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THE GEOLOGY OF THE BOWUTU MOUNTAINS, NEW GUINEA.

by

D.B. Dow and H.L. Davies.

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SUMMARY

The geology of the Bowutu Mountains and environs is described, with particular attention to the Papuan Basic Belt, and the economic mineral potential of the area is discussed.

The area mapped extends from Salamaua southward to the Papua - New Guinea border and lies between the Owen Stanley Range and the Morobe Coast. The Bowutu Mountains consist of igneous rocks of the Papuan Basic Belt and the Mageri Volcanics; the Owen Stanley Range is made up of metasediments of the Owen Stanley Metamorphics. The two mountain ranges are separated by the Trist - Waria Depression. The Nipanata Beds and the Salamaua Volcanics occur as faulted wedges between the Basic Belt and the Metamorphics.

The Owen Stanley Metamorphics includes the Kaindi Metamorphics and the Sampa Beds. Shelf and trough-type sediments of the Kaindi Metamorphics were laid down in a north-westerly-trending geosyncline in Palaeozoic or Lower Mesozoic time. Pre-Cretaceous orogeny regionally metamorphosed the sediments to give biotite schist, stretched conglomerate and marble. Fossiliferous greywacke and siltstone of the Sampa Beds were deposited unconformably upon the Kaindi Metamorphics in the Upper Jurassic or Lower Cretaceous. Folding and metamorphism of the Sampa Beds, in Upper Cretaceous? time, may have been accompanied by the intrusion of the Morobe Granodiorite. In Lower Tertiary? time the fine-grained sediments and basic volcanics of the Nipanata Beds and the Salamaua Metavolcanics were deposited. The Papuan Basic Belt was emplaced in the Upper Cretaceous or lower Middle Tertiary and the Mageri Volcanics were deposited on the eastern flank of the Belt in the Middle Miocene. Andesite porphyry intruded the metamorphics and the Salamaua Metavolcanics in Upper Tertiary time.

The Papuan Basic Belt is an elongated complex of plutonic igneous rocks ranging in composition from ultrabasic to acid; it is 230 miles long in a north-westerly direction, and up to 25 miles wide. Ultramafic rocks are restricted to the south-western side of the Belt and acidity generally increases towards the north-eastern margin.

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, intermediate 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 north-western third of the Belt forms the Bowutu Mountains. Here the order of crystallization was as follows :

1. Ultramafic rocks : dunite, pyroxene peridotite, pyroxenite.
2. Basic rocks : eucrite, norite, gabbro, anorthosite.
3. Intermediate and acid rocks : diorite, tonalite, trondhjemite, granodiorite, quartz veins.
4. Basic and intermediate dyke rocks; these are probably related to the Mageri Volcanics.

Ultramafic rocks are best developed in the north-western part of the range. Basic, intermediate and acid rocks crop out to the east and south-east.

Basic rocks intrude the ultramafic rocks and are themselves intruded and partly assimilated by intermediate and acid rocks. Near the contact with the Mageri Volcanics the intermediate and acid rocks are intruded by basic and intermediate dykes.

The Owen Stanley Metamorphics and the Basic 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 Basic Belt moving north-west relative to the Owen Stanley Metamorphics. Where this movement is impeded by the northerly curve of the Owen Stanley Fault, the Basic 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 Basic Belt, and the Mageri Volcanics, and about 1,000 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 mineralisation was seen 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 range.

GENERAL INFORMATION.

Location.

The area covered by this report extends from Salamaua southward to the Papua - New Guinea 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, and at Dona near Morobe, and Salamaua on the coast, but these have not been used since the war years 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.

Garaina and Morobe are connected by a well-kept foot-track which, for the most part, follows the course of the Waria River. Several minor tracks cross the Bowutu Mountains between Garaina and Morobe and Maiama but these are rarely used and are poorly defined.

Garaina and Wau are connected by a good foot-track through the Upper Waria, Biaru, Korpera, and Upper Bulolo valleys. 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.

The object of the survey was to reconnoitre the Bowutu Mountains, a part of the Papuan Basic Belt and consequently an area of economic mineral potential. Dow spent seven weeks in the area. He first traversed from Wau to Morobe via Lake Trist, Garaina, and the Lower Waria River, then ascended the Paiawa and Saia Rivers and returned to Wau via Guadagasal.

Davies spent ten weeks in the area. He crossed the Bowutu Mountains from Garaina to Morobe via the Haus Kapa track, with side traverses east and west of Motetei, then re-crossed the range, returning to Garaina by the Maiama track. He proceeded to Wau via Lake Trist, making a number of side traverses into the Basic Belt. The northern part of the range was not crossed because of movement difficulties but a number of traverses were made from the eastern and western flanks.

Fresh rock exposure is generally confined to the beds of water-courses, 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 type, particularly in the case of the highly feldspathic diorite and trondhjemite. Most of the foot-tracks are sited 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.

Each party employed a permanent line of fourteen native carriers. This permits 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 in the vicinity of each village there is a network of hunting tracks which give access to the surrounding bush. However, much of the Basic 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 as the natives commonly regard unknown bush with superstitious fear.

Aerial Photography.

Field observations were plotted on aerial photographs wherever possible. Vertical photography of the following One-mile areas is now available (February, 1961) :

Wau,
Biaru,
Bowutu Mountains (Run 5 only),
Garaina, and
Waria River (Runs 4 and 5 only)

(see "Airphoto Coverage", Plate 1). A number of trimetrogon runs are also available, notably series M718, M220, 53Z, and 105YY, so that only a small part of the area is not covered by vertical or oblique photography.

The base map for Plate 2 was prepared by tracing from uncontrolled assemblies of aerial photographs and reducing these from their various scales to a scale of 2 miles to 1 inch. The coastline was reduced from Military One-mile maps of Salamaua, Baden Bay, and Mageri Point. The only control is a line connecting two points on the Buisaval and Lower Waria Rivers, which was taken from the Salamaua and Buna "Fourmil" sheets, published by the Administration Department of Lands, Surveys and Mines.

Photo interpretation is only practicable on a broad scale owing to the young topography and the forest cover. 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 Sampa Beds, but within the Basic 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 :

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

(Nat.Dev., 1951). On the coast rainfall is distributed throughout the year; the average annual rainfall at Morobe is 117 inches, the wettest months being April, May, June, November and December (ibid). In the Middle Waria Valley the South-East season is drier; the annual figure for Garaina 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 uplands are commonly blanketed with cloud and can be very bleak.

Flora

Three main types of vegetation were observed; (i) rain forest, (ii) grasslands, and (iii) stunted hardwoods. Rain forest covers most of the mountainous country. Over metamorphic rocks the forest has little undergrowth and is relatively easy to penetrate. Over the Basic 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. Pine trees were noted north of Bapi and also occur in the Ono and Upper Waria valleys where Fisher (1939) has noted Araucaria klinkii and cunninghamii. Stands of Kamarere Gums (Eucalyptus deglupta) were seen on the flats of the Maiama, Paiawa, and Saru Rivers, and Casuarina nodosa was noted in the Paiawa valley.

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 at 9,000 or 10,000 feet in the valleys of Kau and Diu Creeks, and small patches of a solid-leafed alpine grass on the divide east of Lake Trist.

Gnarled and stunted hardwoods grow on the divide east and south-east of Lake Trist (elevation 7,000 - 8,500 feet), and on exposed points at slightly lower altitudes. The transition between rain forest and stunted hardwoods is quite clear on the aerial photographs but does not indicate a geological boundary.

Fauna

Pigs, wallabies, tree-climbing kangaroos, ring-tailed possums, echidnas, cassowaries, pigeons, cockatoos, ducks and a variety of other birds abound in the foothills, but high in the Bowutu Mountains game is scarce. There are no edible fish in the Middle and Upper Waria River and tributaries, but fish were seen in the coastal rivers and off-shore.

Mosquitoes are generally not a nuisance but a large stinging fly, not unlike the Australian "march fly", was encountered on the Saia River and in the bamboo country south and east of Lake Trist.

Population and Industry

Approximately 12,100 natives inhabit the area; of these 5,400 live on the coast and Lower Waria Valley, and 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.

Eurppeans 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 conducts 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 the current 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, Wau, mapped the area north of Lake Trist in August-September, 1958 (Dow and Siedner, 1958).

Report Preparation

In this report the Owen Stanley Metamorphics have been described by Dow and the Papuan Basic Belt by Davies. 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 recognised in the area mapped viz., the Owen Stanley Range, the Trist-Waria Depression, the Bowutu Mountains, and the Coastal Region (see Fig.1, page 6).

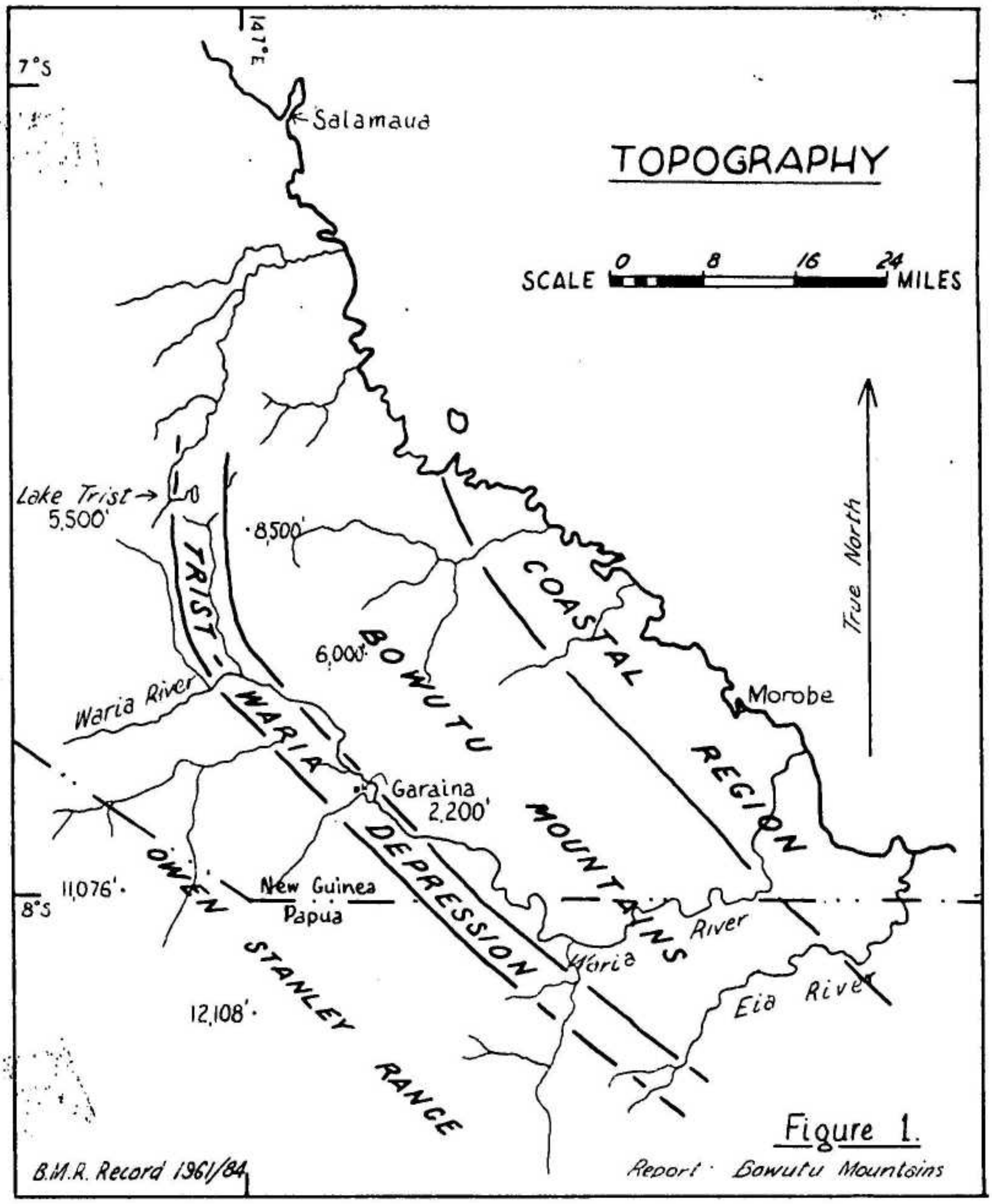
Owen Stanley Range

South-west of the map area a broad massif, the north-western extension of the Owen Stanley Range, rises to over 12,000 feet above sea level. The massif is relatively flat-topped and there are no outstanding peaks; it is deeply dissected by three major rivers, the Upper Waria, Ono, and Bubu rivers which flow generally north-eastward in deep, steep-sided valleys.

