage and low-relief topography which is developed over the highly feldspathic diorite and trondhjemite. Ultramafic country is characterized by sub-rounded massive spurs and ridges and generally a broad drainage pattern. In the youthful stages of erosion, the rivers flow through steep gorges rather than the V-shaped valleys which are typical of the metamorphics. Where basic and ultramafic rocks are intimately associated, the topography is not distinctive. Many of the major streams are consequent, and flow either eastwards or westwards to the coast or to the Waria Rift Valley. Others, such as the Saru River, parallel the northerly trend of the range and are controlled either by primary layering of the pluton, by contacts between the different rock-types, or by jointing. Bigo Creek, a headwater tributary of the Wiwo River, is an interesting example of consequent easterly drainage controlled by strong northerly jointing in massive miciodiorite. The result is a course characterized by right-angle bends.

The Coastal Region corresponds to the coastal part of the Mageri Volcanics; the razor-backed ridges are formed by the erosion of fine-grained dolerite and andesite, and the sunken coastline is due to the tilting of the igneous block.

ECONOMIC GEOLOGY

Gold, copper, nickel, cobalt, chromium, mercury, platinum, and osmiridium occur in the mapped area, but only gold and platinum have been commercially exploited.

Gold, platinum, and osmiridium

European miners worked alluvial gold in the Middle Waria Valley at Timanagosa, Juni, and Piawaria before 1940, and on the Wiwo River and near Dona before 1914 (Fisher, 1944; Fraser, pers. comm.). Known production was 850 fine ounces (Fisher, 1944), but this figure probably does not include production before 1914. Since 1945 native miners have won about 150 ounces from Kau Creek on the Upper Ono River, from the Waria River between Garaina and Agutame, and from the Wiwo and Wuwu Rivers (Fraser, pers. comm.).

Emmons (1937, p.456) writes that 'placers of the Waria River region are estimated to contain 915,600,000 cubic yards of wash, with fourpence per yard gold' and quotes Sutherland (1930, pp.247-250) as his source. Sutherland's figures are open to question as there is no record of any extensive programme of prospecting and drilling before 1930, and subsequent mining has been on only a small scale. Possibly Sutherland obtained his figures from a report written by a German engineer which is mentioned by Fisher (1939); this report has not been sighted by Fisher or the writers. Since publication of Sutherland's book, Bulolo Gold Dredging Ltd and Sunshine Gold Development Ltd (Fisher, 1939) have done some drilling in parts of the Middle Waria Valley, and on Kau or Tinai Creek, but it was not followed up and it is assumed that the prospects were not economic.

Fisher (op.cit.) examined the Timanagosa and Juni workings and noted that 'working has mostly been confined to low terraces near the river as, owing to the prevalence of flood conditions, the lower ground is difficult to work, and the higher ground is too poor. Occasional flats have been found workable, and the upper portion has been skimmed off beaches in the rivers'.

Reef gold crops out on the Middle Waria River, one mile east of Tida-ura (Thompson, 1957), and unpublished reports). The gold occurs with chalcopyrite in a narrow vein of white quartz, which intrudes gabbro and pyroxenite. Quartz reefs on upper Kau Creek contain a trace of gold and about 4 ounces of silver per ton (Fisher, 1939). Fisher (1944) notes that the alluvial gold of the Middle Waria Valley has mostly shed from the Upper Ono River, where andesite porphyry intrudes slate, schist, and limestone of the Kaindi Metamorphics. There is little alluvium in the fast-flowing upper Ono River, and most of the gold has been carried down to the Middle Waria Valley near Timanagosa and Juni Creek. The little gold which has been won from near the porphyry intrusion has a fineness of 750, that at Timanagosa averages about 760, and the Juni gold is usually about 780.

The Ono porphyry is mineralogically similar to the Lower Edie porphyry, which crops out in the Wau area and which sheds gold of about 760 fine (Fisher, 1944).

Small parcels of gold from Juni have fineness as high as 854 with individual nuggets as high as 866. Fisher suggests that this gold is shed from a nearby stock of Morobe Granodiorite, which here has the composition of monzonite; he notes that gold shed from the Morobe Granodiorite normally has fineness between 860 and 880. We regard the monzonite as a member of the acid group of rocks of the Papuan Ultrabasic Belt.

