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DEPARTMENT OF NATIONAL DEVELOPMENT  
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

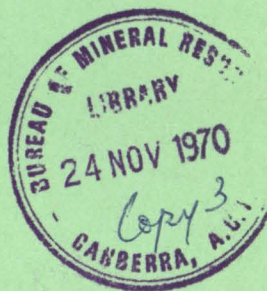
REPORT No. 115

REPORT PNG 3

## Geology of Woodlark Island, Papua

BY

D. S. TRAIL



*Issued under the Authority of the Hon. David Fairbairn  
Minister for National Development*

1967

BMR  
S55(94)  
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DEPARTMENT OF NATIONAL DEVELOPMENT

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THIS REPORT WAS PREPARED IN THE GEOLOGICAL BRANCH

ASSISTANT DIRECTOR: N. H. FISHER

*Published by the Bureau of Mineral Resources, Geology and Geophysics  
Canberra, A.C.T.*

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## SUMMARY

Woodlark is an isolated island about 170 miles north-east of the eastern point of Papua. The island is composed of a raised and slightly tilted Quaternary coral platform around a deeply eroded and locally mineralized Tertiary volcanic pile.

In 1960, a Bureau of Mineral Resources field party worked on Woodlark for four months to establish the geological setting of known gold and copper-iron mineralization, and to test the application of geochemical techniques in rough heavily forested terrain with a high rainfall.

The oldest exposed rocks are the Loluai Volcanics, which are composed of andesitic basalts and associated pyroclastic rocks interbedded with fine-grained siliceous sediments. They are succeeded unconformably by the lower Miocene Suloga Limestone, which is overlain by a thick sequence of andesitic basalts, pyroclastics, and associated tuffaceous sediments, and by the Nasai Limestone. The Nasai Limestone contains lower Miocene Foraminifera and was deposited on the flank of the volcanic pile after the main eruptive phase. Most of the island is covered by Quaternary coral limestone and subordinate marine clay and interbedded conglomerate.

The centres of Tertiary vulcanism are not generally recognizable, but the discordant breccia at Mount Kabat probably represents one of the vents. Dolerite sills intrude the formations in the lower part of the succession. Large and small dykes of granite intrude almost the entire Tertiary succession. The porphyries associated with the granites may be metasomatically altered volcanic rocks. The boulders of felsite at Kulumadau are probably derived from dykes. Dykes of diorite, lamprophyre, basalt, and ultrabasic rock also intrude the Tertiary volcanics.

During lower Miocene time Woodlark existed as a volcanic island or island group which changed rapidly in form as periods of volcanic activity alternated with periods of quiescence and erosion. During the late Tertiary and Quaternary, coral reefs, and marine clay and conglomerate, were deposited as a wide platform around the eroded volcanic pile. Finally, uplift and regional tilting resulted in the formation of the island as it is today.

Structural interpretation is restricted by poor exposures. Regular folding exists only in the oldest rocks. A zone of steep dips on the south-eastern flank of the Okiduse Range may mark the margin of a volcanic subsidence. Most faults and shear zones trend between 160° and 180°.

Gold was consistently produced from many alluvial deposits and a few small reefs between 1895 and 1918.

Small parcels of copper carbonate ore were won from superficial workings at Loluai and Norac on Suloga Peninsula in 1917. Many of the small rich gold reefs were worked down to the water-table only. The Kulumadau gold mine, which alone successfully tackled the formidable water problem, was mined to a depth of 400 feet.

Most of the gold has been derived from the Okiduse Volcanics or from rocks intruding them. The gold-bearing reefs are commonly pug-filled shear-zones trending between 160° and 180° and ranging from a few inches to 100 feet in width. In the primary zone the gold

is associated with galena, sphalerite, chalcopryite, pyrite, calcite and quartz; it appears to be the product of a late hydrothermal phase of volcanic activity. Pyrite is common throughout the Tertiary rocks. A small deposit of manganese oxide occurs in the Loluai Volcanics.

At Loluai and Norac on Suloga Peninsula dyke-like copper-bearing magnetite-hematite lodes occur in skarn rocks, near dolerite sills intruded into the lower members of the Tertiary succession. These deposits were tested for copper by a geochemical survey.

Alluvial gold may be present in payable quantities in the conglomerates interbedded with the soft Quaternary marine clays to the east and west of the Okiduse Range. The alluvial flats of the Sinkurai River where it emerges from the Okiduse Range warrant testing as a gold-dredging prospect.

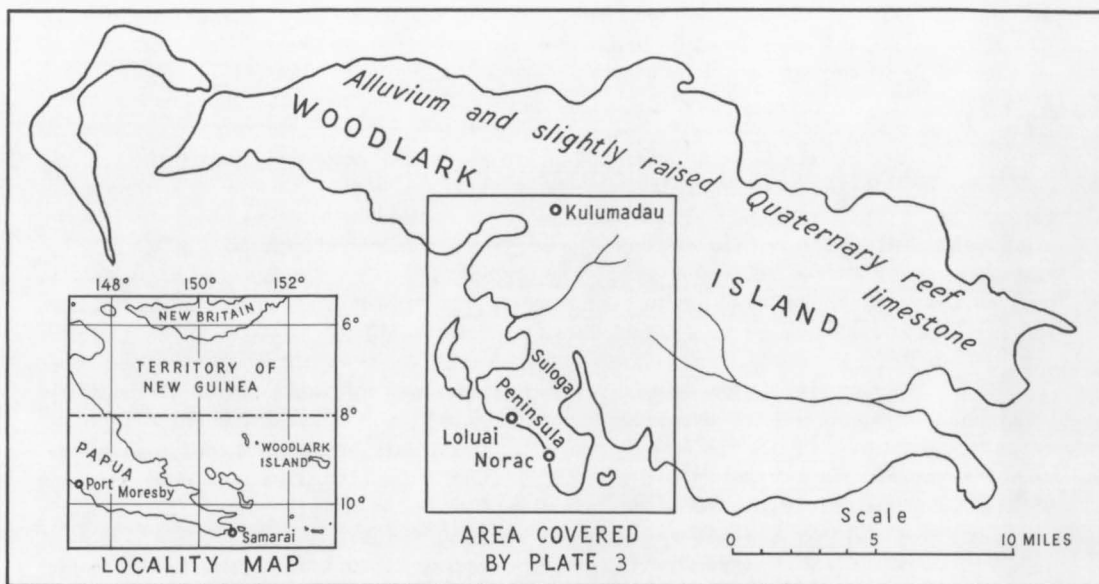


Fig. 1 Locality Map

## INTRODUCTION

Woodlark Island lies about 170 miles north-east of Samarai, the administrative headquarters at the eastern tip of Papua. The island is about 40 miles long from east to west, 15 miles across at its widest part, and about 280 square miles in area. Brass (1959) has compiled an excellent history of Woodlark and the surrounding islands. At Kulumadau, near the centre of the island, the average annual rainfall is 180 inches. The monthly rainfall ranges from 5 to 30 inches, with less rain in November than other months.

A European family living at Kulumadau maintains daily radio contact with Samarai. About 1000 indigenes live on the island in villages of up to 130 persons, and as small family groups. Irregular supplies of fish, fruit, and vegetables can be purchased with cash, tobacco, or trade goods.

Most of the bridges on the roads connecting Kulumadau with the old mining centres of Busai, Reillys Creek, Karavakum, and Bonivat have collapsed.