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.

Trist-Waria Depression

A slightly curved depression, called here the Trist-Waria Depression, 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 depression has only low relief in the northern and central parts, and ranges in elevation from 6,000 feet near Lake Trist, to 1,500 feet near Motetei. South-east of Motetei the floor rises and becomes hilly.



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

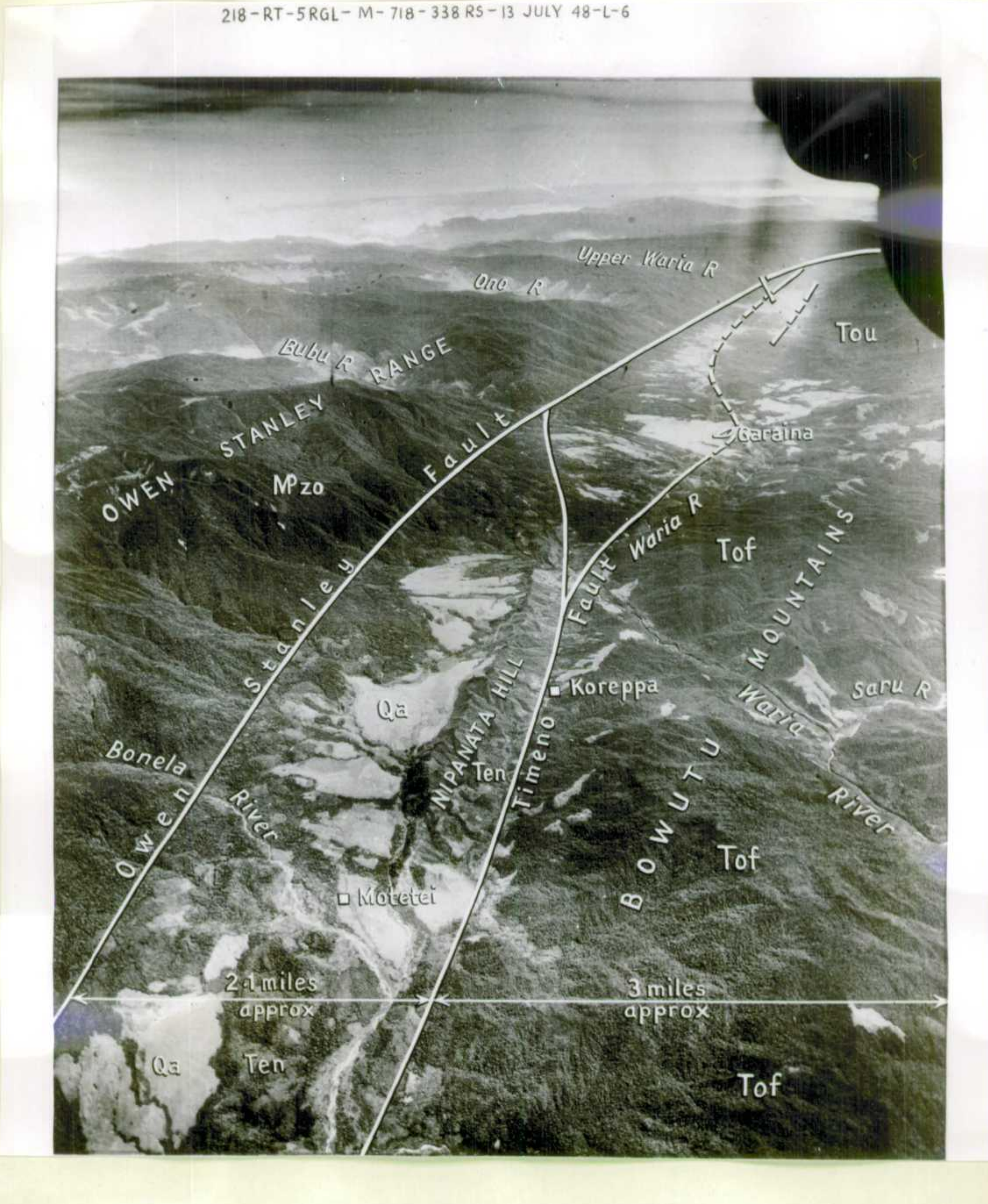
In their lower reaches the Ono and Superua rivers flow south-eastwards along the Depression before joining the Waria River.

Bowutu Mountains

The Bowutu Mountains form a fairly well-defined mountain chain between the Trist-Waria Depression 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 8,500 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 characterised 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.



<u>Figure 2.</u> The Middle Waria Valley, part of the Trist-Waria Depression, flanked by the Owen Stanley Range and the Bowutu Mountains. Geological features are shown.

Figure 3. Coast north-west of Morobe showing the embayed coastline and sharp ridges characteristic of the Coastal Region.

STRATIGRAPHY

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

Quaternary		Alluvium	
	Pliocene?	Andesite porphyry intrusions	
	Miocene	Mageri Volcanics	
Tertiary	Oligocene?	Papuan Basic Belt	
	Eocene?	(Salamaua Metavolcanics (Nipanata Beds	
Mesozoic	Upper Cretaceous?	Morobe Granodiorite	
	Cretaceous	Sampa Beds	) Owen Stanley Metamorphics
Mesozoic OR Palaeozoic		Kaindi Metamorphics	)

The igneous intrusives are considered under separate heading.

The Kaindi Metamorphics and Sampa Beds are regionally metamorphosed and are not easily differentiated in the field or on aerial photographs. Accordingly, they have been mapped as Undifferentiated Owen Stanley Metamorphics, except in areas where no detailed examination was made. The Nipanata Beds and the Salamaua Metavolcanics, which are thought to be correlative, 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 Sampa Beds and the Iauga Formation (ibid.) where diagnostic fossils have been found.

OWEN STANLEY METAMORPHICS

The Owen Stanley Metamorphics forms the mountain range west of the Owen Stanley Fault. It comprises at least two formations, the Kaindi Metamorphics and the Sampa Beds, which are probably separated by an unconformity. The Kaindi Metamorphics are of higher metamorphic grade than the Sampa Beds. Even the coarser-grained sediments of the Kaindi Metamorphics have been largely recrystallised, bedding is generally masked by schistosity, and conglomerate pebbles are severely distorted. In the Sampa Beds bedding is usually preserved and fossils are only slightly distorted.

Kaindi Metamorphics

The Kaindi Metamorphics (Fisher, 1939) 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 have not been differentiated from the rest of the Owen Stanley Metamorphics. North of the Bitoi River the metamorphics are generally fine-grained while to the south they are medium- and coarse-grained.

North of the Bitoi River the predominant rock type is dark-coloured fine-grained quartz biotite schist with some quartz sericite schist. Calcareous schist is fairly common in this area and travertine is formed at seepages on the sides of the streams. Massive, green silicified medium-grained biotite schist also occurs. In all these rocks the schistosity has almost completely obliterated the bedding, and only in Buipal Creek, west of Mubo, was bedding seen. Here 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 and minor marble, calcareous schist, and stretched conglomerate. The most common rock type is a massive, 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 $\frac{1}{4}$ 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 coarse-grained quartz biotite schist matrix. 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. Pure white, fine-grained marble was seen, but it is usually grey with thin lenses (about $\frac{1}{8}$ inch thick, and several inches long) of brown mica schist which have been derived from original argillaceous impurities in the limestone. One large lens of marble, several hundred feet thick, was seen at the head of Kiname Creek but was not visited.

Fisher (1939) noted a green schist in the Upper Ono valley; he suggests 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. The transition from schist, in which bedding can still be seen, to the "streaky schist", was seen 2 miles to the west of the map area in the headwaters of the Bulolo River. The schist derives from laminated and thin-bedded quartz sandstone and quartz greywacke with thin shale and siltstone inter-beds. In the first stage of the transformation it is folded into tight symmetrical folds and completely recrystallised; the coarse beds are silicified and the finer-grained beds become biotite schist with the schistosity roughly parallel to the axial plane of the folds. Further stress causes the limbs of the folds to stretch and the fold-noses to thicken. In the next stage the limbs part and the fold-noses streak out into lenses and plates to give the "streaky schist". In the extreme case, lenses are 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 Beds north of Wau (Dow, 1960), may be of Palaeozoic or Lower Mesozoic age.

Sampa Beds

Sampa Beds is the name given to greywacke and sericite schist exposed in Sampa Creek, a tributary of the Buiawim River, seven miles west of Lake Trist. In the time available the beds were only cursorily examined, and the area warrants more detailed mapping.

The greywacke was seen only as boulders shedding from the head of Sampa Creek. It occurs towards the bottom of the formation and is a dark-coloured, medium-grained to fine-grained indurated rock consisting of rounded to sub-angular grains of feldspar, quartz, ferromagnesian minerals and rock fragments. The finer-grained greywacke is sub-schistose.

The overlying beds are black and grey fine-grained sericite schist, in which thin-bedding and lamination can usually be seen at an angle to the schistosity.

Fossils occur in the greywacke but they are not abundant, and, as the rock is indurated, they are difficult to collect. The following is a brief palaeontological report by Skwarko (1960):-

"The dating of Lake Trist collection has been made difficult by poor preservation accentuated by considerable distortion of the limited number of specimens available for research.

"The fossil assemblage, which consists of pelecypods, gastropods, a barnacle and a small fragment of an ammonite - mostly hitherto undescribed species -- is definitely Mesozoic, and unlikely to be older than Middle Jurassic or younger than Middle Cretaceous.

"There are definite, though limited, affinities between the Lake Trist fauna and the fauna from Snake River (about 40 miles to the north west) which Glaessner thought to be probably Middle Cretaceous in age. The similarity is seen in the common occurrence of Tibia(?) morobica Glaessner, Cardium sp. and Ashcroftia sp., the last two not necessarily the same species as described by Glaessner. Respective lithologies are also alike.

"The apparent differences between the two faunas are, however, of sufficient magnitude to discourage definite correlation being made at this juncture."

The writers tentatively correlate the Sampa Beds with the Cretaceous Snake River Beds, as the formations are similar in lithology and degree of metamorphism.

Undifferentiated Owen Stanley Metamorphics

South-east of the Buiawim River, only short traverses were made into the metamorphics and this area has 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.

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 limestone, and altered basic volcanics. The finer sediments appear to be calcareous but do not react with dilute acid. Calcite veining is common and may derive from the original lime content of the sediments.

Tightly folded, green and black sericite schist was observed near the Owen Stanley Fault, west of Timanogosa 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) 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; further from the fault they have been hardened by heat from the fault or from the igneous rocks of the Basic 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 Sampa and Snake River Beds both in lithology and degree of metamorphism, and the writers favour a Lower Tertiary age. The Nipanata Beds may be correlatives of the Salamaua Metavolcanics (see below), the Lasa Creek sediments in the Yodda Valley (Davies, 1959) and possibly the Urere Metamorphics in the Musa River area (Smith and Green, 1959).