Small amounts of alluvial gold have been won from rivers which drain the outcrop area of the Mageri Volcanics; these include the Wiwo and Mo Rivers (Robinson, 1959) and the tributaries of the lower Maiama River (reported by Maiama natives).

Nickel, cobalt, chromium

Nickel may occur over ultramafic rocks as either lateritic concentrations in the soil or veins of nickel silicate in the zone of weathered rock (de Vletter, 1955; Thompson, 1957). However, in those parts of the Papuan Ultrabasic Belt which have been tested, nickel concentrations are below economic grade.

Fresh peridotites commonly contain about 0.2% nickel, probably in the lattice of the olivine crystal. The development of lateritic concentrations of nickel is discussed by de Vletter (1955). Concentration of the nickel requires:

(i) a warm humid climate which favours chemical weathering,

(ii) a near-flat topography, so that ground-water movement is not so rapid as to remove the products of chemical weathering, and

(iii) time.

Carbonated rain-water dissolves silicon, magnesium, and iron compounds, but the iron is almost immediately precipitated as oxides. Relatively insoluble elements, such as nickel, chromium, and cobalt, are residually concentrated. If the carbonated water has leached all the magnesium from a zone, it may then attack the nickel, carry it down, and redeposit it, probably as a colloidal precipitate, in a zone of plentiful magnesium. This nickel-enriched zone migrates downwards as weathering proceeds.

Stanley (1919) was the first to note nickel in the Papuan Ultrabasic Belt on the Mamama River, east of Kokoda. Grey (1955) drew attention to the possibility that nickel silicate ore may have developed over ultramafic rocks near Kokoda, and recommended further investigation. Thompson (1957) defined the Ultrabasic Belt and aroused interest in the nickel potential of the ultramafic part of the Belt. He instigated hand-drilling programmes at Koreppa in the Middle Waria Valley, and in the Ajura Kujara Range near Kokoda. International Nickel Company and Bulolo Gold Dredging Ltd also carried out a programme of hand-drilling west of Lake Trist.

The results of these investigations were not sufficiently encouraging to stimulate intensive prospecting or detailed investigation of known deposits. Campbell (1958) suggests that the climate of the Lake Trist area is not favourable in that temperatures are not high and there is no alternation of marked wet and dry seasons. Near the Owen Stanley and Timeno Faults lateritic concentration of nickel may have been inhibited by the severe serpentinization of the peridotite.

The current survey located an untested area in which nickeliferous soils may be present in economic grade and quantity (see under Recommendations); nickel silicate mineralization was noted south-west of this area in the upper Iwiri River.

Small amounts of cobalt are invariably present in lateritic nickel ore. At Koreppa the black cobalt oxide, asbolan, is associated with soft black nodules of manganese wad (Thompson, 1957, and pers. comm.).

Alluvial concentration of chromite has been observed in streams draining the Papuan Ultrabasic Belt, and chromite is a minor constituent of heavy mineral sands on the north-eastern coast of Papua (Thompson, op. cit). It derives from disseminated chromite in the ultramafic rocks.

Copper

Copper mineralization occurs in the Ultrabasic Belt near the Timeno Fault, on the Paiawa and Saia Rivers, and in the Mageri Volcanics on Bigo Creek and at Enoto Point.

Mineralization close to the Timeno Fault was seen near Tida-ura and Upupuru villages. Chalcopyrite occurs in the gold-bearing quartz vein which crops out a mile east of Tida-ura. On Bakewa Hill, west of Upupuru, chalcocite and ?chrysocolla occur in altered ultramafic rocks (Edwards, 1957). Apparently, movement on the Timeno Fault has induced shearing and jointing in the adjacent ultramafic rocks into which hydrothermal solutions from the acid rocks have introduced copper and other minerals.

Basic rocks found as boulders in the Paiawa and Saia Rivers show partial replacement by iron, copper, and rare nickel sulphides; the source of the boulders was not found. G.J. Greaves has examined the specimens and reports as follows (pers. comm.):

'Specimen W32 from Sou Creek, a tributary of the Paiawa River, consists of hornblende-hypersthene gabbro with 5 to 10% sulphides; the rock is constituted as follows: labradorite 55%, hornblende 25%, hypersthene 5%, clinopyroxene 5%, sulphides 5-9%, ilmenite 1%. The sulphides comprise pyrite 30%, melnicovite pyrite 25%, marcasite 30%, chalcopyrite 10%, millerite? (a nickel mineral) 5%, pyrrhotite rare. Some of the plagioclase is zoned: hornblende appears to have formed from the clinopyroxene.