Kwaiapan Bay, the port for Kulumadau, is a sheltered anchorage used by small ships, and ships of larger tonnage can shelter in Suloga Harbour, about 10 miles east of Kwaiapan Bay. The M.V. Yelangili, a 60-foot coastal vessel, maintains a monthly service between Samarai and Woodlark. A grass airstrip is located at Guasopa, at the eastern end of the island. Although there is no regular service, passengers and freight can be flown to Woodlark, as an extension of the service from Port Moresby to the Trobriand Islands, but the Department of Civil Aviation must be advised well in advance of proposed landings at Guasopa.

### Field Work

A Bureau of Mineral Resources field party, consisting of a geologist (D.S. Trail), a chemist (A.G. Fricker), a survey hand, and 22 labourers, worked on the island from May to September 1960.

The geologist mapped about 50 square miles of Tertiary volcanic rocks in the central-southern part of the island, which contains all the known gold and copper-iron mineralization. The geology was plotted on 1:20,000 vertical air-photographs taken by the U.S. Army Air Force in 1943, and the map compiled by the U.S. Army Corps of Engineers served as a base map. Vertical air-photographs at 1:30,000 scale, taken by the U.S. Army Air Force in 1948, were also available. Geological interpretation from the air-photographs is limited by the thick forest cover and the lack of differential erosion.

Geological observations were made along the coast and creek beds. In the steep hills in the south, outcrops are rare but fresh rubble is abundant; in the low hills in the centre of the island, the rocks are deeply weathered. The approximate heights of prominent hills were determined with aneroid barometers.

The chemist tested a number of geochemical methods for detecting copper, lead, and zinc under the prevailing conditions of high rainfall and rapid runoff. Analyses of soils proved most successful and this method was applied to several areas of gold and copper-iron mineralization by close sampling with hand augers. At Loluai and Norac on the Suloga Peninsula, the copper values were contoured to indicate anomalous areas possibly related to concealed mineralization. The details of the geochemical investigations have been presented separately (Fricker & Trail, 1961), but the main results are included in this Report.



Geological and geophysical investigations carried out between 1960 and 1962 by officers of the Department of Lands, Surveys, and Mines of the Territory of Papua and New Guinea are recorded briefly in the Appendix.

### Previous Investigations

E.R. Stanley (1912) carried out the first geological investigation of the mines and prospects on Woodlark Island. His report includes the regional geology, and detailed description of many gold mines and prospects. Other reports on mining and mineral deposits on Woodlark have been made by Newman (1912), Rich (1936), Gray (1952), the Broken Hill Proprietary Co. Ltd (1956), Thompson (1960), and Fricker & Trail (1961).

In 1955, Adastra Hunting Geophysics Ltd carried out an aeromagnetic survey of the Suloga Peninsula for Broken Hill Proprietary Co. Ltd.

### PHYSIOGRAPHY

Woodlark Island is located on the crest of a well defined broad rise in the sea-floor; the rise trends about 100° and extends for 250 miles from the Lusancay Reefs in the west through the Trobriand Islands, the Marshall Bennett Islands, Woodlark, and Cannac Island, to the Laughlan Islands in the east.

Woodlark Island consists of a broad subcircular platform of coral limestone built asymmetrically around the eroded remnant of a Miocene volcanic pile. The platform, 30 to 40 miles in diameter, is tilted gently to the south, where it is submerged and supports living coral and a few islets of coral sand.

The south coast of Woodlark, where the platform emerges from the sea, is low and covered by mangrove swamp, except where the core of Miocene rocks forms the steep and hilly Suloga Peninsula, the highest part of the island, which rises 1100 feet above sea level. The peninsula trends north-west for about 5 miles, and Nasai Island lies on the same trend. North-east of the peninsula the Okiduse Range extends inland for 5 miles, diminishing in height towards the centre of Woodlark.

From the south coast, the coral platform slopes gently upwards to the cliffs along the north coast, which rise to a maximum height of 300 feet. The terraces, escarpments, and well defined depressions in the limestone surface, which are visible on the air-photographs, suggest that uplift of the coral platform may have been due to spasmodic and differential movements along fault planes. Remnants of a coral reef are preserved 380 feet above sea level on Kulumadau Hill in the centre of the island.

The isolated and steep hills at Mount Kabat and Manau Hill are eroded vents. No vents were recognized in the Okiduse Range or on the Suloga Peninsula, but the zone of steeply dipping rocks forming the south-east margin of the Okiduse Range may represent the eroded wall of a caldera.

In the Tertiary rocks and most of the coral platform, the creeks occupy shallow steep-sided valleys. East of the Okiduse Range, the Sinkurai River flows in broad meanders, incised down to about 50 feet in Recent marine clays which elsewhere underlie the coral. The rejuvenation of the drainage is probably a result of the latest recession of the sea, when a large part of the coral platform emerged.

## STRATIGRAPHY

The stratigraphy of Woodlark Island is summarized in Table 1.

TABLE 1 : STRATIGRAPHY OF WOODLARK ISLAND

Age	Formation	Thickness (ft)	Description
QUATERNARY		300+	Swamp mud, alluvium, coral limestone, marine clay, conglomerate
----- UNCONFORMITY -----			
	( (Nasai Limestone	600+	Massive limestone
	(----- INTRUSION OF GRANITE AND DYKES -----		
	(Okiduse Volcanics	2000+	Agglomerate, conglomerate, lava, tuff, siltstone mudstone;
	(		tuff, tuffaceous siltstone;
LOWER	(Wonai Hill Formation	850	conglomerate
	(		
	(----- UNCONFORMITY -----		
	(		
MIOCENE	(----- INTRUSION OF DOLERITE -----		
	(		
	(Tabukui Beds	1800	Tuff, tuffaceous siltstone, mudstone; conglomerate
	(		
	(		
	(Suloga Limestone	500	Massive limestone
	(----- UNCONFORMITY -----		
TERTIARY(?)	Loluai Volcanics	1500+	Thermally metamorphosed tuffs and lavas; some fine-grained sediments

The Tertiary rocks represent a period of almost continuous volcanic activity, mainly in lower Miocene time, during which a volcanic island or island group was created. Prolonged lulls in vulcanism are represented by fine-grained clastic sediments, limestone, and coarse alluvial deposits.

### Tertiary(?)

#### Loluai Volcanics

Near Suloga Point the Loluai Volcanics are overlain, probably unconformably, by lower Miocene limestone. The similarity of the Loluai Volcanics to the Tertiary volcanic rocks higher in the succession suggests that they are of Tertiary age.

Interbedded volcanic rocks and fine-grained sediments crop out on the shore east and west of Loluai. The volcanics are dark grey to black massive rocks, and are commonly sheared and indurated. They are cut by irregular veins of epidote and a few quartz veins.

The volcanic rocks include fine-grained tuffs, lavas, pillow lavas, and thin agglomerates; the rocks have commonly been partly recrystallized and their textures partly obliterated.

The volcanics consist mainly of pyroxene andesite or andesitic basalt. They are composed of altered calcic andesine and uraltized pyroxene; fresh pyroxene is rare, but magnetite and pyrite are abundant. Epidote veins are common.

The sediments interbedded with the Lolui Volcanics include green, grey, red, and cream indurated siltstone and mudstone, with some shale and a few thin beds of quartzite. The sediments are well laminated, and individual beds are commonly less than 1 foot thick. The thin beds and nodules of blue-grey chert in the Lolui Volcanics do not persist laterally, and locally exhibit slump structures. Ironstaining is common in the weathered sediments, and some thin beds of quartzite contain small lenses of rusty or steely black hydrated iron oxides. The sedimentary members range from a few feet to 400 feet in thickness, but only the thicker units are shown on Plate 1.

North of Lolui, the sedimentary members of the Lolui Volcanics are separated by sills of medium-grained dolerite. The beds do not appear to have been disturbed by the intrusions.