SALAMAUA METAVOLCANICS

This group of rocks was defined and named by Dow and Siedner (1958), and the following account is taken from their report.

"The Salamaua Metavolcanics occur as a wedge-shaped faulted segment near Salamaua. They are mainly altered basic volcanic and intrusive igneous rocks with minor siltstone and marble.

"Both the volcanics and the intrusives are dark green massive rocks, well jointed and containing irregular thin chlorite veins up to $\frac{1}{4}$ inch thick. The volcanic rocks are fine-grained holo-crystalline and are classed as altered prehnite-bearing basalt. The intrusive rocks, classed as kaolinised 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 inter-beds of siltstone and marble, the whole having been intruded by dolerite.

"The Salamaua Metavolcanics are faulted against the Papuan Basic 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."

Petrographic descriptions of rocks from this area are included in the Appendix.

The Salamaua Metavolcanics are tentatively correlated with the Lower Tertiary? Nipanata Beds. The marble and siltstone are not unlike the Nipanata sediments, and the two formations are similarly disposed, being bounded to the west by the Owen Stanley Fault and to the east by the Basic Belt.

MAGERI VOLCANICS

The Mageri Volcanics take their name from the Mageri Point one-mile area in which they are the predominant rock type; the volcanics are exposed at Mageri Point and along the shore of Mageri Bay. They crop out between the Basic Belt and the coast, and consist of intrusive and extrusive rocks of basic, intermediate, and probably acid composition, the common types being basalt, dolerite, andesite and microdiorite. More acid types are exposed in the eastern part of the outcrop area, which was probably the top of the sequence. This suggests that the magma became more acid as the volcanic cycle progressed.

Magnificent pillow lavas are exposed on the Mo, Wiwo and lower Waria Rivers; these are 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. This is particularly common near the western margin where they may have intruded along the hypothetical fault which separates the Basic 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 (P537A). The original rock in this case was probably a melanocratic quartz-bearing pigeonite microdiorite (P537B):

> andesine (An_{36}) 52, quartz 3, pigeonite 35, chlorite (pennine)7, magnetite 3, pyrite, chalcopyrite accessory.

Andesine and pigeonite occur as phenocryst laths up to 0.8 mm. long; this is an unusual habit for pigeonite which, according to Barth (cited in Kerr, 1959), is usually confined to the groundmass of volcanic rocks. Pigeonite in P537B is very pale green in colour, has an extinction angle, c to Z of 48°, birefringence about 0.027, optic axial angle less than 40°, and is optically positive. All of the pigeonite laths are partly altered to pennine chlorite.

Greenish pillow lava which crops out on the Mo River (P544) has been identified as chloritized and epidotized vesicular and amygdaloidal porphyritic basalt :

> calcic andesine or labradorite 10, pigeonitic augite 5, chlorite 35, amygdules 45, vesicles 5

Plagioclase occurs as phenocryst laths and rarely as anhedra up to 0.6 mm. long. Carlsbad twinning is common but albite twinning is rare and in places obscured by alteration. Pale green pigeonitic augite forms phenocrysts up to 0.5 mm. long Extinction is at 38° to the slow ray, optic axial angle is about 45° and optic sign is positive. The amygdules consist of quartz, finely granular green chlorite with an anomalous brown interference colour, zeolite, calcite (rare), epidote, and prehnite.

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 basalts to augite andesites and quartz micro-diorite. These are accompanied by agglomerates, andesitic tuffs and tuffaceous sandstones" (ibid.). The Formation is conformably overlain by Miocene f_{1-2} Stage limestone, and is thus probably Lower Miocene.

Figure 4. Pillow lavas forming a small waterfall in a tributary of the Lower Waria River.

Figure 5. Pillow lavas, Lower Waria River.

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 conglomerate, 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 may extend back as far as twelve miles from the coast. As the rivers are not deeply incised the depth of alluvium is not known, but it may be of the order of 2,000 feet. The upper part of the Saia River flows through a gorge cut in valley-fill material which consists of chaotically deposited angular and sub-rounded ultra-mafic 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 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.

IGNEOUS INTRUSIVES

MOROBE GRANODIORITE

The Morobe Granodiorite take its name from the Morobe Goldfield (Fisher, 1944) in which area it is the predominant igneous rock. The three main outcrop areas are north and south of Wau; the largest exposure is between Bulolo and Salamaua where it crops out over an area of about 300 square miles (see Plate 1). Smaller stocks and bosses are exposed east of Wau and one of these is thought to crop out within the area covered by this survey where, north of the upper Buisaval River, a distinctive topographic pattern is apparent on the aerial photographs.

The name, Morobe Granodiorite, is not a fortunate choice as the Granodiorite does not crop out near Morobe Patrol Post, nor on the Morobe River, and the area in which it does crop out, the Wau - Bulolo area, is no longer officially defined as the Morobe Goldfield. Dow (1960) has suggested the name Baiune Granodiorite, after the Baiune River which drains the western part of the major batholith east of Bulolo.

The Granodiorite intrudes the Kaindi Metamorphics and the Lower or Middle Cretaceous Snake River Beds and is thus of Upper Cretaceous age or younger. It is possibly cosanguinous with the Papuan Basic Belt as in some exposures it is similar in composition to the intermediate and acid rocks of the Basic Belt and the fineness of gold shed from the two is similar (see below under Papuan Basic Belt in the Bowutu Mountains).

The most comprehensive description of the granodiorite is contained in a report by Noakes (1938). He states that the composition of the original magma was probably intermediate between granite and granodiorite; local differentiation has produced more basic types, e.g. :-

Sandy Creek : Granodiorite

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

The constituent minerals are quartz, potash feldspar, andesine or calcic andesine, biotite, hornblende and (in the tonalite) a little augite.

PAPUAN BASIC BELT

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

ANDESITE PORPHYRY

Hornblende andesite porphyry intrudes undifferentiated Owen Stanley Metamorphics on the Ono River (Fisher, 1939), Kaindi Metamorphics in the Buiawim River (Dow and Siedner, 1958), and Salamaua 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 of Upper Tertiary age but definite evidence 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 (ibid.). This indicates that the fault existed before intrusion of the porphyry but does not preclude the possibility that the fault was active after the intrusion as subsequent movement might simply have by-passed that part of the fault zone.

DOLERITE

Metadolerite intruding the Kaindi Metamorphics, Nipanata Beds and Salamaua Metavolcanics appears to be associated with the extrusion and deposition of volcanic members of the Nipanata Beds and Salamaua Metavolcanics and is thus probably of Lower Tertiary age. Slightly altered dolerite and andesite which intrudes the Papuan Basic 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.

PAPUAN BASIC BELT

The Papuan Basic Belt is a linear complex of ultrabasic, basic, intermediate and acid rocks, more than 230 miles long and up to 25 miles wide and extends from the New Guinea coast near Salamaua to the Musa River area in Papua (see Plate 1). The Belt has a north-westerly trend and parallels the faulted front of the Owen Stanley Range. For the greater part of its length it is bounded by faulting on the south-western margin, but in the Musa River area the margin is not well defined and the ultrabasics are seen to intrude Mesozoic? or Lower Tertiary? metamorphics (Smith & Green, 1959). 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 pluton and he gave it the name Papuan Ultrabasic Belt. This title fails to draw attention to the large proportion of basic and intermediate rocks in the belt and suggests, rather, Benson's (1926) typical "alpine" type of ultrabasic belt which consists solely of peridotite and serpentinite. Smith and Green (1959) preferred the name Papuan Basic and Ultrabasic Belt. In conference with Thompson, the writers have chosen the briefer name, Papuan Basic Belt, and have assumed that the presence of ultramafic differentiates in a basic pluton might be taken as understood. "Belt" is preferred to "pluton" or "complex" as it accentuates the linear nature of the body.

The Basic Belt may have 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. He suggests that intrusive contacts in the Musa River area (Smith and Green, 1959) are the result of subsequent regeneration of ultramafic magma caused by tectonic stress after solid emplacement.

PAPUAN BASIC BELT IN THE BOWUTU MOUNTAINS

This report deals specifically with the northern third of the Papuan Basic Belt, which is exposed in the Bowutu Mountains. Here the Belt is bounded to the west by the Timeno and Owen Stanley Faults, and to the east is overlain by the Mageri Volcanics. On the accompanying map (Plate 2) it has been divided into Ultramafic and Feldspathic Zones, and the boundary between the two has been arbitrarily placed so as to include all large bodies of ultramafic rocks in the Ultramafic Zone. Basic, intermediate and acid rocks occur within the Ultramafic Zone and constitute about 50% of the rocks in the northern part of the Zone near the coast. The Feldspathic Zone consists almost exclusively of basic, intermediate and acid rocks with rare peridotite. Dykes of dolerite and andesite, which are genetically a part of the Mageri Volcanics, intrude the feldspathic rocks in the eastern part of the Zone.

There were apparently four stages of crystallization :

1. ultramafic rocks e.g. peridotite, pyroxenite

2. gabbroic rocks with calcic plagioclase (bytownite or anorthite) e.g. eucrite, anorthite gabbro, norite, anorthosite.

3. intermediate and acid rocks with sodic plagioclase (andesine or labradorite, less commonly oligoclase, albite and potash feldspar), e.g. diorite, tonalite, trondhjemite, granodiorite and quartz.

4. andesite and dolerite dyke rocks.

The evidence is as follows :

(i) norite pegmatite and anorthosite intrude ultramafic rocks on Iteleng Creek (P597), Bateve Creek (P605) and on the lower Iwiri River.

(ii) tonalite intrudes anorthite microdiorite west of the Ono-Waria River junction (P580) and leucocratic microtrondhjemite intrudes quartz bytownite dolerite on Husuve Creek (P509). Quartz intrudes gabbro on the Waria River near Sako, and trondhjemite west of Piawaria. Intermediate and acid rocks containing basic xenoliths were also seen north and west of Piawaria (P508B, P646) and on Baira Creek (P548) but in each case the xenolith is similar to the host rock in mineral composition. These are thought to be partly assimilated remnants of more basic rock but may simply be cognate xenoliths.

(iii) andesite and dolerite? dykes intrude the intermediate and acid rocks exposed between Ipoa Creek and the headwaters of the Morobe River.

Extrusion and shallow intrusion of the dolerite and andesite of the Mageri Volcanics probably constitute the final stage of the magmatic cycle. The close association of volcanic and plutonic rocks throughout the length of the Basic Belt suggests that the two are comagmatic; petrographic work may give further evidence.

The time interval between the stages of crystallization and intrusion can only be guessed. It is likely that stage 2 followed closely on stage 1, though there was sufficient time for the rocks of stage 1 to solidify and be faulted (see below).

The intrusive rocks are described below under the headings (1) Ultramafic Rocks, (2) Basic Rocks, (3) Intermediate and Acid Rocks, and (4) Andesite and dolerite dykes.

1. Ultramafic Rocks

In the map area, ultramafic rocks crop out in a northerly trending belt more than 75 miles long and up to 18 miles wide and 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 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 rocks.

The ultramafic rocks are dunite, pyroxene peridotite, pyroxenite, serpentinite and actinolite schist.

The dunite consists of chrysolite and forsterite olivine with accessory chromite and picotite. Alteration products include serpentine minerals (the most common), xylotile, iddingsite?, bowlingite?, magnetite and limonite. Rare ilmenite or titaniferous magnetite, and some magnetite, may be primary minerals. The rock varies in colour from green to greenish black, depending on the degree of serpentinization. Some is dark brown (P611), possibly owing to the presence of brown xylotile, and weathered dunite is usually light brown, owing to alteration to limonite.