'Specimen W51 from the Saia River consists of micronorite with 30 to 50% sulphides. The mineral composition is: labradorite 30-40%, hypersthene 10-20%, prehnite 10%, chrysotile and antigorite minor, sulphides 30-50%. The sulphides comprise pyrrhotite 70%, pyrite 20%, chalcopyrite 10%. These occur interstitial to the silicate minerals, as rounded grains within the plagioclase, and as rims around the hypersthene grains, which are generally rounded. Prehnite occurs as veins up to 1.5 mm. across which transgress both silicate and sulphide minerals, and as narrow (0.01 mm.) reaction rims between the sulphides and the enclosed pyroxenes.'

Minor pyrite and chalcopyrite occur in quartz veins in the trondhjemite which crops out south of Kui.

At Enoto point, between Kui and Sipoma, a quartz-chalcopyrite vein, six to ten inches wide, intrudes a zone of brecciated and silicified light-coloured andesite or fine-grained dolerite. The brecciated zone is 100 feet wide. Both the vein and the banding in the adjacent dolerite dip to the south-south-east at an angle of 50^{o}. Greaves (pers. comm.) has identified the following minerals in a specimen from this vein: quartz 70%, epidote 10%, sulphides 10%, malachite 5%, hydrated iron oxide 5%. The sulphides are: chalcopyrite 70%; covellite, chalcocite, and minor digenite 30%.

Minor pyrite and chalcopyrite occur disseminated in part-epidotized microdiorite of the Mageri Volcanics on Bigo Creek.

Mercury

Alluvial cinnabar has been recovered from Kau Creek (Fraser, 1960).