Pillow lava and agglomerate crop out on Suloga Point at the south-eastern end of Suloga Peninsula. The dark and fine-grained pillow lava contains pillows up to 8 feet long. It consists of andesitic basalt, composed of uraltized pyroxene and altered andesine; epidote veins are common. The agglomerate is subordinate; it consists of subrounded fragments of basaltic volcanics, up to 6 inches in diameter, set in a fine-grained indurated tuffaceous matrix.

Mapas Island,  $1\frac{1}{2}$  miles north-east of Suloga Point, consists mainly of dolerite containing large inclusions of indurated basalt, some of which show vague relics of pillow structure. On the southern shore of the island there are a few large boulders of cherty siltstone.

The Wasilas area, north-east of Mapas Island, is composed of andesitic basalt, similar to the volcanics at Lolui. Although locally metamorphosed by large granite dykes, the pillow structure and epidote veins are preserved by some of the rocks, particularly at Seota Point. On the shore north-east of Wasilas Point the volcanics contain boulders of cherty siltstone.

Since the altered volcanics at Wasilas, Suloga Point, and Lolui are similar they have been grouped together as the Lolui Volcanics. The exposed thickness of the volcanics at Wasilas is about 1500 feet. The thickness of the volcanics is uncertain at Lolui because of the presence of thick dolerite sills. The base of the Lolui Volcanics was not seen. At Lolui, they are overlain unconformably by tuffs of the Wonai Hill Formation. The Lolui Volcanics are probably unconformable with the Suloga Limestone at the southern end of the Okiduse Range, but the contact is concealed.

PLATE 1

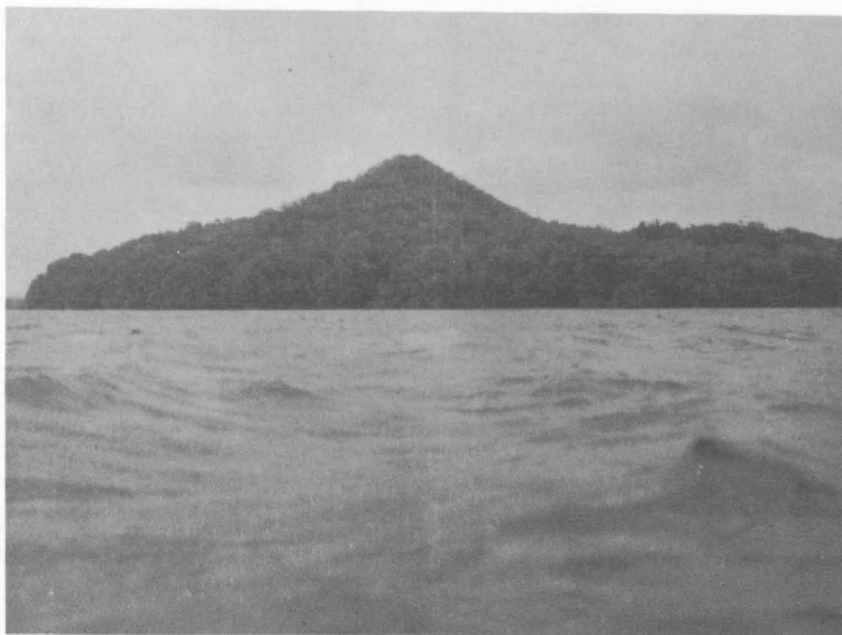


Fig. 1. Manau Hill, an eroded volcanic vent

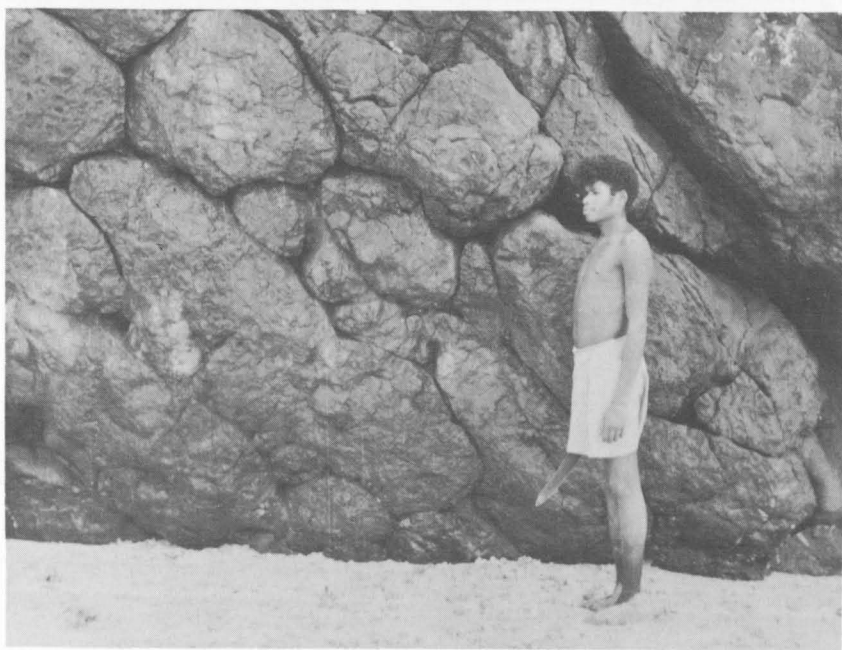


Fig. 2. Pillow lavas in Loluai Volcanics, near Suloga Point

## Miocene

### Suloga Limestone

The Suloga Limestone is well exposed in low cliffs along the coast on the west side of Suloga Point. Small exposures also occur in the low-lying country west of the mangrove swamp between Suloga Point and Wabeo Point, and along the south-eastern flank of the Okiduse Range.

The limestone is dark grey to black and fine-grained; it is massive when fresh but shows bedding on weathered surfaces. Lower Miocene Foraminifera (D. Belford, BMR, pers. comm.) are common in the Suloga Point outcrop. Small pyrite crystals occur in the matrix and in thin calcite veins.

About 500 feet of the Suloga Limestone are exposed on the south-eastern flank of the Okiduse Range. The limestone thins to the west of the range, and at Suloga Point it has in places been removed by erosion before deposition of the succeeding formation. This period of erosion may also account for the absence of the Suloga Limestone near Loluai. In the Okiduse Range, the limestone grades upwards through calcareous siltstone to the fine-grained tuff of the Tabukui Beds, with no intervening basal conglomerate; so deposition was presumably continuous.

### Tabukui Beds

The Tabukui Beds occupy most of the south-eastern part of the Suloga Peninsula, including Tabukui (1120 feet above sea level), the highest hill on Woodlark Island. The Tabukui Beds are predominantly green-grey fine-grained and very fine-grained tuff with subordinate siltstone and thin beds of red mudstone. They are massive to well laminated, usually cleaved, and invariably hard and tough.

Thin lenses of volcanic conglomerate and agglomerate are common and a large lens of conglomerate, 800 feet thick and about 1000 yards long, forms the base of the formation near Suloga Point. The conglomerate is a dark grey massive rock with subangular to rounded pebbles, ranging up to 6 inches in diameter, set in a poorly sorted tuffaceous matrix. The dark glassy pebbles, with a few small phenocrysts of calcic andesine and pyroxene, may represent volcanic bombs and lapilli. The matrix of the conglomerate is composed of a poorly sorted aggregate of angular fragments of labradorite and uralitized pyroxene; pyrite is common throughout.

Typically, the tuffs are composed of angular fragments of andesine, uralitized pyroxene, and some amphibole set in a fine-grained matrix of amphibole and sericitized plagioclase. Pyrite is abundant in the Tabukui Beds and some of the tuffs weather to limonite beds. The tuffs near the base of the formation contain small calcite crystals and Globigerina(?).