In thin section the olivine forms colourless anhedra up to 3 mm. across which are dissected into angular fragments (up to 0.4 mm. across) by a meshwork of serpentine veins. Chromite or picotite occurs as subrectangular grains, up to 0.4 mm. across, disseminated in both olivine and serpentine.

The fabric observed in the thin section of specimen P623B is probably typical of the partially serpentinized dunites. Angular olivine fragments are set in a fine-grained matrix of anhedra and fibres of antigorite which is, in turn, dissected by a meshwork of cross-fibre veinlets of chrysotile. Usually a thin stringer of finely granular magnetite, with some chromite or picotite, runs lengthwise down the centre of the chrysotile veinlet. Dark red-brown iddingsite? may also be present in the veinlet. In P611 xylotile forms faintly pleochroic yellow-brown rims around the olivine fragments and in the same thin section rare calcite appears to pseudomorph olivine.

The degree of serpentinization is apparently related to proximity to faults and to younger feldspathic intrusive rocks. Worst (1958) has revived the theory that serpentinization is related to weathering; in the Bowutu Mountains no evidence was found to support or refute this theory. In two of the thin sections examined (P611 and P623B) serpentine minerals account for 50-60% of the rock. Hand specimens of dunite from the Saia River appear to be fresher, while specimens from fault zones and from the vicinity of norite pegmatite intrusions are completely serpentinized.

Serpentinite near the Timeno Fault (P527) is black and schistose and contains rounded boulders of black serpentinite up to 3 inches across. This does not show mesh texture and consists of a more or less homogeneous aggregation of antigorite? anhedra with irregular veinlets of epidote. Chromite occurs as anhedra up to 0.4 mm. across, with granulated margins, and as veinlets made up of very fine grains.

Where the Timeno and Owen Stanley Faults converge there is a zone, up to half a mile wide, of serpentinite pug (P604; identified spectrographically by W.M.B. Roberts).

Serpentinite breccia from a probable fault zone on lower East Iwiri Creek (P627) consists of angular fragments of mesh serpentine, and of an unidentified mineral of the chlorite-serpentine group, in a matrix which is partly opalline silica. Chrysotile? in the mesh serpentine is slightly pleochroic in pale brown. The unidentified mineral is buff-coloured, has a refractive index lower than canada balsam, and is very nearly isotropic. In the hand specimen it is yellowish with a waxy appearance and hardness 3-4. Bowlingite? occurs as an alteration product of olivine and as fibrous laths in the matrix. It is pleochroic in greenish yellow-brown, length slow with birefringence between 0.030 and 0.035. Unlike typical bowlingite it has a lower refractive index than balsam.

Except for the absence of magnesite and andradite garnet this serpentinite breccia is not unlike ultramafic breccias found by Green (Smith and Green, 1959, Green, 1961) in the Musa River area. The Musa breccias are thought to be vent breccias and extruded vent breccias of peridotitic country rock, brecciated and entrained by volcanic gases derived from a subjacent source. There are no definitely hydrothermal minerals in the Iwiri breccia and the simplest hypothesis is that it is a fault breccia; the opalline silica matrix probably derives from silica ex-solved from peridotite in weathering and re-deposited at depth.

The Iwiri breccia is bounded to the east by a vertical face of jointed brown limonitic serpentinite which strikes at 020°. This is probably one wall of the fault zone but owing to lack of exposure it was not traced along strike.

Pyroxene peridotite is the predominant ultramafic rock type. There is probably a complete range in composition between the two end members, dunite and pyroxenite. The thin sections examined vary from pyroxene olivinite, with only 30% pyroxene, to olivine pyroxenite, with about 90% pyroxene. The terminology used is that suggested by Johannsen (1938, vol.4, p.402) but names indicating mineral composition are employed in preference to such names as lherzolite and saxonite; for instance the name augite olivinite is preferred to wehrlite (ibid., p.419).

Pyroxene peridotite is readily distinguished in the field as the pyroxene crystals tend to stand in slight relief on a weathered surface, and on a fresh surface the pyroxene is identified by its cleavage. In some instances the pyroxene crystals are seen to be arranged in layers.

Serpentine comprises between 5 and 50% of all of the pyroxene peridotite examined in thin section and is mostly derived from olivine rather than pyroxene. Serpentinized olivine usually exhibits a mesh fabric similar to that noted in the dunites. Alteration of the pyroxene may produce serpentine which cannot be distinguished from that derived from olivine but in one thin section, P639, bastite pseudomorphs are developed. In another section, P634, the margins of the pyroxene crystals have been altered to antigorite and serpentinization has penetrated along the cleavage planes so that the ends of the crystals have a frayed appearance.

In sheared peridotite on Uraba Creek, a headwater tributary of Teperu Creek, the pyroxene is augite or possibly diopside; rare crystals show diallage parting (P513). Peridotites on the Upper Iwiri River and on East Iwiri Creek contain colourless magnesian hypersthene crystals up to 6 mm. long; some of the crystals show simple twinning and most have marked iron-stained partings (P622, P634). Four miles east of Lake Trist, peridotite contains crystals of colourless magnesian hypersthene which probably has a composition of about En_{20} since the optic axial angle is about 85° and optic sign is negative. The crystals contain thin lamellae of augite parallel to the cleavage (P623). Remnants of augite or diopside lamellae were also seen in bastite in specimen P639.

The pyroxene crystals are commonly partly altered to colourless tremolite or pale green actinolite. Rarely tremolite occurs as narrow veinlets, green in hand specimen, cutting across the peridotite. This is shown in thin section P634 where the tremolite appears to be replacing antigorite; such a reaction would require the introduction of lime and silica. Another peculiarity of P634 is the presence of a brownish mica, probably phlogopite.

Accessory minerals are chromite, picotite, magnetite and ilmenite; the latter two may be secondary. All are generally restricted to the olivine and serpentine.

Very coarse-grained (up to 11 and 12 mm.) yellow-green and greyish pyroxenite commonly intrudes the peridotite as irregular veins and blebs. A similar rock collected by Dow and Siedner (1958), south of Salamaua, has been identified as enstatite pyroxenite (see Appendix, specimen SG.19/c). The intrusive nature of the pyroxenite may be attributed to the injection of pyroxene magma along joints in the peridotite or to the alteration of olivine by siliceous solutions, according to the reaction

$$(Fe,Mg)_2\ SiO_4 \ + \ SiO_2 \ = \ (Fe,Mg)_2\ Si_2O_6$$

The second hypothesis, suggested by Bowen and Tuttle (1949), should result in a gradational contact between pyroxenite and peridotite, unless the pyroxene solution were formed "off-stage" and subsequently injected.

Pyroxenite exposed in Koreipo Creek, near the Timeno Fault, is sheared, uralitized, and partly serpentinized (P623). The rock consists of enstatite and actinolite, with accessory picotite and chromite and veinlets of chrysotile and greenish antigorite? which follow shear planes. The enstatite is a colourless ferriferous variety (optic axial angle 90°) and occurs as crystals up to 1.75 mm. long, some of which show curved cleavage planes. The predominant mineral is fine-grained actinolite which probably derives from uralitization of enstatite.

Actinolite schist, which occurs with black serpentinite in the shear zone of the Timeno Fault, probably derives from pyroxenite, though no pyroxene remnants were seen in the thin section examined (P527B). The rock consists of actinolite with accessory chromite and narrow stringers of calcite.

2. Basic rocks

This group includes such rock-types as eucrite, gabbro, norite and anorthosite; all are characterized by the presence of calcic plagioclase varying from bytownite to extremely calcic anorthite (An_{98}). The areal extent of the group is probably not great and will be more accurately known when more thin sections have been examined. The best defined locality is between Orupu Creek, Saru River and the Waria River near Garaina where all the observed rocks are gabbroic. To the north-west, near the Ono - Waria confluence, and to the south-east, near Piawaria, gabbroic rocks have been intruded and partly assimilated by intermediate and acid rocks. To the east, in the headwaters of the Morobe River and on Baira Creek, there are xenoliths in the intermediate and acid rocks which may originally have been gabbroic but now have the mineral composition of the younger rock (see Figure 6); this is tentatively ascribed to assimilation. Gabbroic rocks are reported in the Paiawa, Buso and Saia River areas and on the lower Waria River between Upupuru and Zema but these have not been examined in thin section.

The basic rocks are generally homogeneous but banding due to segregation of femic minerals was noted in several localities. Banded norite crops out on the lower Saru River, boulders of a banded anorthosite-gabbro?-peridotite rock were noted on the Orupu - Morobe River watershed, and a banded anorthosite-gabbro-norite rock crops out on the coast south of Buansing (Dow and Siedner, 1958). Smith and Green (1959) regard similar banded rocks in the Musa River area as a group transitional between basic and ultrabasic rocks.

Figure 6 Trondhjemite or tonalite with basic xenolith (left) and an almost completely assimilated basic xenolith (right), near Piawaria village.

Banding on a finer scale was noted in gabbroic rocks on the lower Waria River and south of Kui. Alternation of twenty to thirty foot layers of gabbro and dolerite on the lower Waria River produces a larger scale layering.

The most common gabbroic rock is bytownite or anorthite gabbro and dolerite. This varies from leucocratic gabbro with 70% plagioclase (P601) to melanocratic dolerite with only 15% plagioclase (P522A). There is possibly a complete range in composition between "end-members" anorthosite and pyroxenite (and its metamorphosed equivalent, actinolite schist).

The main constituent minerals of the gabbro are calcic plagioclase, rare quartz, augite, diopside?, rare hypersthene, hornblende and actinolite which is a product of the alteration of pyroxene. The following associations have been noted :

P601	anorthite - diopside? - hypersthene
P522A and P580 (a xenolith in tonalite)	anorthite - actinolite
P561	anorthite - actinolite - quartz
P514	anorthite - augite - actinolite
P562	anorthite - augite - hornblende
P556A	anorthite - augite - actinolite - hornblende
P555	bytownite - hornblende
P509 (a xenolith in trondhjemite)	sodic bytownite - hornblende

Magnetite is a common accessory mineral and constitutes about 5% of P555 and P509. Titaniferous magnetite and rare pyrite are accessory minerals in P555.

There may be an overall gradation from pyroxene anorthite gabbro in the west to hornblende bytownite gabbro in the east. This is inferred from the compositions of specimens P562, P561, P556A and P555 which were collected between the Waria River near Garaina, in the west, and Dupuru Creek in the east.

The most common plagioclase is sodic anorthite, An_{90-91}, but composition varies between sodic bytownite, An_{71}, (xenolith P509) and anorthite, An_{95} (xenolith P580). Bytownite crystals in P555 and anorthite crystals in P556A have rims of labradorite, An_{52-54} and twinned anorthite in P556A contains veinlets and blebs of untwinned labradorite. Carlsbad, albite and pericline twinning is present in most of the plagioclase except in P522A. In sheared gneissoid gabbro, P514, the twin planes are curved. Plagioclase is fresh or moderately altered except in xenoliths where it is considerably kaolinized near contacts with the more acid rock.

The most common pyroxene is augite (and possibly diopside); this is colourless (P514), pale green (P556A, P601), or slightly pleochroic from pinkish brown to colourless (P562). It is usually subhedral to euhedral and in one specimen (P562) contains accessory magnetite in the cleavage planes. Hypersthene is present in specimen P601 as subhedra and rarely as lamellae in the cleavage planes of the clinopyroxene. It is pleochroic as follows :

X pale pink brown, Y very pale pink brown, Z very pale green.

Uralitization of pyroxene is very common. In three specimens (P522, P561 and P580) pyroxene is completely altered to actinolite, while in two others (P514, P556A) more than 50% of the pyroxene is altered. Actinolite occurs as pale green fibrous aggregates and as anhedra which may show simple twinning and faint pleochroism as follows :

X pale brown, Y pale brownish green, Z pale dark green.