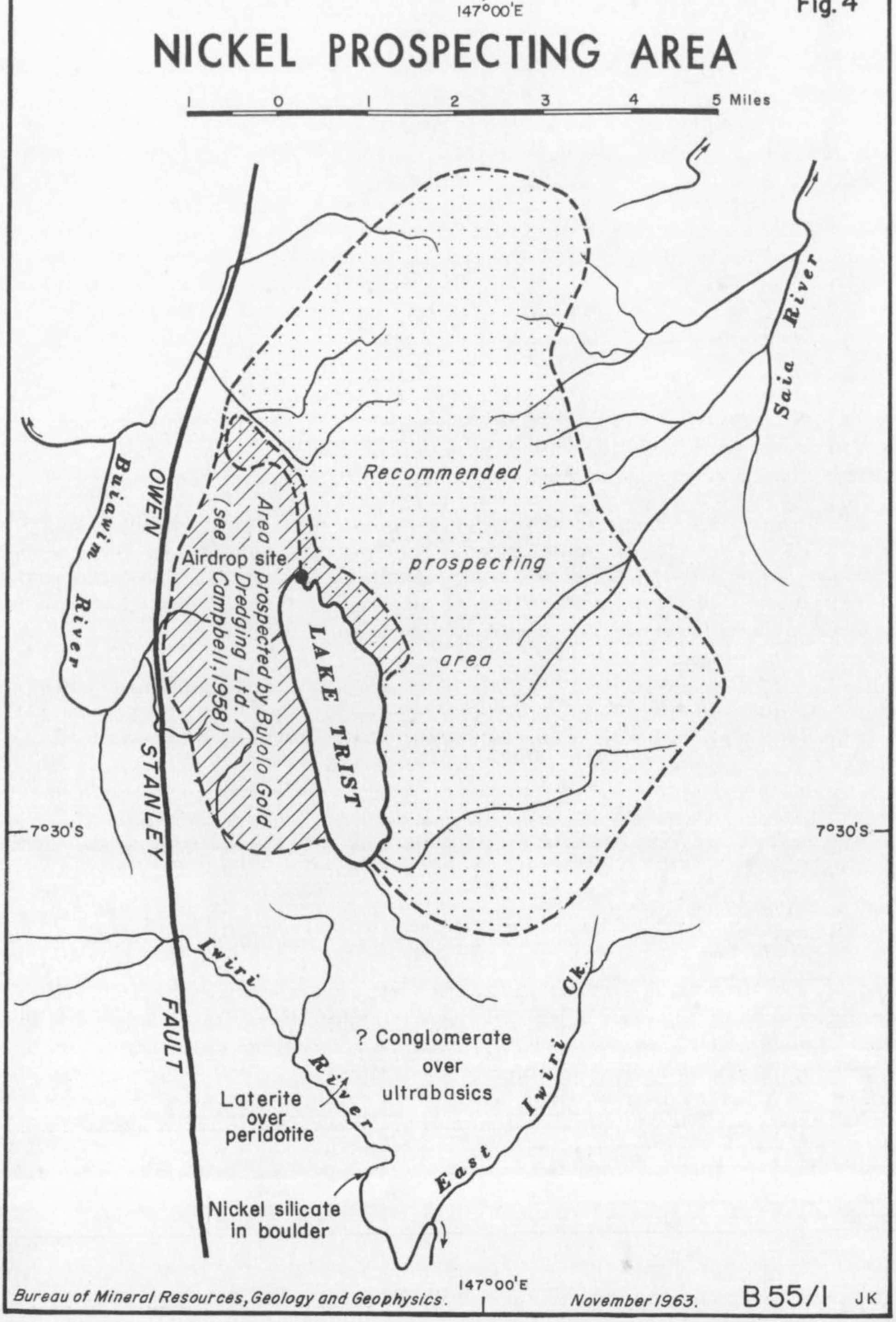

Fig. 4
NICKEL PROSPECTING AREA
147°00'E
1 0 1 2 3 4 5 Miles
Recommended prospecting area
Area prospected by Bulolo Gold Dredging Ltd. (see Campbell, 1958)
Airdrop site
LAKE TRIST
OWEN STANLEY FAULT
Buiawim River
Saia River
Iwiri River
East Iwiri Ck.
7°30'S
? Conglomerate over ultrabasics
Laterite over peridotite
Nickel silicate in boulder
Bureau of Mineral Resources, Geology and Geophysics.
November 1963.
B 55/1 JK

RECOMMENDATIONS

1. Further nickel prospecting should be carried out east and north of Lake Trist, where there is a low-relief area of about 30 square miles (see Fig. 4) underlain by ultramafic rocks. A small area, mostly west of Lake Trist, was tested by Bulolo Gold Dredging Ltd under the direction of F. A. Campbell in 1958.

In the initial stage of the proposed programme, holes should be spaced at half-mile intervals so that local irregularities, such as shearing or the presence of pyroxenite or gabbro, do not unduly influence the results. It is important that assay results be made available without delay so that when a reconnaissance augering programme is completed, detailed testing of the areas with high nickel values can be undertaken. Ideally, assays should be done in the field, but this may not be practicable. Alternatively, samples could be taken to Wau by runner or collected by a chartered float-plane. Access to the area is by means of a foot-track from Wau, a walk of two to four days. Supplies for the Bulolo Gold Dredging prospecting party were dropped on an area of springy grass at the northern end of Lake Trist and a Qantas Beaver float-plane was landed on Lake Trist with supplies and personnel (Campbell, 1958).

The recommended equipment is 4-inch post-hole augers, heavier augers to break through any boulders in the soil, and threaded three-foot lengths of 3/4 inch pipe. The optimum working team is three to six natives per auger, depending on the depth of the hole. In the Kokoda area this equipment has been used to drill holes as deep as 70 feet.

Bovio Hill, a day's walk north of Garaina between Timanagosa and Bapi, may also warrant testing as a lateritic nickel prospect. The hill is about one square mile in area, and is composed of jointed dunite with a moderate soil cover.

2. The Timeno Fault zone should be examined for copper mineralization from Tida-ura south-eastwards to the limit of the map area and beyond. Known exposures of mineralization, at Tida-ura and Bakewa Hill, are very small, but closer examination and pitting might reveal larger bodies.

3. The source of boulders containing chalcopyrite in the Paiawa and Saia Rivers might be found by detailed geological or geochemical survey. Such a survey would be hampered by the difficulty of traversing these rivers, and by the poor exposure at bedrock in the accessible parts of the river beds. Geochemical prospecting might be defeated by rapid run-off into swift-flowing streams, absence of fine-grained alluvium in the stream beds, and a sparsity of residual soil on the valley slopes. The most promising method of geochemical prospecting is the analysis of residual soils from the ridge tops.