The stone axe-heads, known as 'suloga' and formerly used by natives throughout the east Papuan islands, are made of indurated tuff from the Tabukui Beds. Heaps of flakes chipped from axe heads and other stone tools are common on the peninsula.

In the Okiduse Range the exposed thickness of the Tabukui Beds is about 1800 feet. At Tabukui the formation is about 1400 feet thick; it thins northwards to about 800 feet

where it is in contact with the Wonai Hill Formation. Towards Loluai, the thickness of the Tabukui Beds was reduced by erosion to about 200 feet before the Wonai Hill Formation was laid down.

At Suloga Point, the basal conglomerate of the Tabukui Beds lies directly and probably unconformably on the Suloga Limestone. To the north, the fine-grained members of the Tabukui Beds rest on the limestone, and in the Okiduse Range the tuff of the Tabukui Beds grades downwards into the calcareous siltstone at the top of the limestone formation.

The contact between the Tabukui Beds and the Loluai Volcanics east of Loluai is not exposed. Since the low-lying tuff of the Tabukui Beds appears to strike directly into the high outcrop of the Loluai Volcanics, a fault has been postulated between the formations.

#### Wonai Hill Formation

The Wonai Hill Formation occupies the high ground in the centre of the Suloga Peninsula, culminating in Wonai Hill, about 1000 feet above sea level. This broad gently dipping outcrop extends north-east as a narrow more steeply dipping belt, striking across Suloga Harbour and along the south-eastern front of the Okiduse Range.

Between Wonai Bay and the Ben mining centre, on the west side of Suloga Harbour, the basal member of the Wonai Hill Formation is a group of tuffaceous rocks; they are typically blue-grey, fine-grained to medium-grained, massive to well bedded, and apparently unmetamorphosed. They are composed of fragments of calcic andesine and partly or wholly uraltized pyroxene crystals set in a microcrystalline matrix containing much disseminated pyrite. Thin beds of tuffaceous siltstone, shale, and conglomerate are interbedded with the tuffs.

At the Ben mining centre, a thick bed of volcanic conglomerate overlies the Tabukui Beds and grades upwards into typical tuffs of the Wonai Hill Formation. The basal conglomerate is a dark brown-grey rock composed of subangular to subrounded fragments of volcanic rocks, ranging up to 6 inches in diameter, set in a poorly sorted tuffaceous matrix. The fragments, which are glassy and contain a few small phenocrysts of uraltized pyroxene and plagioclase, are probably volcanic bombs and lapilli. The matrix of the conglomerate consists of an aggregate of fresh pyroxene, uraltite, and saussuritized plagioclase, with thin lenses of calcite and a calcitic cement.

Around the summit of Wonai Hill the tuffaceous member of the Wonai Hill Formation is succeeded by a mudstone member. The mudstone is a black very fine-grained uniform and massive rock with a few silty lenses. It consists of a microcrystalline aggregate of quartz and feldspar with a few lenses of calcite, some thin black carbonaceous bands, and scattered small foraminifera.

In the narrow extension of the outcrop to the north-east of the Ben mining centre the tuffaceous member thins and the conglomerate thickens. In the Okiduse Range the mudstone member lies directly on the conglomerate. Between the Ben mining centre and the summit of Wonai Hill, the tuffaceous member is about 600 feet thick; it thins north-westwards to about 200 feet at Wonai.

The conglomerate member attains a maximum thickness of about 300 feet in the Okiduse Range. The thickness of the mudstone is constant at about 250 feet throughout its outcrop.

North of Loluai, the tuffs of the Wonai Hill Formation rest on an irregular eroded surface of Loluai Volcanics and dolerite. East of Loluai, the Wonai Hill Formation and the Tabukui Beds are separated by a disconformity. A disconformity may also occur at the base of the conglomerate in the Okiduse Range.

The mudstone member is succeeded in the Okiduse Range by green-grey fine-grained tuff and tuffaceous siltstone belonging to the Okiduse Volcanics, but westwards, towards Wonai Bay, the mudstone is overlain by conglomerate.

#### Okiduse Volcanics

The green-grey tuffaceous rocks overlying the mudstone of the Wonai Hill Formation form the discontinuous basal member of the Okiduse Volcanics. They are banded, hard and tough, and strongly resemble the tuffs of the Tabukui Beds.

A large lens of these green-grey tuffaceous rocks in the Okiduse Range and the Suloga Peninsula is succeeded by a thick group of dark grey lava, tuff, and volcanic agglomerate and conglomerate. These volcanics form the bulk of the Okiduse Range, and the large inliers in the Quaternary sediments at Busai and Kulumadau. The rocks of Manau Hill and Mount Kabat have been grouped with the Okiduse Volcanics.

The Okiduse Volcanics are massive porphyritic and non-porphyritic rocks. They consist predominantly of andesitic basalt composed of calcic andesine and pyroxene, commonly altered to uranalite or actinolite. Calcite pseudomorphs after plagioclase and pyroxene are common. Pyrite is common to abundant, and leucoxene is present in places. In the conglomerate and agglomerate, the fragments may be angular or well rounded and range from 2 feet in diameter down to coarse tuff. The tuff is a fine-grained indurated rock, indistinguishable in hand specimen from the lava, and can only be identified where it is associated with agglomerate and conglomerate.

A few light grey rocks in the Okiduse Volcanics may be of dacitic composition.

The Okiduse Volcanics have a maximum exposed thickness of 2000 feet. The rocks have been subjected to prolonged erosion since Miocene time and the underlying coarse-grained granites exposed; the original thickness may therefore have been considerably greater.

The volcanic agglomerates are irregularly distributed in the main outcrop of the Okiduse Volcanics; they were probably erupted from nearby vents, but the vents have not been identified.

The three isolated outcrops of coarse-grained volcanics at Kulumadau, Mount Kabat, and Manau Hill may represent the youngest centres of volcanic activity.

At Kulumadau, a triangular mass of volcanic conglomerate about 500 yards long rests on lavas or tuffs. Abundant oyster shells and carbonized wood were found in a boulder of medium-grained tuff in the conglomerate. The conglomerate is probably one of the youngest members of the Okiduse Volcanics and may lie near the centre of latest activity at Kulumadau.

Mount Kabat, an isolated hill 4 miles east of Kulumadau, is probably an eroded remnant of one of the latest volcanic vents. The mountain consists of coarse volcanic agglomerate and conglomerate composed of angular and rounded fragments, which range up to 2 feet in diameter, in a medium-grained fragmental matrix. The fragments are black, and very fine-grained; they contain small phenocrysts of feldspar and pyroxene in a glassy groundmass.

Manau Hill, on the north side of Wonai Bay, is also an eroded vent of the youngest eruptive phase. The well-defined circular vent, filled with coarse volcanic breccia, is surrounded by volcanic agglomerate and well-bedded tuff.

#### Nasai Limestone

Nasai Island and the western end of the Suloga Peninsula are composed of gently dipping lower Miocene limestone resting with marked unconformity on the Loluai Volcanics and the associated dolerite sills.

The weathered Nasai Limestone is light grey and well bedded. The fresh rock is dark grey to black, very fine-grained, massive, and hard. Lower Miocene foraminifera are locally abundant. No pyrite is visible in the Nasai Limestone, it is unaffected by the volcanic and other igneous activity, and contains no detrital or pyroclastic material. It is thought to be younger than the Okiduse Volcanics, though its field relationships indicate only that it is younger than the intrusion of the dolerite. The maximum exposed thickness is about 600 feet.

#### Quaternary

Along the south-east and north-west flanks of the Okiduse Range, around the large volcanic outcrop containing Busai and Reillys Creek, and at the north end of the Kulumadau inlier, the volcanic rocks are overlain unconformably by soft blue marine clay and silt containing large thick lenses of boulder and pebble conglomerate. The abundant marine macrofauna found in some of the clays is apparently Recent; other clays contain carbonized wood and seeds.