Hornblende is the predominant mineral in hornblende gabbro (P555) where it forms anhedral phenocrysts up to 10 mm. long. In gabbros containing both hornblende and pyroxene, hornblende is interstitial and forms rims around the pyroxene (P562) or poikilitically encloses pyroxene and plagioclase (P556A).

It is usually unaltered and is pleochroic as follows :

X colourless or very pale brown
Y green, pale green or brownish green
Z dark bluish green or dark green

Polysynthetic twinning was seen in hornblende in specimen P555.

Dolerite xenolith P509 contains about 5% quartz, possibly introduced by younger intrusive trondhjemite. Uralitized dolerite P561 contains about 10% quartz: this is interstitial but is probably a primary mineral.

Magnetite was seen in all thin sections of gabbro except P601. In most it is accessory but in P509 and P555 it constitutes about 5% of the rock and occurs as skeletal crystals up to 1.5 mm. long.

The less common basic rock types are eucrite, norite and anorthosite.

Eucrite (P511) crops out on Api Creek, a tributary of Teperu Creek. The constituent minerals and their approximate proportions are as follows :

Hornblende 27, hypersthene 20, augite 20, olivine 20,
bytownite 10, magnetite and ilmenite 3.

Hornblende is pleochroic from pale brown (X) to pale dark green (Z) and has an optic axial angle near 85°. Hypersthene is pleochroic in pale pinkish brown; magnesian composition is indicated by an optic axial angle of about 85° (negative sign). Augite is pale brown with an extinction angle, c to Z, of 54°. Olivine is colourless chrysolite, Fo_{80-87}, and is dissected by a meshwork of sinuous veinlets of finely granular magnetite. It is partly altered to fibrous, slightly pleochroic brownish green bowlingite? which has refractive indices higher and lower than canada balsam and a birefringence of about 0.035. Bytownite shows carlsbad, albite and pericline twinning; it may have been introduced from a nearby vein of anorthosite.

Norite crops out on upper and lower Saru River and norite pegmatite intrudes ultramafic rocks in the Bateve Creek-Iwiri River-Iteleng Creek area.

Norite on the lower Saru River (P573) is banded due to partial segregation of the femic minerals. Its composition is as follows :

bytownite 70, hypersthene 20, augite 2, actinolite 8, magnetite rare accessory.

Composition of the bytownite is about An_{80} and it is clouded owing to slight kaolinization.

Hypersthene forms euhedral to subhedral crystals up to 3 mm. long, with the long axes aligned parallel to the banding. It is pleochroic from pale pinkish brown to colourless and pale green. Augite forms greenish crystals up to 1.5 mm. long and has an extinction angle, c to Z, of about 50°. Rarely it forms narrow rims around hypersthene. Pale green fibrous actinolite is an alteration product of hypersthene and is localized along a crack or joint plane in the thin section.

Norite on the upper Saru River (P558A & B) may actually be hypersthenite with veinlets of andesine-labradorite anorthosite. The hand specimen shows a contact between the two rock types but it is not known whether one intrudes the other or the two are part of a banded norite. The feldspathic rock is 95% andesine-labradorite, the remainder being made up of quartz, apatite, hypersthene and alteration products of hypersthene (actinolite and talc). Apatite occurs as aggregates of anhedra up to 1 mm. across. The hypersthenite is 95% hypersthene, with actinolite, talc and accessory magnetite. Hypersthene occurs as subhedral rounded prisms up to 3 mm. long; it is pleochroic in pale pink-brown with absorption X)Y)Z. Actinolite is a primary mineral and is interstitial between the pyroxenes; it shows pleochroism as follows :

X pale brown Y pale green Z green.

A little fibrous actinolite occurs as an alteration product on the pyroxene rims. Talc is a product of the alteration of hypersthene and is localized in a veinlet, 0.8 mm. wide. Magnetite is associated with talc and actinolite. Texture of the hypersthenite is granular and lacks any orientation.

The norite pegmatite is a spectacular rock in which the main constituent minerals are anorthite, hypersthene and actinolite; the femic crystals are up to 3 inches long. In the Bateve Creek-Iwiri River-Iteleng Creek area it intrudes the ultramafic rocks as dykes in joints and as irregular bodies containing angular fragments of ultramafic rock. In the examined specimen (P597) its composition is as follows :

anorthite 60, hypersthene 14, actinolite 12, talc 5, zeolite 5, chlorite and limonite 2

but the mineral proportions vary; near contacts the rock is generally more feldspathic.

The plagioclase is anorthite, An_{92}, with inclusions of andesine-labradorite commonly located on the twin planes. Zeolite occurs as finely fibrous aggregates in cracks within the plagioclase and as veinlets with chlorite at contacts between plagioclase and actinolite. Hypersthene is pleochroic from pale pinkish brown (X) to pale green (Z) and is partly altered to talc and limonite. Actinolite exhibits typical amphibole cleavage and forms reaction rims around hypersthene.

There is no evidence that the melt contained any volatile components, except perhaps water, so magmatic emplacement appears likely. If this is the case the host rock must have been held at a particularly high temperature for some time in order to permit the growth of pegmatitic crystals. This suggests that the pegmatite intruded the ultramafic rocks soon after they solidified.

Anorthosite also occurs as dykes in the ultramafic rocks and, on the lower Iwiri River, forms the matrix in a peridotite fault breccia. A specimen from Bateve Creek consists almost solely of anorthite, An_{98}; twin planes are curved and fractured in places and the crystal margins are granulated. Granulation may be due to intrusion as a crystal mush (Hatch, Wells and Wells, 1952, p.288) but is more likely a result of stress after emplacement brought about by movement on the Owen Stanley Fault.

3. Intermediate and Acid Rocks

Intermediate and acid rocks comprise a large proportion of the Feldspathic Zone. Bosses of more or less pure trondhjemite and tonalite up to six miles across are located around Kui, in the Sakia River-Ipoa Creek area, on the upper Morobe River and in the Piawaria - Zaka area; a distinctive topography with low-relief fine dendritic drainage is developed over these. Trondhjemite and tonalite also crop out on Baira Creek and on the Orupu - Morobe River watershed. Trondhjemite and diorite intrude sheared uralitized pyroxenite in the Timeno fault zone on Koreipo Creek and tonalite intrudes anorthite dolerite near the Ono-Waria confluence. The topography over these latter exposures is not distinctive, probably because of the presence of other rock types such as dolerite and pyroxenite.

Less common acid rocks are granodiorite, which crops out between Sepi Creek and Onepa River, and leucocratic granodiorite, which crops out on upper Orupu Creek.

The nomenclature used is that defined by Hatch, Wells and Wells (1952): diorite with up to 10% quartz is termed tonalite, and similar rocks with more than 10% quartz (and little or no potash feldspar) are termed trondhjemite. The mineralogy of specimens examined in thin section is tabulated below; the figures indicate the approximate proportions in parts per hundred.

Diorite:

P508A	Labradorite 60, hornblende 35-40, magnetite 2, quartz rare.
P522D	Andesine 60, cummingtonite 15, actinolite 15, quartz (introduced) 10.

Tonalite:

P508A	labradorite 70-75, hornblende 20, quartz 5-10, chlorite, magnetite.
P548A	(xenolith in trondhjemite) albite 30-40, tremolite 5-10, chlorite 50, quartz 5-10.
P580	andesine 70, hornblende 22, actinolite 3, quartz 5.

Trondhjemite:

P509	oligoclase or andesine 65, quartz 30, hornblende and magnetite 5.
P522C	oligoclase 50, quartz 50, sericite and chlorite.
P548A	labradorite 35, quartz 45, hornblende 13, chlorite 7.
P548B	andesine 20, albite or K feldspar 10, quartz 50, hornblende 10, chlorite 10.

Trondhjemite: continued

P551 labradorite 50, quartz 15, actinolite 31, chlorite 2, biotite 2.
P646 (host) andesine-labradorite 30, quartz 65, hornblende 5, magnetite, titaniferous magnetite or ilmenite, leucoxene, sphene?.
P646 (xenolith) andesine-labradorite 20-30, quartz 30-40, hornblende 30-50.

Granodiorite:

P534 albite 35, K feldspar 10, quartz 40-45, hornblende 10-15, magnetite.
P554 albite 40?, quartz 40?, sanidine 20?, limonite, hematite.

A xenolith in tonalite P508B has the following composition :

hornblende 90, magnetite 5, labradorite 3, quartz 2.

It may be cognate or possibly represent partially assimilated pyroxenite.

Plagioclase ranges in composition from sodic bytownite and labradorite, in the diorites and tonalites, to albite in the granodiorites. Bytownite, andesine and oligoclase crystals are zoned with more sodic rims except in specimens P509 (fine-grained), P522D, P548B, and P646; examples are listed below :

Diorite:

P508A labradorite An_{62} with sodic andesine An_{32} rims.

Tonalite:

P508B labradorite An_{62} and sodic bytownite An_{73} with andesine An_{42} rims.

P580 andesine An_{46} with andesine An_{32} and rare oligoclase An_{27} rims.

Trondhjemite:

P522C oligoclase or andesine with albite rims

P548A labradorite An_{57-58} and rare sodic bytownite An_{76} with oligoclase, albite and possibly K feldspar rims

P551 sodic bytownite An_{70-72} with rims of andesine An_{30-40} and oligoclase An_{14} .

The cores are more altered than the rims, the alteration products being kaolin, minor sericite and rare epidote. Carlsbad, albite and pericline twinning were seen in most of the thin sections; in specimens from Koreipo Creek, near the Timeno Fault, the twin planes are curved and the grains show undulose extinction (P522 C & D).

Potash feldspar was noted in specimens P534 and P554. Orthoclase in P534 exhibits carlsbad twinning and is less altered than the associated albite. Sanidine? in P554 has low relief, an optic axial angle of about 10°, negative optic sign, and very low birefringence; the rock is sheared leucocratic granodiorite and is definitely not of volcanic origin.

Quartz is common to all of the intermediate and acid rocks; in most it is a primary mineral but in some it has been introduced. Examples of the latter are diorite and trondhjemite from near the Timeno Fault in Koreipo Creek (P522 C & D) in which quartz has been introduced along shear planes after solidification and shearing of the host rock. The primary plagioclase and amphibole crystals show curved twin planes and granulation whereas the quartz crystals exhibit delicate intergrowths and are not cracked. Generally primary quartz is interstitial indicating that it was the last mineral to crystallize but in the granodiorite it forms symplectic intergrowths with feldspar; this indicates eutectic crystallization of quartz and feldspar. A peculiar feature of the quartzose trondhjemite, P548B is that individual interstitial grains of quartz, 0.5 and 0.6 mm. across, are optically continuous over as much as 6 mm. of the thin section.

The predominant femic mineral is green hornblende which is pleochroic as follows :

X colourless, light brown, or pale yellowish-green
Y brownish green, brownish green, or dark green
Z dark (bluish) green, dark green, or dark bluish green.

This is commonly partly altered to colourless tremolite which occurs as rims and as irregular blebs within the hornblende crystals. Partial alteration to fibrous actinolite and green pennine chlorite is also common.

An unusual hornblende occurs in the Baira Creek trondhjemite; this is pleochroic as follows :

X light greenish brown, Y light brown, Z strong pale brown.

Two of the specimens examined do not contain hornblende. The Koreipo Creek diorite (P522) contains primary cummingtonite which is partly pseudomorphed by actinolite with magnetite; the actinolite is, in turn, partly altered to chlorite. Trondhjemite from the Morobe River headwaters (P551) contains prismatic and fibrous actinolite which is pleochroic as follows :

X very pale brown, Y pale brownish green, Z weak dark green.