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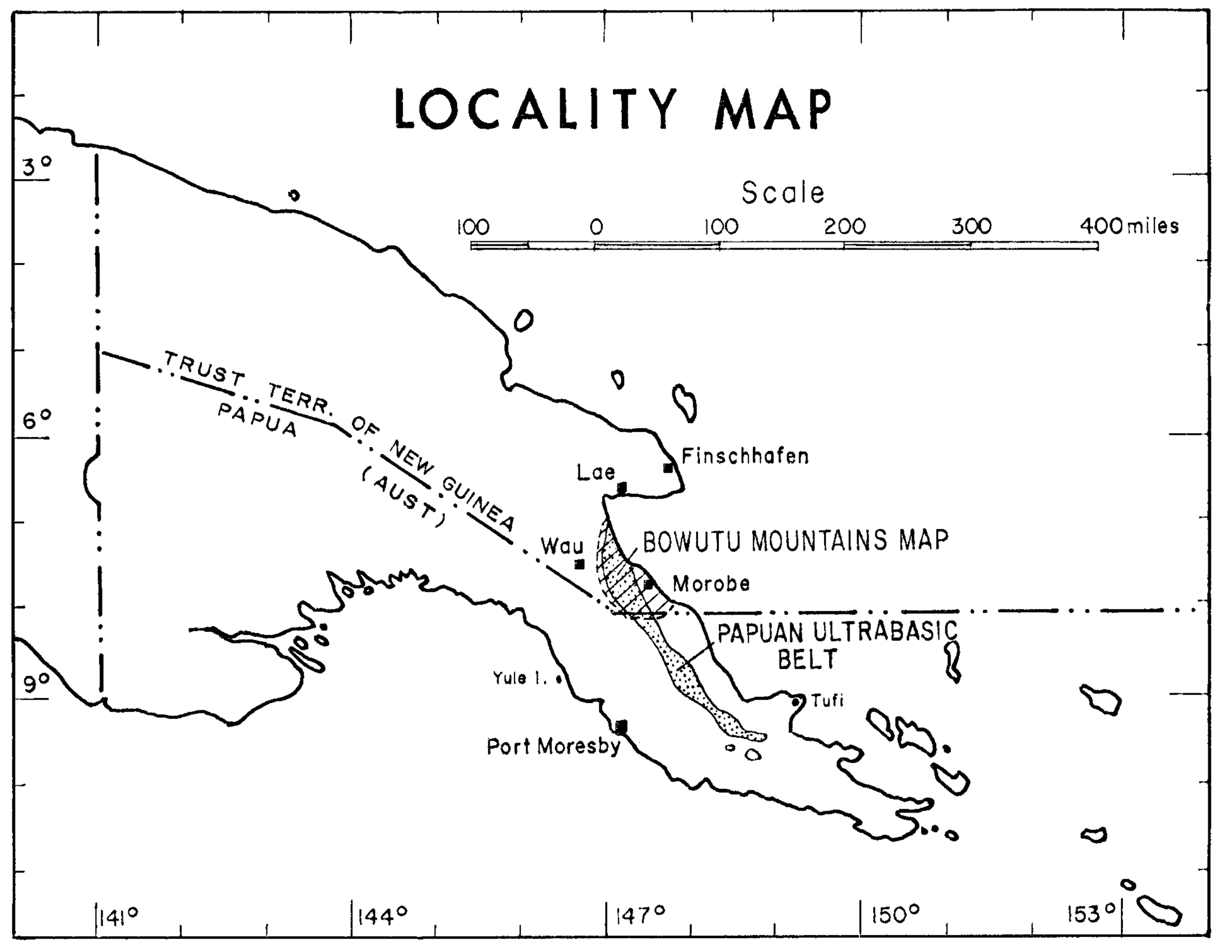