At McKenzies Creek, the clay becomes more calcareous upwards and grades into the overlying coral limestone. At Busai and in Reillys Creek, the coarse conglomerate in the clay has been successfully worked for gold.

East of the Okiduse Range, the Sinkurai River and its tributaries reveal extensive exposures of blue marine clay and interbedded conglomerate. The plain of the Sinkurai River is probably composed dominantly of clay, with little overlying coral. West of the Okiduse Range, the clay is probably little more than 50 feet thick, but in the plain of the Sinkurai River, the clay may be hundreds of feet thick.

Raised coral limestone forms the bulk of Woodlark Island. The rock is yellowish white and is commonly recrystallized to coarse calcite. Coral remains and marine shells are found locally. Caves and sinkholes are common throughout the limestone outcrop.

Along the north coast, the coral is more than 300 feet thick. In the centre of the island it is about 50 feet thick, and many creeks have cut through the limestone into the underlying clay. The limestone is thin or absent along the south coast of the central part of the island. Large areas of the low coral platform are covered by a thin layer of swamp mud composed almost entirely of organic material.



PLATE 2

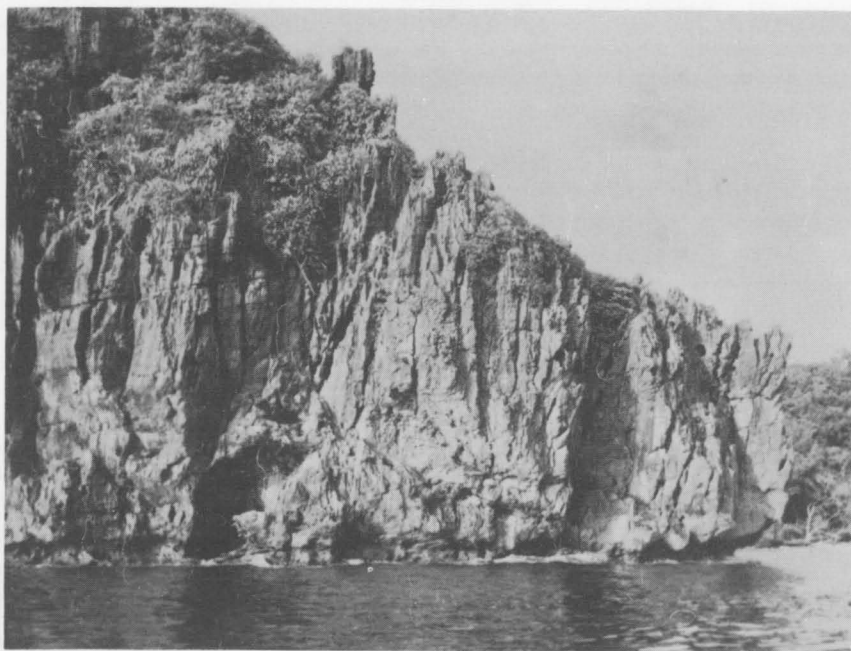


Fig. 1. Nasai Limestone, west coast of Nasai Island



Fig. 2. Excavating an old ore dump at Norac

Around the volcanic outcrops, fine and coarse-grained sediments containing alluvial gold have accumulated on top of the coral limestone. Stanley (1912) recorded that at Busai in a sandy loam below the surface clay a stone pestle and mortar were found. These implements are unknown to the present inhabitants of Woodlark Island (R.C. Neate, pers. comm.).

### IGNEOUS ACTIVITY AND ASSOCIATED METAMORPHISM

The dolerite sills in the Loluai Volcanics and the Tabukui Beds are the earliest intrusives. The granitic intrusions described by Stanley (1912) range from granite to diorite; they vary considerably in texture and intrude all the formations older than the Nasai Limestone. Lamprophyre dykes are confined to a small area about a mile east of Wonai Bay, and basalt dykes are associated with the young volcanics at Mount Kabat. The volcanics and sediments in contact with the dolerite and granitic rocks have in places been metamorphosed. Uralitization and epidote veining are more widespread in the volcanics.

#### Vent Breccia

Manau Hill is a circular vent about 400 yards in diameter, filled with coarse breccia. The vent is surrounded by conglomerate, agglomerate, and bedded tuff. The breccia is composed of large angular blocks of reddish porphyritic andesite or basalt set in a matrix of small rock fragments.

#### Dolerite

Between Loluai and Wonai Bay, the sedimentary members of the Loluai Volcanics are separated by dolerite sills containing many irregular blocks of basic volcanic rock. Uskweilele, a hill above Suloga Point, is capped by a dolerite sill overlying pillow lavas of the Loluai Volcanics, and about 1 mile north of Uskweilele on the eastern slope of Tabukui sill-like masses of dolerite have invaded the conglomerate member at the base of the Tabukui Beds. The dolerite sill on Uskweilele probably occurs in the position of the conglomerate. Mapas Island is composed almost entirely of dolerite.

The dolerite is a dark grey medium-grained massive rock with many xenoliths of basic volcanic rock. The feldspar is greenish grey and forms about 50 percent of the rock. Many specimens contain abundant magnetite. The rock has an ophitic texture with laths and plates of sodic labradorite partly embedded in large plates of augite. A little of the pyroxene has been replaced by green amphibole, and a little interstitial quartz is present. At Mapas, veins of epidote occur in the dolerite.

The dolerite sills near Loluai have a total thickness exceeding 2000 feet, but the sill east of Tabukui is less than 300 feet thick. The form of the dolerite intrusion at Mapas is unknown.

Between Loluai and Wonai Bay, large and small masses and blocks of basic volcanic rock are abundant in the dolerite, and the exposures commonly range from fine-grained dolerite to coarse-grained basalt. Since the sediments of the Loluai Volcanics are little disturbed by the intrusion of the dolerite, a considerable part of the large mass of dolerite separating the sediments may be basic volcanic rocks which have been recrystallized by the dolerites.

The fine-grained and coarse-grained members of the Tabukui Beds in contact with the dolerite are no more indurated than those distant from obvious igneous intrusives. The small intrusive mass of quartz in the conglomerate at the old Suloga mining centre may be a differentiate of the dolerite.

Skarn rock is developed at the margin of the dolerite sill complex at Loluai and at Watavai Creek, 600 yards north-east of Loluai. Skarn rock also occurs at Norac, on the west shore of the south-east arm of the Suloga Peninsula. Samples of skarn from Norac were found to contain 0.2 to 6 percent copper. The dolerite sill emplaced in the conglomerate member of the Tabukui Beds  $1\frac{1}{2}$  miles east of Norac, is the only large intrusive body exposed near the Norac skarn and copper-iron mineralization.

The skarn is a reddish massive friable rock composed of garnet crystals with fine-grained interstitial epidote, and some quartz and calcite; pyroxene is rare.

The skarn rock at Loluai and Norac has probably been produced by contact metamorphism and metasomatic alteration of limestone. Harker (1950) records that iron from igneous intrusives may combine with limestone to form garnet. The conversion of limestone to garnet rock involves considerable reduction in the volume, and excess iron and other ore minerals are deposited in pore spaces created by the reduction in volume. Magnusson (1936) has suggested a similar mode of formation for the skarn iron ores of central Sweden.

The contact of the dolerite with the Suloga Limestone, which crops out from Wabeo Point for about  $1\frac{1}{2}$  miles south towards Uskweilele, is not well exposed, but there appears to be a sharp contact between the medium-grained dolerite and the limestone, which has been recrystallized but otherwise unaffected by the intrusion. No skarn is developed in the limestone.