Another peculiarity of this specimen is the presence of rare biotite which is pleochroic from colourless (X and Y) to brownish green (Z). This is the only observed occurrence of a mica mineral in the feldspathic rocks. It is partly altered to pennine chlorite which is pleochroic from colourless (X and Y) to green (Z).

Pennine chlorite is a common product of the alteration of amphibole in the intermediate and acid rocks and is distinguished by the anomalous blue interference colour.

Magnetite is a common accessory mineral and is invariably localized in or near the femic minerals.

The intermediate and acid rocks show some petrological similarity to the more basic phases of the Morobe Granodiorite and gold shed from monzonite in the Basic Belt has similar fineness to gold shed from the Morobe Granodiorite (Fisher, 1944, and see under Economic Geology). Possibly the Granodiorite is related to the Basic Belt.

4. <u>Andesite and dolerite dykes</u>

Andesite and dolerite dykes intrude the intermediate and acid rocks in the area between Ipoa Creek and the Morobe River headwaters. In hand specimen these are similar in appearance to the andesite and dolerite of the Mageri Volcanics and it is thought that they are genetically related to the Volcanics.

Andesite dyke rock from Baira Creek (P548C) is minerallogically similar to massive microdiorite which crops out in Bigo Creek (P537B). The latter is thought to be an intrusive member of the Mageri Volcanics and, if this is so, a genetic relationship between dyke rocks and Volcanics is likely. The compositions of the two rocks are as follows :

P548C (Baira Creek) melanocratic quartz-bearing pigeonite andesite; albite 54, quartz 3, pigeonite 15, chlorite 23, epidote 5

P537B (Bigo Creek) melanocratic quartz-bearing pigeonite microdiorite: sodic andesine 52, quartz 3, pigeonite 35, chlorite 7

In both the pyroxene is pigeonite and the colour index is about 43.

One thin section of volcanic rock (highly altered pillow lava P544) has been examined and this revealed few similarities with the andesite dyke rock.

Alteration and Mineralization

Serpentinization has affected olivine and pyroxene in the peridotites (see under Ultramafic Rocks above). Water required for serpentinization may have been introduced by the younger basic, intermediate and acid rocks, or have been squeezed out of the Nipanata Beds, or be meteoric in origin (cf. Worst, 1958).

Uralitization has affected pyroxenes in the ultramafic and basic rocks, the usual product being actinolite.

Chloritization has affected amphiboles in the intermediate and acid plutonic rocks and in the basic and intermediate dyke rocks.

Epidotization has affected femic and feldspathic minerals in the intermediate and acid plutonic rocks and the basic and intermediate dyke rocks.

Saussuritization has affected the calcic cores of zoned plagioclase crystals in the intermediate and acid rocks.

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 diorite 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" and is therefore closely related to the rock-type known as rodingite. 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 post-Middle Cretaceous, have folded and regionally metamorphosed rocks of the Owen Stanley Metamorphics. Faulting, probably largely transcurrent, with minor folding, has continued until Recent times.

The Kaindi Metamorphics were subjected to pre-Cretaceous regional metamorphism which in most cases has obliterated the bedding. Where bedding is discernible, the rocks are seen to be very tightly folded, with the schistosity 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 post-Middle Cretaceous 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 near vertical; this is interpreted as a result of vertical movement along the Owen Stanley Fault.

In the Sampa Beds the observed dips and strikes of bedding planes suggest a tight, north-easterly trending, syncline, the limbs of which dip at between 40° and 90°. However, schistosity generally dips at a shallower angle than bedding and this observation does not agree with the above structural interpretation. More detailed mapping is planned. In the finer-grained rocks any bedding is masked by schistosity.

Faulting

Major transcurrent faults have been active along the Trist-Waria Depression 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 Trist-Waria Depression; it brings the Owen Stanley Metamorphics against the younger Nipanata Beds and the Papuan Basic Belt. The fault is marked by a zone, up to half a mile wide, of intensely sheared rocks of the Papuan Basic 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 refted boulders of unaltered dunite. Between Lake Trist and the Iwiri - Waria junction the zone consists of serpentinite and serpentinite pug but further south and south-east it is concealed by alluvium. The fault plane is probably vertical throughout its length, as the fault trace is relatively straight and unaffected by topography and, where seen, 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 the fault. 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 8,000 feet, but this discrepancy is 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 relatively recent.

North of Mubo the Owen Stanley Fault splits, one branch trending north-east to Buansing, and the other trending north to a point on the coast west of Salamaua. These two faults enclose a wedge of Salamaua Metavolcanics between the Kaindi Metamorphics and the Basic 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 a quarter of a mile wide, and shows no evidence of recent movement.

Apparent displacement of the Nipanata Beds, seen in the aerial 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 2,000 feet by a fault trending 280°. 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, aerial photos 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 Basic 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 partially arrested and translated into vertical movement. Such vertical movement might elevate the ultramafic basal part of the pluton which could be exposed, by subsequent 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 west and the easternmost 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 re-opened by very recent movement" about two miles north of Lake Trist.

The contact between the Papuan Basic Belt and the Mageri Volcanics is probably fault-controlled as it is relatively 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 Sampa Beds. 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 Plate 1), probably represent the marginal sediments (limestone reefs, conglomerate, quartz greywacke, and greywacke) of the western flank. The Kaindi sediments emerged and were folded and metamorphosed before deposition of the Sampa Beds. The latter are not older than Middle Jurassic nor younger than Middle Cretaceous (see palaeontological report under Stratigraphy above). The folding of the Sampa Beds may have been contemporaneous with the emplacement of the Morobe Granodiorite, which intruded as several major plutons and a number of stocks and bosses, probably in Upper Cretaceous time.

The Nipanata Beds and Salamaua 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 Basic 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. It is possible that the Belt was emplaced in a solid state by faulting (see Thompson's hypothesis under Papuan Basic Belt above) and that emplacement took place in Upper Cretaceous time. The data are as follows :

(i) the Belt is overlain by volcanics of the Iauga Formation which are conformably overlain by Miocene f_{1-2} stage limestone (Paterson and Kicinski, 1956), and

(ii) ultramafic rocks appear to intrude the Urere Metamorphics in the Musa River area (Smith and Green, 1959).

The first observation indicates that the Belt was emplaced (in either fluid or solid state) in pre-Burdigalian time. The inference from the second observation is not as clear for several reasons :

(a) the age of the Urere Metamorphics is not known but it most likely Cretaceous or Lower Tertiary. The writers favour a Lower Tertiary age as the Urere Metamorphics differ from the Cretaceous Sampa and Snake River Beds both in lithology and degree of metamorphism but the argument is not strong.

(b) the intrusive nature of the ultramafics in the Urere Metamorphics is apparently in doubt. In a recent paper, Green (1961) has stated that all contacts in the Musa area are faulted and provide no support for the concept of the existence of a peridotite magma at crustal levels. According to J.W. Smith (pers.comm.) contacts were not seen owing to lack of outcrop but the irregular outline of the ultramafic bodies and the presence of inliers of metamorphics within them argue for an intrusive relationship.

Whichever view is accepted, it is most likely that the emplacement of the Belt post-dates the deposition of the Urere Metamorphics and thus probably took place in Upper Cretaceous, Lower Tertiary or lower Middle Tertiary time.

The Belt may have been emplaced in fluid, near-solid, or solid state. The writers favour the more conventional view that the Belt was emplaced in fluid state as a pluton of gabbroic magma which subsequently differentiated into ultramafic, basic, intermediate and acid rock types. Thompson (see under Papuan Basic 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.

The writers 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 was probably 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 of eucrite (minor), gabbro, norite, pyroxenite (minor) and anorthosite (minor), and leaving a residual magma of quartz diorite 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 intermediate and sodic plagioclase, amphibole, quartz and very rare biotite, resulting in such rock types as diorite, tonalite, 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 groups.

6. Intrusion of dykes of basalt, dolerite, andesite and microdiorite characterized by the presence of sodic or intermediate plagioclase and pigeonite or pigeonitic augite, into the intermediate and acid rocks.

7. Extrusion of the Mageri Volcanics probably accompanied stage 6.

The mineral composition of the Mageri Volcanics indicates that they are not late-stage differentiates of the Basic Belt pluton. They may derive from remelting of the basic part of the pluton or from a second generation of basic magma.

The contact between the Mageri Volcanics and the plutonic rocks of the Papuan Basic 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 evidence of faulting in the field might be due to late-stage intrusions of dolerite and microdiorite along the fault zone.

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

Major faulting probably commenced in Upper Cretaceous or Lower Tertiary time and has continued until the Recent; the most recent fault movements have been predominantly transcurrent and anticlockwise. The Basic 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 Basic Belt has been elevated and in these areas erosion has exposed the ultramafic basal part of the plutoh.

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.

Quaternary 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 broadly 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 Trist-Waria Depression 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 anticlockwise transcurrent movement along the Owen Stanley Fault.

The central and southern part of the Trist-Waria Depression is a graben bounded by the Owen Stanley and Timeno Faults. To the north there is no evidence that the depression originated from down-faulting and it may have been formed merely by rapid erosion of rocks imbricated by movement on the Owen Stanley Fault. Minor Recent faulting in this area has formed lakes and swamps. The Iwiri River flows southward through this zone of imbrication. The Middle Waria River flows through the graben 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 Basic 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 east or west to the coast or the Trist-Waria Depression. Others, such as the Saru and Sakia (Maiama) Rivers, parallel the northerly strike 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 microdiorite. The result is a course characterized by right-angle bends.

The Coastal Region corresponds to the coastal part of the Mageri Volcanics; the razorbacked 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 map 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 Timanogosa, Juni and Piawaria before 1940, and on the Wiwo River and near Dona before 1914 (Fisher, 1944, and 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 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 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 as no follow-up action was taken it is assumed that the prospects were not economic.

Fisher (ibid.) examined the Timanogosa 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, unpublished reports). The gold occurs with chalcopyrite in a narrow vein of white quartz which intrudes gabbro or pyroxenite. Quartz reefs on upper Kau Creek contain a trace of gold and about 4 oz. 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 Timanogosa and Juni Creek. The little gold which has been won from near the porphyry intrusion has a fineness of 750, that at Timanogosa 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 fineness about 760 (ibid.).

Small parcels of gold from Juni have fineness as high as 854 with individual nuggets as high as 866. Fisher suggests that this high fineness 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. The writers regard this monzonite as a member of the intermediate and acid group of rocks of the Papuan Basic 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). Gold from the Dona area may also be shed from the Volcanics. Platinum and osmiridium occur with the Middle Waria gold and probably derive from the rocks of the Basic Belt.

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 (Vletter, 1955, and Thompson, 1957). However, in those parts of the Papuan Basic Belt which have been tested, nickel concentrations are below economic grade.

The development of lateritic concentrations of nickel is discussed by de Vletter (Vletter, 1955). Fresh peridotites commonly contain about 0.2% nickel, probably in the lattice of the olivine crystal. 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 (1916) was the first to note nickel in the Papuan Basic Belt, when he investigated a report of edible earth on the Mamama River, east of Kokoda. Gray (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 Basic 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 Kujera Range near Kokoda. The International Nickel Company and Bulolo Gold Dredging Ltd. made separate investigations at Koreppa and in the Kokoda area 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 alteration 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 mineralisation 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 concentrations of chromite have been observed in streams draining the Papuan Basic Belt, and chromite is a minor constituent of heavy mineral sands on the north-eastern coast of Papua (ibid.). It derives from disseminated chromite in the ultramafic rocks.

Copper.