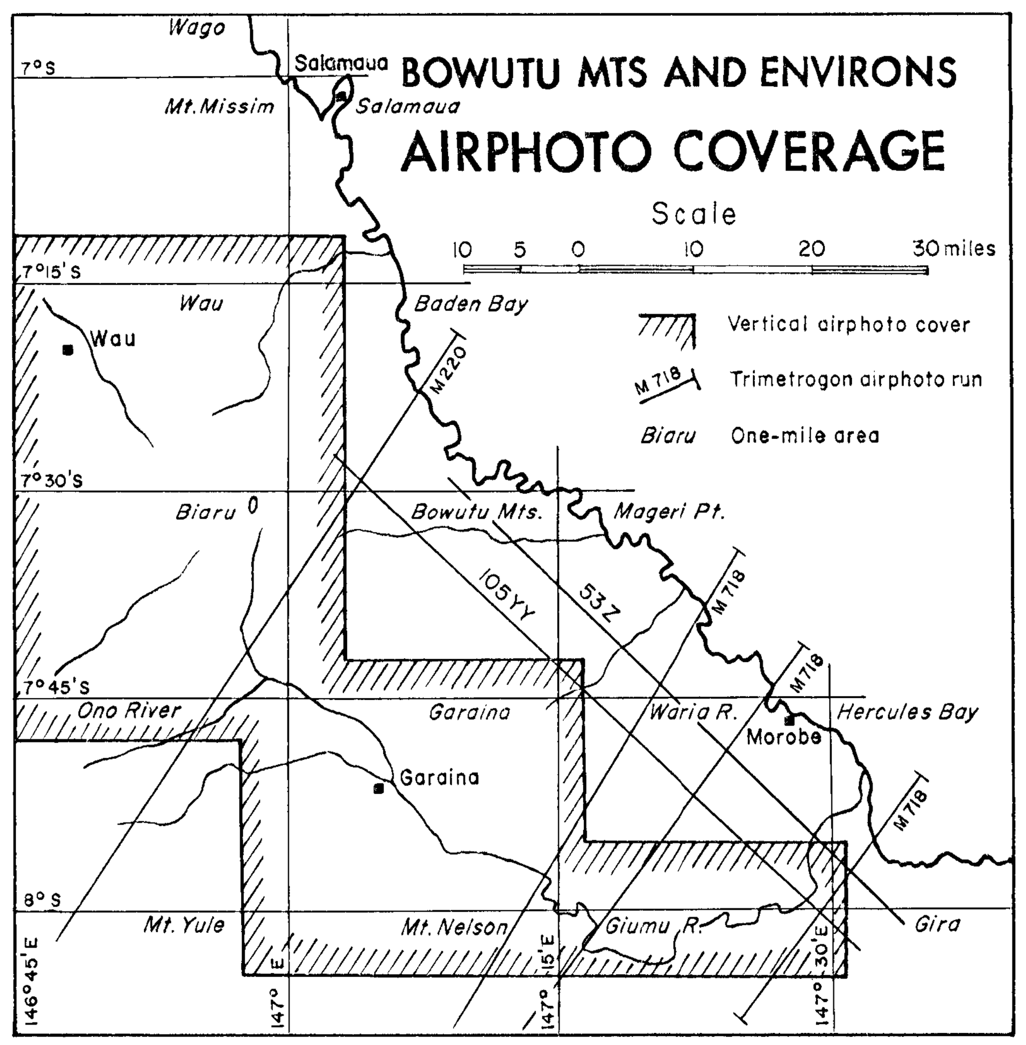
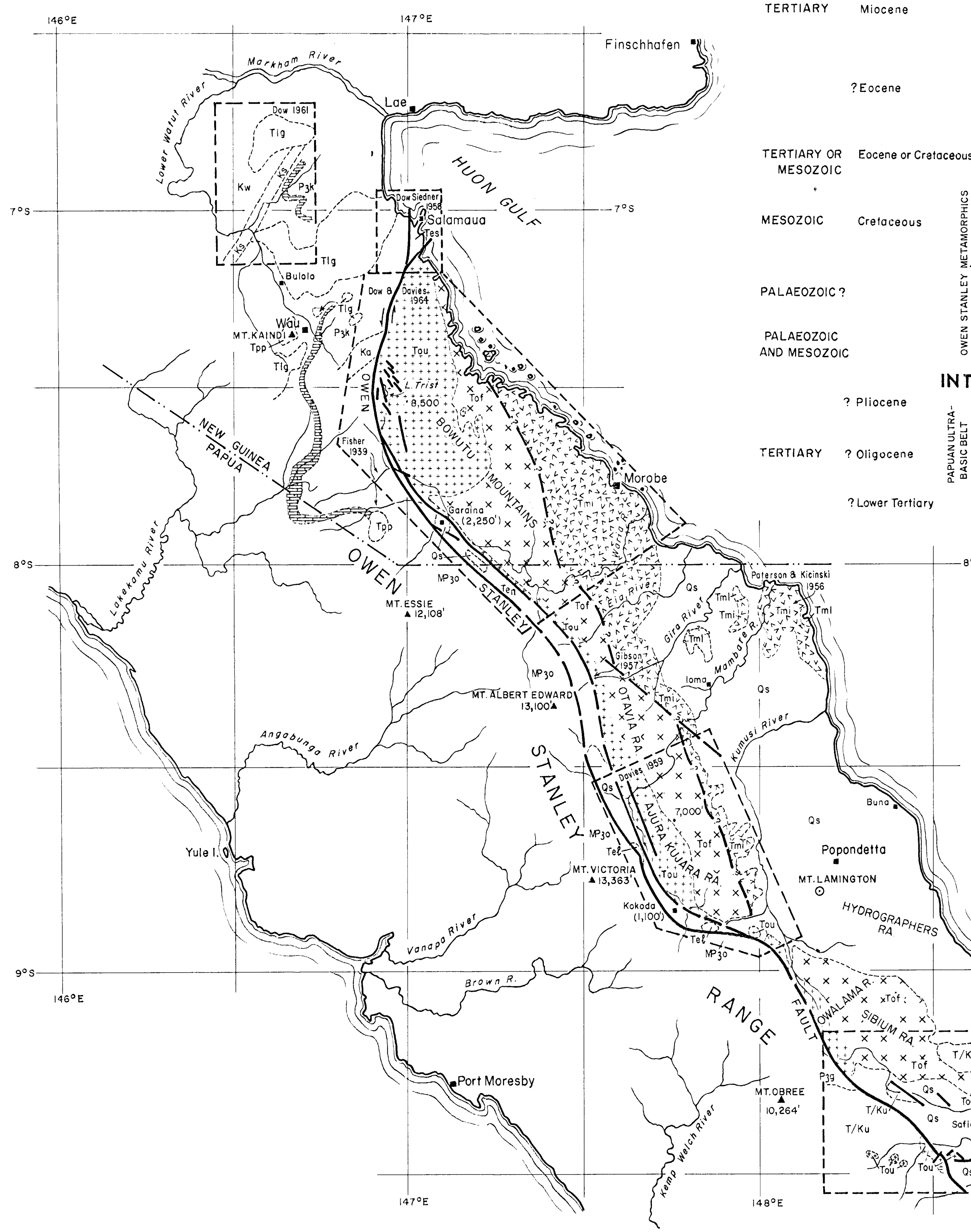
Plate I.