The magnetite bodies in the skarn outcrops at Loluai and Norac have been described in detail by Thompson (1960). The near-vertical dyke-like lodes range from 5 to 50 feet wide, and trend about  $170^{\circ}$ . They are composed of massive and crystalline magnetite and hematite, with small quantities of garnet, epidote, quartz, pyrite, chalcopyrite(?), and secondary copper minerals. The magnetite boulders on Mapas are probably derived from a similar body. The magnetite bodies represent concentrations of the late fugitive constituents of the dolerite magma, and have probably been deposited in tension fissures. Magnusson (1936) suggests that such concentrations may form at relatively low temperatures.

In Elliotts Creek, near Wonai, the contact between dolerite and granite is gradational, and the hybrid medium-grained dioritic rock along the margin of the granite has apparently been formed by reaction with the dolerite.

#### Granite, Porphyry, and Felsite

In the Okiduse Range and the Wasilas area, almost the whole of the Tertiary succession has been intruded by large and small dykes and dyke-like masses of granite and porphyry. The intrusives extend westwards into the Suloga Peninsula and northwards into the Busai inlier. Felsite dykes intrude the volcanic rocks at Kulumadai.

A coarse-grained biotite-hornblende granite with elongated xenoliths of basic volcanic rock crops out at Granite Point. The granite contains laths of hornblende up to 3mm long and plates of biotite scattered through a medium-grained groundmass of orthoclase, albite, and minor quartz and pyrite. In many exposures large aggregates of corroded hornblende crystals adjoin ill defined basic xenoliths and broad veins of acid rock. Some of the hornblende at least appears to have been derived from pyroxene during intrusion of acid magma into pyroxene-bearing andesitic basalts. In one exposure a medium-grained felsic leucocratic granite cuts the typical coarse-grained hornblende granite.

Most of the intrusive bodies in the Okiduse Range, the Wasilas area, Suloga Peninsula, and the Busai inlier are medium-grained hornblende granites with associated porphyries. The porphyries contain phenocrysts of feldspar and mafic minerals set in a fine-grained groundmass. Biotite granite is rare.

These yellow-weathering medium-grained hornblende granites, though commonly lacking biotite, resemble in hand specimen the granite of Granite Point. They are quite unlike the dark fine-grained Okiduse Volcanics, yet the contact between the large masses of granite and the volcanics is rarely distinct.

In many places, the contact between the granite and the volcanics is occupied by a thick body of porphyry which grades into the volcanics but which has a sharp contact with the granite. In the gradation towards the granite, the groundmass of the volcanics becomes increasingly felsic, the feldspar crystals increase in size, and the dark minerals form clumps of enlarged corroded crystals. The porphyries are hybrid rocks formed by metasomatism of the volcanics during the intrusion of the granite.

However, many of the large bodies mapped as intrusive rocks are composed almost entirely of similar porphyry, and masses of porphyry are common within the large granite bodies. Although the porphyries may all be metasomatized volcanic rocks, they are so intimately associated with the granite that they have not been differentiated on the map.

In the Wasilas area, where the Loluai Volcanics are intruded by granite dykes, medium-grained diorite commonly occupies a zone a few feet wide around the margins of the dykes. In places a narrow zone of ultrabasic rock, probably pyroxenite, occupies the contact between this diorite and the volcanics.

Felsite boulders are abundant in the creeks on the north-west side of the central part of the volcanic outcrop at Kulumadau. No exposure of felsite was found, but the boulders have probably been derived from dykes forming ridges between the creeks. The felsite is typically composed of laths of feldspar up to 5mm long in a blue-grey very fine-grained matrix. The boulders of quartz in the creeks may be associated with the felsite.

Most of the granite contacts observed are vertical; none is inclined at less than  $60^{\circ}$ .

On Suloga Peninsula, granite bodies strike between  $040^{\circ}$  and  $080^{\circ}$  towards the granites of the Okiduse Range. In the Wasilas area, and in the Okiduse Range, the granite contacts trend predominantly between  $120^{\circ}$  and  $150^{\circ}$ . In the hills around the headwaters of the Sinkurai River the granite intrusives appear to be in a semicircle centred near the boundary of Tertiary and Quaternary rocks on the Sinkurai River.

### Minor Intrusions

Diorite dykes are common in the Lolui Volcanics along the shore both east and west of Lolui. On the shore, 1 mile east of Lolui, two diorite dykes cut the Tabukui Beds. The intrusion at Norac described by Thompson (1960) as a granodiorite may be a similar dyke. The dykes are porphyritic or non-porphyritic fine-grained and medium-grained rocks. The porphyritic dykes have a microcrystalline groundmass of saussuritized feldspar laths and dark minerals, and phenocrysts of andesine and hornblende; pyrite and magnetite are accessory.

The diorite dykes range from a few feet to about 20 feet in thickness, and trend between  $160^{\circ}$  and  $180^{\circ}$ . Their contact with country rock is commonly irregular though abrupt. Some dykes show marginal chilling; others are even-grained throughout their width. They may be related to the hornblende granite. Lamprophyre dykes from 10 to 20 feet wide and with various trends intrude the mudstone member of the Wonai Hill Formation and the adjacent granite east of Wonai Bay. The dykes are grey, very fine-grained, and porphyritic. In places they contain biotite phenocrysts; elsewhere they consist of hornblende phenocrysts set in a feldspathic groundmass.

Half a mile west of Suloga Point, two dykes of light grey very fine-grained dacitic rock, each less than a foot thick, cut the Suloga Limestone. They trend  $005^{\circ}$ ; one dips at  $45^{\circ}$  to the east and the other is vertical.

Poorly exposed basaltic dykes, up to 25 feet thick, cut the volcanic agglomerate and conglomerate at Mount Kabat. One trends at  $160^{\circ}$ . They are black and very fine-grained, with phenocrysts of a bronze-coloured dark mineral.

In a large creek, 1200 yards east of Lolui, a dyke of black coarse-grained hornblende pyroxenite, about 2 feet wide and trending at  $170^{\circ}$ , cuts tuff of the Wonai Hill Formation. The pyroxenite is composed almost entirely of large crystals of augite and brown hornblende, with a few altered feldspar crystals, set in a sparse groundmass of light green amphibole.

### Metamorphism

The silicification of the sediments in the Lolui Volcanics may be due to hydrothermal solutions associated with mildly active volcanoes, or with the intrusion of the dolerite.

Epidote veins are almost confined to the volcanic members of the Lolui Volcanics. The veins may have been formed before the dolerite intrusion, or they may have resulted from the metamorphism of calcite veins by the dolerite.

In most of the thin sections of the volcanic rocks, the pyroxene has been completely or partly altered to amphibole, commonly uraltite. Uralitization of pyroxene may be a normal process undergone by igneous rocks while cooling (Harker, 1950), but the fine-grained Tertiary volcanic rocks of Woodlark Island presumably cooled rapidly, and the pyroxene was probably not altered until later, by thermal metamorphism. The widespread replacement of pyroxene by uraltite throughout the volcanic succession indicates that all these rocks have been more or less uniformly affected.

The volcanics of Woodlark Island occupied a deep level in a large active volcanic complex. The uralitization of the pyroxene in all the rocks and the indurated appearance of many of the volcanics are probably not related to a single phase of intrusive igneous activity, but may be the results of repeated reheating of the volcanic complex beneath a thick blanket of younger volcanic rocks which has since been removed by erosion.

### STRUCTURE

Regular folding is confined to the Loluai Volcanics and steep dips appear to be confined to a monoclinical zone along the south-east flank of the Okiduse Range. Lack of bedding and the paucity of exposure hinder structural interpretation. Faults, in particular, are difficult to locate and only a few could be mapped.