Copper mineralisation was seen in the Basic Belt near the Timeno Fault, on the Paiawa and Saia Rivers, and in the Mageri Volcanics on Bigo Creek and at Enoto Point.

Mineralisation 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 intermediate and acid rocks have introduced copper and other minerals.

Boulders of basic rocks from 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°. Greaves (pers.comm.) has identified the following minerals in a specimen (W41) 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 (537B).

<u>Mercury</u>

Alluvial cinnabar has been recovered from Kau Creek (Fraser, pers. comm.) and specimens have been sighted by the writers.

<u>RECOMMENDATIONS</u>

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 Figure 7) 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 anomalies, 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, say, fortnightly float-plane charter.

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 $\frac{3}{4}$ 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 Timanogosa 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 mineralisation from Tida-ura south-east to the limit of the map area and beyond. Known exposures of mineralisation, at Tida-ura and Bakewa Hill, are very small but closer examination and pitting might reveal larger bodies.

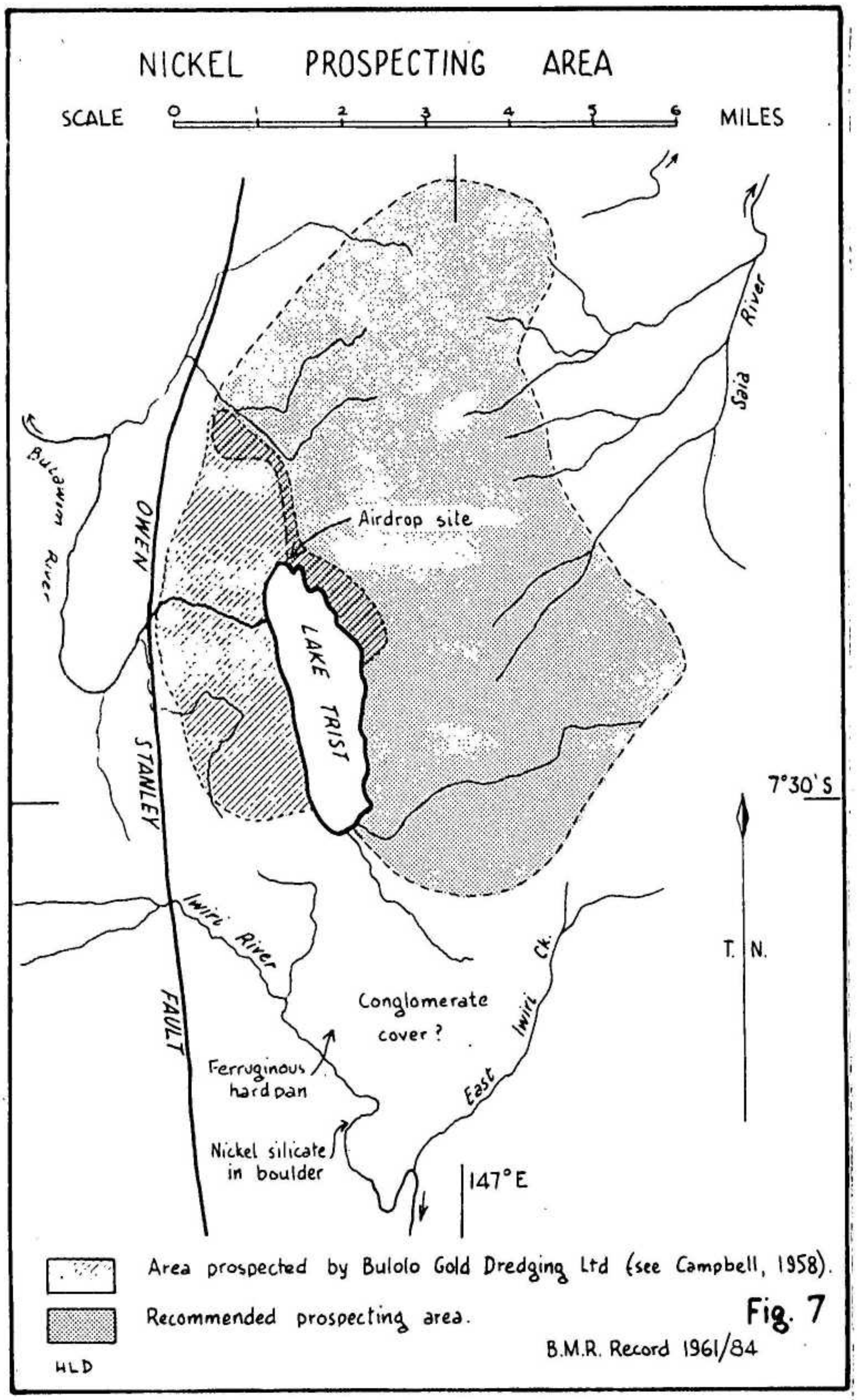


Fig. 7

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

(i) steep gorges, large boulders, and the volume of water in the streams,

(ii) poor exposure of bed rock in the accessible parts of the stream beds, and

(iii) the observed rarity of chalcopyrite-bearing boulders.

Geochemical prospecting might be defeated by the heavy rainfall and steep topography which induces

(i) rapid run-off into swift-flowing streams,

(ii) absence of fine-grained alluvium in the stream beds, and

(iii) a sparsity of residual soil on the valley slopes.

The most likely method of geochemical prospecting is the analysis of soil samples from the ridge tops where there are residual soils.

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APPENDIX

Petrographic description, by W.R. Morgan, of specimens from the Bitoi-Salamaua area collected by D.B. Dow and G.Seidner.

SG1/a

Hand Specimen. The rock is basic and apparently porphyritic. It has a fine-grained, dark green groundmass, speckled with white, which encloses numerous black "phenocrysts" of pyroxene. The "phenocrysts" are subhedral, and measure up to one or two millimetres in size. A possible slickenside bounds the specimen on one side: the surface of the rock here has a thin coat of a black, shiny mineral.

Thin Section. The specimen has a fine to medium-grained, hypidiomorphic and amygdaloidal groundmass, which surrounds large plates of augite, which ophitically enclose groundmass crystals. The groundmass consists of tabular laths of plagioclase, with a pale green, nearly isotropic chlorite occupying the interstitial spaces. Plagioclase is strongly kaolinized; its refractive index is greater than that of balsam, and indistinct albite twinning may be seen. It is biaxially positive, and some extinction angles suggested that it is labradorite. As well as the chlorite, augite occurs as small interstitial grains.

Augite also occurs as large plates, ranging between 0.5 and 2.25 mm. in size, which commonly enclose groundmass feldspar laths. It is colourless, and forms, often, very irregular crystals. It is biaxially positive, with 2V=55°. Augite is often altered to a green chlorite, which occurs in irregular patches in the host mineral.

The amygdales tend to be elongated in a common direction. They are filled with a very pale green fibrous chlorite, which has its larger fibres tending to be oriented parallel to the elongation. Small crystals of a brownish-green amphibole? occasionally occur, enclosed by chlorite. A vein, cutting at right-angles to the amygdale elongation, contains pale green chlorite at its centre, and nontronite? on its edges. Leucoxene occurs as irregular crystals in the groundmass.

An estimation of the percentages of minerals present is:- feldspar: 45, olivine and augite: 30, chlorite (excluding the amygdales): 20, leucoxene: 5. The rock is a kaolinized dolerite, or basalt.

SG1/b

Hand Specimen. The rock is dark and basic: it has a fine-grained groundmass enclosing very small sparse phenocrysts. The sample is cut by irregular veins.

Thin Section

In texture, the rock is fine-grained, hypidiomorphic and seriate porphyritic, the small crystals of pyroxene being clustered. The phenocrysts are pyroxene, either augite or diopside. They form colourless prismatic to granular crystals and are biaxially positive, with 2V=55° and extinction, c to Z, 41°.

Pyroxene is found as small, granular crystals in the groundmass. Rather fibrous prehnite also occurs in the groundmass, interstitially to the pyroxene. Very fine chlorite, greenish or almost colourless, may be found as a background to the other minerals. Numerous very small irregular grains of sphene, which are pleochroic in shades of brownish yellow, are present. Occasionally, small crystals of pumpellyite? (see below) may be seen, distinguished by their being pleochroic from almost colourless to bright green.

The rock is cut by thin veins of very pale green chlorite; the veins appear to be interrupted by micro-faults. Apart from these, a thick vein with a large pocket is present. The major part of the vein and pocket consists of prehnite, which is colourless with a fairly strong relief. It is biaxially positive, with 2V=50°-60°. The mineral tends to occur as coarse, sub-radiating columnar bodies. An unidentified mineral, which may be pumpellyite, occurs in the vein. It has high relief, with a refractive index of 1.68 -1.71, i.e., slightly greater than that of pyroxene. Its pleochroism is X = pale green yellow; Y= pale yellow green; Z= deep green, with absorption: Z)Y)X. The extinction is oblique, but is difficult to measure because of incomplete and "wavy" extinction. The birefringence is approximately 0.027. An interference figure was not obtainable. The properties mentioned agree to a certain extent with those of pumpellyite, except for the scheme of pleochroism: Winchell (1951) and Bloxam (1958) state that the absorption scheme should be Y)Z)X in the former reference, and Y)Z =X in the latter.

The rock itself appears to be an altered prehnite - bearing basalt.

SG15/b

Hand Specimen. The specimen is dark greenish black, with pink, irregular streaks running through it: a cut surface gives the appearance of serpentine. Small amounts of olivine may be seen, as black shiny mineral.

Thin Section. The rock is a strongly serpentinized dunite: it consists of scattered grains of olivine separated by masses of lamellar serpentine. Groups of the olivine grains are seen to extinguish together, indicating that these are parts of original crystals. The olivine is biaxially negative, with 2V=85°, showing it to be chrysolite. Some subhedral to anhedral grains of chromite are present: they are nearly opaque, showing a dark red translucency in strong light.

SG.19/a

Hand Specimen. The rock consists mostly of mottled grey and black serpentinous material, partially enclosing the region of black serpentine. The mottled zone appears to be related to the weathered surface.

Thin Section. The rock is composed almost entirely of serpentine, which consists of a meshwork of veinlets of a fibrous mineral pleochroic in very pale yellow green, enclosing large lamellae of almost colourless material which has a slightly lower refractive index, and is biaxially negative, with 2V=20°. None of the serpentine minerals present have a refractive index less than that of balsam.

A few relict grains of olivine are present. Probable magnetite, a by-product of serpentinization of olivine, occurs in veinlets of chrysotile. Anhedral to subhedral crystals of chromite occur: it also forms small granules along the veinlets mentioned above. Some staining by hydrated iron oxide was noted.

The rock is serpentine, almost certainly derived from dunite.

SG.19/c.

Hand Specimen. The rock is dark grey, and very coarse grained. It consists mostly of pyroxene, with some greenish chloritic material. A very indistinct "foliation" that is apparent in the hand specimen is seen in section to be caused by small parallel veins.

Thin Section. The specimen is very coarse-grained and is composed mostly of enstatite: it has parallel extinction, and is biaxially positive, with $2V = 85^{\circ}$. Small subhedral "square-shaped" crystals of chromite are sparsely scattered in the rock. A little alteration to colourless tremolite has taken place along numerous sub-parallel cracks in enstatite. The cracks are rarely parallel to the cleavage. A few thicker veins occur parallel to enstatite cleavages: these are connected to the thin veins, and contain tremolite.

The rock is a slightly uralitized enstatite pyroxenite.

SG.19/d.

Hand Specimen. The rock is basic and coarse-grained, consisting of serpentine. It may be scratched with a knife, and has a "soapy" feeling. Scattered crystals of shiny black chromite? can be distinguished.

Thin Section. The specimen is rather similar to SG.19/a in that it is a serpentinized dunite. Rather more chromite is present in the veinlets. Anhedral to subhedral crystals of chromite are also present.