THE PAPUAN ULTRABASIC BELT

Geology by: Fisher, Kicinski, Thompson, Davies, Smith, Green, Dow, and Siedner - Bureau of Mineral Resources.
Gibson and Mitchell - Bulolo Gold Dredging Ltd.
Compiled by H. L. Davies.







REFERENCE

QUATERNARY			Qs	*Alluvium and volcanics.*
TERTIARY	Miocene		Tml	*Limestone.*
		Iauga Formation (includes? Mageri Volcanics)	Tmi	*Basalt, dolerite, andesite, agglomerate, tuff, pillow lava.*
	?Eocene	Nipanata Beds	Ten	*Fine-grained sediments and metadolerite.*
		Lokanu Metavolcanics	Tes	
		Lasa Beds	Teℓ	
TERTIARY OR MESOZOIC	Eocene or Cretaceous	Urere Metamorphics	T/Ku	*Hornfelsed basalt, agglomerate, siltstone.*
MESOZOIC	Cretaceous	OWEN STANLEY METAMORPHICS: Snake River Greywacke	Kw	*Siltstone, greywacke, minor conglomerate, sericite & mica schist.*
			Ks	
			Ka	
PALAEOZOIC ?		Kaindi Metamorphics	P3k	*Mica schist, phyllite, stretched conglomerate. Marble member.*
		Gorupu Metamorphics	P3g	*Mica schist, phyllite.*
PALAEOZOIC AND MESOZOIC		Undifferentiated Owen Stanley Metamorphics	MP3o	*Sericite schist, phyllite.*

INTRUSIVE IGNEOUS ROCKS

	? Pliocene		Tpp	*Hornblende andesite porphyry.*
TERTIARY	? Oligocene	PAPUAN ULTRA-BASIC BELT: Feldspathic Zone	Tof	*Mostly gabbroic, some ultramafic, some intermediate.*
		Ultramafic Zone	Tou	*Peridotite, pyroxenite, serpentinite, some gabbroic rocks.*
	? Lower Tertiary	Morobe Granodiorite	Tlg	*Granodiorite, minor tonalite.*

SYMBOLS

Fault
Fault, position approximate.
Inferred fault
Geological boundary, approximate
Inferred geological boundary
Territory border
Dow & Siedner 1958 *Survey boundary and reference*
Volcano
Towns, Villages.