At the west end of the Suloga Peninsula, in the Loluai Volcanics, the general northerly dip steepens steadily from  $10^{\circ}$  on the coast west of Loluai to  $40^{\circ}$  at Wonai. Within this regional structure, the rocks are folded into gentle synclines and anticlines pitching north and dipping gently north-east and north-west. The copper-bearing skarn at Loluai lies in the trough and along the west limb of a gentle syncline within this system. The fold pitches north at about  $15^{\circ}$  and the limb dips about  $15^{\circ}$  north-east.

The folding of the sedimentary members and the shearing and veining of the volcanic members of the Loluai Volcanics apparently preceded the deposition of the Suloga Limestone.

Along a zone of steep dips extending inland from Suloga Harbour along the south-east flank of the Okiduse Range, the Tabukui Beds dip northwards at  $40^{\circ}$  to  $80^{\circ}$ . Farther north, the conglomerate and mudstone of the Wonai Hill Formation dip at about  $30^{\circ}$  to the north, and the regional dip decreases northwards to subhorizontal in the Okiduse Volcanics. In the Suloga Peninsula along the westward extension of this zone of steep dips the Tabukui Beds are cleaved where they dip gently under the Wonai Hill Formation, and dips are horizontal again a short distance to the north. The basal conglomerate member of the Wonai Hill Formation on the west side of Suloga Harbour also dips north at about  $50^{\circ}$ .

The steep dips may be the result of caldera collapse rather than lateral compression. To indicate this diagrammatically, a normal fault in the older and possibly more competent Loluai Volcanics beneath the Tabukui Beds is shown in section GH (Pl. 3). The collapse may have followed the first eruptions of the Okiduse Volcanics from a centre north of the zone of steep dips. The weight of the pile of pyroclastics on the country to the north, combined with the expulsion of a large volume of lava from the underlying magma chamber, may have resulted in large-scale subsidence bounded by faults or steep monoclines.

At Suloga Point, the Suloga Limestone abuts against the Loluai Volcanics along a north-trending fault with a vertical displacement of about 200 feet. This fault was probably active during deposition of the Suloga Limestone, but subsidence had ceased before the basal conglomerate of the Tabukui Beds was deposited.

A north-trending fault with a vertical displacement of about 100 feet extends from the coast at Loluai along the upper valley of Loluai Creek. The fault is defined by a low scarp of skarn forming the west bank of the upper part of Loluai Creek; the presence of a fault is also indicated by the abrupt change in the copper content of the soils on either side of Loluai Creek from 100 ppm on the east to 2000 ppm on the west (Trail & Fricker, 1961). This fault forms the east boundary of the cupriferous skarn at Loluai and is also the western limit of the Wonai Hill Formation.

One mile east of Loluai, a north-trending fault with a vertical displacement of about 200 feet has been inferred to explain the relative positions of the Loluai Volcanics and the Tabukui Beds. This fault has probably not been active since the deposition of the Wonai Hill Formation.

A fault trending about  $080^{\circ}$  and dipping  $45^{\circ}$  north cuts the Loluai Volcanics on Nasai Island. Another fault trending at  $140^{\circ}$  to  $160^{\circ}$  and dipping  $70^{\circ}$  east was seen in the Nasai Limestone on the west coast of Nasai Island. The vertical displacement on the faults is unknown.

Indications of faulting and shearing, mainly with trends between  $160^{\circ}$  and  $180^{\circ}$ , are common throughout the Okiduse Volcanics. The gold-bearing lodes have the same trend and consist of zones of blue pug occupying faults or shear-zones ranging from a few inches to 100 feet wide.

Almost all the faults observed on Woodlark Island trend between  $160^{\circ}$  and  $180^{\circ}$ ; this is also the strike of the magnetite lodes, and the diorite dykes of the Suloga Peninsula. The consistent northerly trend of the faults and dykes suggests regional east-west tension.

A small hot spring, temperature about  $100^{\circ}\text{F}$ , near the boundary between Tertiary volcanics and Quaternary limestone at Karavakum is probably related to a fault rather than to waning volcanic activity. Mild earthquakes in 1960 indicate that the island is still tectonically active.

Van Bemmelen (1949) locates Woodlark Island on a non-volcanic outer arc of the D'Entrecasteaux orogenic system, extending from the Lusancay Reefs to the Laughlan Islands, complementing a volcanic inner arc along the 'tail' of Papua and the D'Entrecasteaux Islands. This interpretation seems unlikely as Woodlark Island is composed entirely of volcanics, clastic sediments derived from the volcanics, and limestone. The nearby island of Cannac, also on van Bemmelen's proposed non-volcanic arc, is also probably composed of volcanic rocks, for Stanley (1917b) stated that the rocks of Cannac are similar to those on the south coast of Woodlark Island.

The Lusancay/Laughlan submarine swell may be a drowned and eroded belt of Tertiary volcanoes, with the same trend as the belt of dormant Recent volcanoes which extends from Dobu to Goodenough Island, in the D'Entrecasteaux group.

### GEOLOGICAL HISTORY

The Suloga Limestone, near the base of the Tertiary succession on Woodlark Island, and the Nasai Limestone possibly at the top of the Tertiary succession, both contain lower Miocene Foraminifera (D. Belford, BMR, pers. comm.). Most of the Tertiary rocks of Woodlark Island were therefore probably extruded or deposited in a comparatively short time.

In the lower Miocene the site of Woodlark was occupied by a group of volcanic islands subject to alternating rapid growth during eruptive periods and rapid erosion to low islands, shoals, and shallow submarine platforms when the volcanoes were dormant. Coral reefs also grew around the islands.

The remarkable growth and denudation of Krakatau (van Bemmelen, 1949) and Isla San Benedicto (Richards, 1959) in the last century demonstrate the rapidity with which a group of volcanic islands may spectacularly change their form.

During the deposition of the Loluai Volcanics, andesitic basalt flowed over the volcanic islands, and pillow lavas formed in the surrounding sea. The quiet extrusion of lava was interrupted by periods of violent explosive activity when large showers of tuff and agglomerate built up the islands both vertically and laterally.

When an eruptive phase temporarily ceased, the unconsolidated pyroclastics were rapidly eroded by rain and waves and redeposited as fine-grained marine sediments around remnant islands. The Loluai Volcanics were subjected to compressive folding and shearing some time before the deposition of the Suloga Limestone, and they may be considerably older than lower Miocene.

During a prolonged period in which there was no volcanic activity, the Suloga Limestone was deposited probably as a reef around a low island or shoal of deeply eroded Loluai Volcanics. The deposition of the limestone was followed by a period of explosive volcanic activity which build up a high volcanic landmass composed of the Tabukui Beds. The thick coarse volcanic conglomerate at Suloga Point may lie close to the eruptive centre. During the building of this pyroclastic pile, dolerite sills were intruded into the underlying Loluai Volcanics and into the basal part of the Tabukui Beds, possibly from the same magma chamber from which the eruptive rocks were derived. The limestones adjacent to the intrusives were metasomatized to skarn with accompanying shrinkage and development of north-trending tension openings into which iron-bearing mineralizing fluids were injected.

When the volcanoes became dormant again a great thickness of unconsolidated pyroclastics were washed away before renewed eruptions deposited the tuffs of the Wonai Hill Formation on an irregular erosion surface. This was a short-lived outburst followed by a long period of erosion producing a low-lying, forested, and swampy landmass around which the uniform mudstone of the Wonai Hill Formation was deposited.

Prolonged and vigorous volcanic activity resulted in the formation of the Okiduse Volcanics, which comprise a very thick pile of lavas, tuffs, and agglomerates. The monoclinial zone bounding the present Okiduse Range may have been formed during the collapse of the caldera over this centre of eruption.