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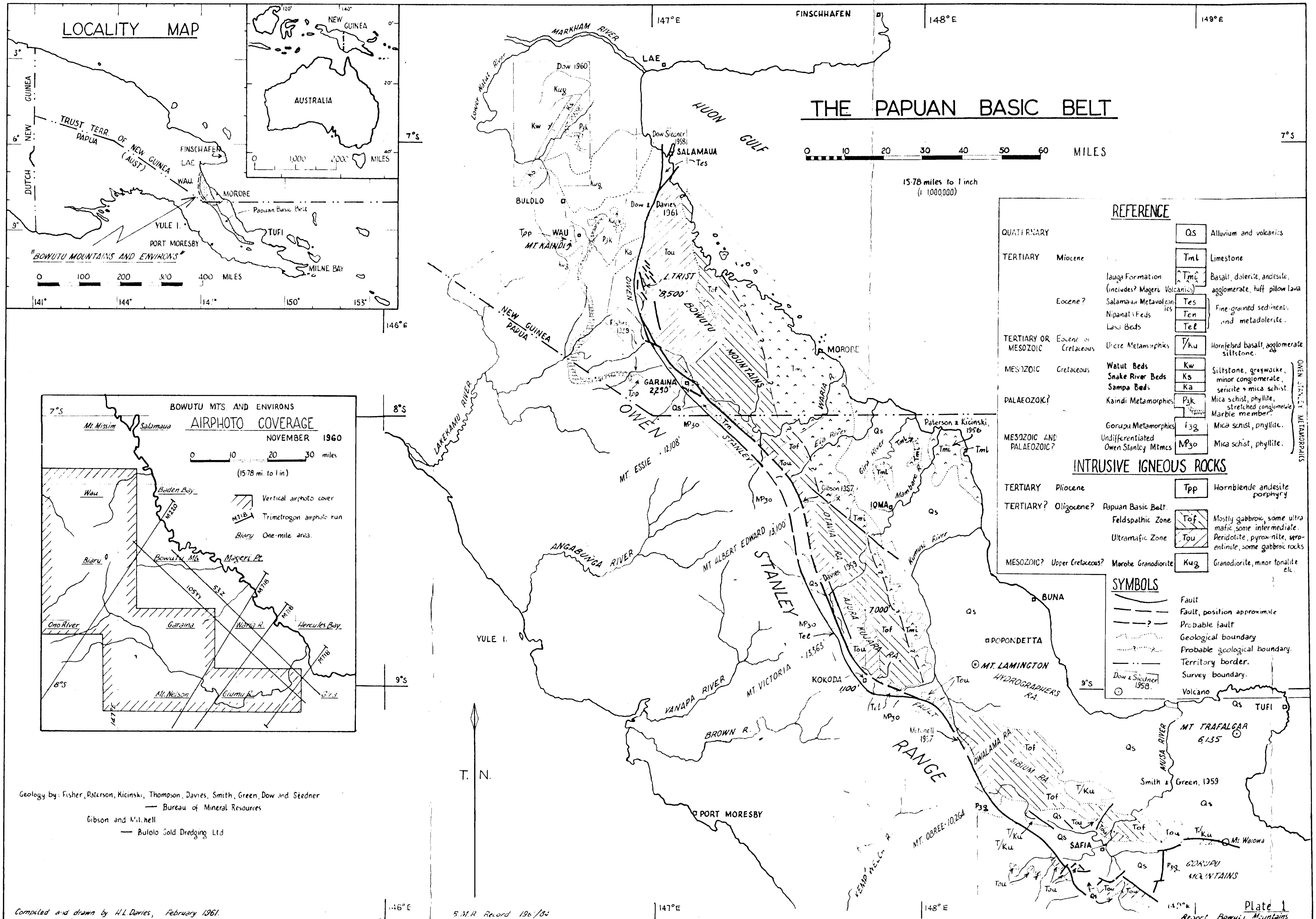

THE PAPUAN BASIC BELT
MILES
15·78 miles to 1 inch
(1:1,000,000)
LOCALITY MAP
NEW GUINEA
AUSTRALIA
DUTCH NEW GUINEA
TRUST TERR. OF NEW GUINEA (AUST)
PAPUA
FINSCHAFEN
LAE
WAU
MOROBE
Papuan Basic Belt
YULE I.
PORT MORESBY
TUFI
MILNE BAY
"BOWUTU MOUNTAINS AND ENVIRONS"
400 MILES
BOWUTU MTS. AND ENVIRONS
AIRPHOTO COVERAGE
NOVEMBER 1960
(15·78 mi. to 1 in)
Vertical airphoto cover
Trimetrogon airphoto run
One-mile area
Mt. Missim
Salamaua
Wau
Baden Bay
Biaru
Bowutu Mts
Mageri Pt.
Ono River
Garaina
Waria R.
Hercules Bay
Mt. Nelson
Ciumu R.
REFERENCE
QUATERNARY
Qs Alluvium and volcanics
TERTIARY Miocene
Tml Limestone
Iauga Formation (includes? Mageri Volcanics)
Tmi Basalt, dolerite, andesite, agglomerate, tuff pillow lava
Eocene?
Salamaua Metavolcanics Tes
Nipanati Beds Ten
Lasu Beds Tel
Fine-grained sediments and metadolerite.
TERTIARY OR MESOZOIC Eocene or Cretaceous
T/Ku Hornfelsed basalt, agglomerate siltstone.
MESOZOIC Cretaceous
Watut Beds Kw
Snake River Beds Ks
Sampa Beds Ka
Siltstone, greywacke, minor conglomerate, sericite + mica schist
PALAEOZOIC?
Kaindi Metamorphics Pzk
Mica schist, phyllite, stretched conglomerate Marble member
MESOZOIC AND PALAEOZOIC?
Gorupu Metamorphics
Undifferentiated Owen Stanley Mtmcs MPzo
Mica schist, phyllite.
OWEN STANLEY METAMORPHICS
INTRUSIVE IGNEOUS ROCKS
TERTIARY Pliocene
Tpp Hornblende andesite porphyry
TERTIARY? Oligocene? Papuan Basic Belt.
Feldspathic Zone Tof Mostly gabbroic, some ultra mafic, some intermediate.
Ultramafic Zone Tou Peridotite, pyroxenite, serpentinite, some gabbroic rocks
MESOZOIC? Upper Cretaceous? Morobe Granodiorite Kug Granodiorite, minor tonalite etc.
SYMBOLS
Fault
Fault, position approximate
Probable fault
Geological boundary
Probable geological boundary
Territory border.
Survey boundary.
Volcano
MARKHAM RIVER
Lower Watut River
FINSCHHAFEN
LAE
HUON GULF
SALAMAUA
BULOLO
WAU
MT KAINDI
GARAINA
MOROBE
NEW GUINEA
PAPUA
OWEN STANLEY RANGE
BOWUTU MOUNTAINS
MT. ESSIE 12,108'
MT ALBERT EDWARD 13,100'
MT VICTORIA 13,363'
MT. OBREE 10,264
LAKEKAMU RIVER
ANGABUNGA RIVER
VANAPA RIVER
BROWN R.
YULE I.
PORT MORESBY
KOKODA
IOMA
BUNA
POPONDETTA
MT. LAMINGTON
HYDROGRAPHERS RA.
TUFI
MT TRAFALGAR 6,135
MUSA RIVER
SAFIA
GORUPU MOUNTAINS
Mt. Waiowa
Waria R.
Eia River
Gira River
Mambare R.
Kumusi River
OWALAMA RA.
SIBIUM RA.
AJURA KUJARA RA.
OTAVIA RA.
Dow 1960
Dow Siedner 1958
Dow & Davies 1961
Fisher 1939
Paterson & Kicinski, 1956
Gibson 1957
Davies 1959
Mitchell 1957
Smith & Green, 1959
T. N.
147°E
148°E
149°E
146°E
7°S
8°S
9°S
Geology by: Fisher, Paterson, Kicinski, Thompson, Davies, Smith, Green, Dow and Siedner — Bureau of Mineral Resources
Gibson and Mitchell — Bulolo Gold Dredging Ltd
Compiled and drawn by H.L. Davies, February 1961.
B.M.R. Record 1961/84
Plate 1
Report Bowutu Mountains

GEOLOGICAL MAP OF THE
BOWUTU MOUNTAINS AND ENVIRONS
Geology by N.H. Fisher, 1933, J.E. Thomson, 1951, 1957, 1958, D.B. Dow, 1958, 1960, G. Siedner, 1958, H.L. Davies, 1960.
SCALE MILES
2 MILES TO 1 INCH
REFERENCE
QUATERNARY Recent Qa Boulder beds, conglomerate, gravel, sand, silt, peat, etc.
TERTIARY Miocene Mageri Volcanics Tmm basalt, dolerite, andesite, microdiorite agglomerate, tuff, pillow lava
Eocene? Nipanata Beds Ten Mudstone, siltstone, fine-grained greywacke, marble and metadolerite.
Eocene? Salamaua Metavolcanics Tes Altered basalt and dolerite, silicified siltstone and marble.
MESOZOIC Cretaceous Sampa Beds Ka Sericite schist, mica schist, fossiliferous greywacke.
PALAEOZOIC? Kaindi Metamorphics Pzk Sericite and mica schist, quartz mica schist, stretched conglomerate, some schist calcareous, some silicified. Marble.
PALAEOZOIC AND MESOZOIC Undifferentiated Owen Stanley Metamorphics MPzo Sericite and mica schist, etc
OWEN STANLEY METAMORPHICS
IGNEOUS ROCKS
TERTIARY Pliocene? Tpp Hornblende andesite porphyry
TERTIARY? Oligocene? Papuan Basic Belt
Feldspathic Zone Tof Trondhjemite and tonalite. Basic, intermediate and acid rocks: Eucrite, norite, gabbro, anorthosite, diorite, tonalite, trondhjemite and rare granodiorite.
Ultramafic Zone Tou Dunite, pyroxene peridotite, pyroxenite, serpentinite, actinolite schist and minor basic rocks.
MESOZOIC? Upper Cretaceous? Morobe Granodiorite Kug Granodiorite, minor tonalite etc
SYMBOLS
Geological boundary, position accurate
" " , 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
Au, Pt, Cu, Hg Gold, platinum, copper, mercury
Py, pyrrh, cpy Pyrite, pyrrhotite, chalcopyrite
5200' Spot height in feet, by uncontrolled barometer
Foot-track
Airstrip.
Amoa Native village.
Territory border
Beds dip 15-45° — air photo interpretation
SG19/a P530 Specimen localities
Section line
SALAMAUA
MOROBE
GARAINA
SOUTH PACIFIC OCEAN
NEW GUINEA
PAPUA
OWEN STANLEY FAULT
WARIA RIVER
LASANGA I.
MAGERI POINT
HYPOTHETICAL SECTIONS
Scale: 2 miles to 1 inch, vertical and horizontal.
OWEN STANLEY RANGE
TRIST-WARIA DEPRESSION
BOWUTU MOUNTAINS
COAST
Probable fault obscured by later microdiorite + dolerite intrusions
Owen Stanley Metamorphics
PAPUAN BASIC BELT
Ultramafic rocks
Ultramafic and basic rocks intruded by trondhjemite and tonalite
Dolerite and microdiorite of Mageri Volcanics, intrude Basic Belt, Nipanata Beds, Salamaua Metavolcanics or simatic crust, and older parts of Mageri Volcanics
Sheared serpentinite
Basic rocks intruded by trondhjemite + tonalite.
Plate 2
B.M.R. Papers 36/84
Compiled and drawn by D.B. Dow and H.L. Davies February 1961
Report Bowutu Mountains