SCALE

10 5 0 10 20 30 40 50 60 miles

Plate 2

GEOLOGICAL MAP OF THE
BOWUTU MOUNTAINS NEW GUINEA
SCALE 1: 250,000
10 MILES
REFERENCE
QUATERNARY Recent — Boulder beds, gravel, sand, silt, peat
TERTIARY Miocene — Mageri Volcanics — Basalt, dolerite, andesite, microdiorite, agglomerate, tuff. Pillow lava.
?Eocene — Nipanata Beds — Mudstone, siltstone, fine-grained greywacke, marble and metadolerite.
?Eocene — Lokanu Metavolcanics — Altered basalt and dolerite, silicified siltsone and marble.
MESOZOIC Cretaceous — Sericite schist, fossiliferous greywacke
PALAEOZOIC ? — OWEN STANLEY METAMORPHICS — Kaindi Metamorphics — Sericite and mica schist, quartz mica schist, stretched conglomerate, calcareous schist. Marble.
PALAEOZOIC and MESOZOIC — Undifferentiated — Phyllite and sericite schist
IGNEOUS ROCKS
?Pliocene — Hornblende andesite porphyry.
TERTIARY ?Oligocene — PAPUAN ULTRABASIC BELT — Feldspathic Zone — Trondhjemite and tonalite. Basic, intermediate and acid rocks. Eucrite, norite, gabbro, anorthosite, diorite, tonalite, trondhjemite and rare granodiorite.
Ultramafic Zone — Dunite, pyroxene peridotite, pyroxenite, serpentinite, actinolite schist and minor basic rocks.
? Lower Tertiary — Morobe Granodiorite — Granodiorite, minor tonalite
SYMBOLS
Geological boundary, position accurate
Geological boundary, position approximate
Inferred geological boundary
Strike and dip of beds
Vertical bedding
Plunge of fold
Bedding trends
Strike and dip of foliation
Vertical foliation
Fault, position accurate
Fault, position approximate
Fault, concealed by alluvium
Inferred fault
Fault, showing relative horizontal movement
Fault, showing relative vertical movement
Macrofossil locality (marine)
Minor mineral occurrence
Alluvial gold workings
Gold, platinum, copper, mercury, nickel, pyrite, pyrrhotite, chalcopyrite
Spot height in feet, by uncontrolled barometer.
Foot-track
Airstrip
Native village
Territory border
Section line
SALAMAUA
LOKANU
Tambu Bay
BUANSING
SAWET
SALUS
MUBO
GUADAGASAL
LABABIA
Nassau Bay
Sachsen Bay
Hessen Bay
Lasanga Island
BUSO
Baden Bay
Wuttenburg Bay
SIPOMA
PAIAWA
Mageri Bay
MAIAMA
ZINAPA
AMOA
GORI
BOSPAIRA
MOROBE
POSE
SAPPA
ZAKA
HAUS KAPA
PEMA
AGUTAME
AKOBE
ZEMA
UPUPURU
GIMMIE
KILA
JUWERA
ASAWA
MOTETE
ARO
KIPU
KAISU
GARAINA
KAPISO
GUSWEJ
KUMISI
PAGAU
SINI
GARAWARIA
PEI-IRA
NEW GUINEA
PAPUA
B O W U T U
M O U N T A I N S
NORITIC ZONE
OWEN STANLEY FAULT
Waria R.
Ono River
Bubu R.
Bulolo
Buipat Ck
MT DZANGHO 8,500'
146°50'
147°00'
147°10'
147°20'
147°30'
147°40'
7°00'
7°10'
7°20'
7°30'
7°40'
7°50'
8°00'
8°10'
SECTIONS (V/H = 1)
A
B
C
D
10,000'
5,000'
S.L.
Bureau of Mineral Resources, Geology and Geophysics.
November 1963
To accompany Report No 75
B 55/15/6