After the accumulation of the thick volcanic pile, granite was intruded into the lower levels of the Okiduse Volcanics and underlying rocks. The presence of felsite dykes and eruptive dacitic rocks at Kulumadau suggests that while the granite was intruding lower levels of the pile, volcanic activity was more acid than usual. The diorite and lamprophyre dykes were probably emplaced in the later stages of the eruptive phase which produced the Okiduse Volcanics.

The isolated vents at Manau Hill and Mount Kabat probably represent the last phase of the prolonged period of vulcanism.

The exact position of the Nasai Limestone in the stratigraphic succession is uncertain, but it is probably younger than the Okiduse Volcanics and was deposited as an extensive fringing reef around an island after volcanic activity had ceased.



The erosion of the Okiduse Volcanics has probably proceeded almost continuously from the lower Miocene to the present day. Small changes in sea level in at least Pleistocene and Recent times have produced alternations of coarse-grained fluviatile and fine-grained marine sediments derived from and deposited around the volcanic hills. While these sediments were being laid down coral grew extensively wherever the environment was favourable, in some places on Quaternary terrigenous sediments.

After the latest lowering of sea level, alluvium was deposited on the coral. This alluvium contains relics of human habitation foreign to the present inhabitants of Woodlark Island.

## ECONOMIC GEOLOGY

### History

The history of the mining on Woodlark Island has been compiled from reports by Stanley (1912, 1917a), Thompson (1960), and Mining Wardens' Reports (1910-1926).

In 1895, alluvial gold was discovered in the Suloga Peninsula, the Okiduse Range, and the Bonivat-Karavakum area. Gold was next discovered at Kulumadau, and a rich alluvial deposit, which yielded several thousand ounces, was found in McKenzies Creek. About the same time gold was found in Colemans Creek at Busai. Alluvial gold was also won at Sinkurai, near the head of the Sinkurai River, Reillys Creek, and at Wonai and the Ben on Suloga Peninsula.

When the gold-bearing soil was sluiced off, the auriferous lodes in the bedrock were uncovered in many places. Lode mining commenced at Kulumadau in 1900 and at Busai in 1902. An open cut on the McKenzies Creek lode began in 1906; in 1910 gold was being produced from lodes at Karavakum and late in 1911 lodes were found and worked at Wonai.

By 1912, the Kulumadau (Woodlark Island) Gold Mining Company had a mine at Kulumadau developed to a depth of over 400 feet on five levels. This was the only mine in which the underground water problem was overcome; several smaller mines failed because of it. The Kulumadau mine produced between 2500 and 6000 ounces of fine gold each year until the company went into liquidation in 1918.

The other principal lode-mining centres were Busai and Bonivat-Karavakum. Mining was hampered by the abundance of underground water and by a shortage of water at the surface. The Federation and the Murua United at Busai, the Woodlark King at Bonivat, and the Little McKenzie at Karavakum were the most successful mines. Many other small mines were worked down to the water-table with varying success.

Lode-mining activity declined after 1918 and was at a low ebb in 1925, but the Federation, the Murua United, and the Woodlark King mines continued through the 1930's. The Woodlark King closed in 1942.

In 1952, Mr G.J. Gray, consulting mining engineer, sampled and reported on exposures in the old open cut at Kulumadau; the underground workings were then inaccessible. In 1957, Mr R.C. Neate produced some gold from an adit driven in the main lode at Kulumadau.

From 1895 to 1932, the total production of gold from Woodlark Island is recorded as 207,850 ounces, but much of the gold from the early alluvial mining was probably not recorded.

The history of investigation of the copper-iron mineralization on the Suloga Peninsula is given in detail by Thompson (1960). In 1914, Captain A.S.R. Osborne, manager of the Dubuna copper mine near Port Moresby, examined the copper deposit at Norac. In 1917, a small quantity of ore averaging 10 percent copper was exported to Australia from Suloga Peninsula, and exploratory work continued at Loluai until 1918, though no returns were made for that year.

Geologists of the Broken Hill Proprietary Co. Ltd examined Loluai and Norac in 1954, and an aerial magnetic survey of the Suloga Peninsula was made for this company in 1955. In 1956, J.E. Thompson, of the Bureau of Mineral Resources, made a detailed survey of the iron-copper deposits at Loluai and Norac. Mr R.C. Neate shipped a 10-ton parcel of hand-picked copper ore from Loluai to Japan for assaying in 1957.

#### Alluvial Gold Deposits

Traces of small alluvial workings are common in the outcrops of the Tertiary rocks, including the inliers at Mount Kabat, Manau Hill, and Wasilas, though there are no records of production from these localities.

Many of the early gold workings consisted of shallow eluvial deposits and soil formed by the weathering of nearby lodes. Small alluvial deposits were commonly found in small gullies where the coarse and little-worn gold had been transported, mainly by soil creep, and concentrated.

The alluvial gold has been derived from several rock types. The most extensive deposits were shed from Okiduse Volcanics and from the granite and porphyry intrusive into the volcanics. The alluvial gold in the Suloga area was apparently derived from the Loluai Volcanics, the Tabukui Beds, and possibly the gabbro sill at Uskweilele. In the Ben and Wonai alluvial mining areas the gold was probably derived from the Wonai Hill Formation and the granite intruding it.

At Busai and Reillys Creek thick deposits of conglomerate within marine clays older than the subhorizontal raised coral were profitably worked for gold. In the 1930's, an inconclusive attempt was made to prove a dredging area in conglomerates in the marine clays south of Busai, though good values of gold were obtained (R.C. Neate, pers. comm.).

Little attention has been paid to the extensive Recent deposits along the Sinkurai River. The sediments are up to several hundred feet thick and include lenses of conglomerate up to 50 feet thick. If these lenses carry profitable quantities of gold, a large dredging area would be available in the flat well-watered country extending eastwards along the plain of the Sinkurai River. An indication of the gold content of the conglomerates could be obtained by dish-prospecting in the steep banks of the Sinkurai River.

## Lode Gold Deposits

In 1960 only a few weathered reefs were located, at Karavakum and Kulumadau; other reefs recorded by Stanley (1912) at Kulumadau, Busai, McKenzies Creek, Bonivat-Karavakum, Okiduse, and Wonai are concealed by vegetation, rock detritus, and mud.

### Kulumadau

The Kulumadau inlier is an isolated outcrop of volcanic rocks cut by a few felsite dykes. The outcrop measures about  $1\frac{1}{2}$  miles from north to south, and three-quarters of a mile from east to west. It is surrounded by Recent coral limestone, and small outliers of coral occur within the inlier up to 400 feet above sea level.

The whole outcrop has been investigated by prospectors. The most important workings in the south were mapped in detail by Stanley (1912). In 1960 only the lode in Kayao Creek, the Great Northern lode, and the main Kulumadau lode were found and examined.

The Kayao Creek lode is a shear-zone in carbonated volcanics; it is about 4 feet wide and trends about  $170^{\circ}$ . The shear is filled with rock fragments and hard and soft blue pug, which contains abundant pyrite, some galena, and gold. This lode was recorded by Stanley (1912) as the lode on Lease 31. Prospectors estimated the lode to contain 1 oz of gold per ton.

The Great Northern lode is 6 to 8 feet wide and trends about  $110^{\circ}$ , which is an uncommon trend on Woodlark; the dip ranges from  $60^{\circ}$  north to  $60^{\circ}$  south. The lode occurs in a shear-zone in brecciated volcanics; it is composed of rock fragments in an abundant matrix of blue pug with oxidized and fresh pyrite. In places, traces of gold may be obtained by panning the lode material. Stanley recorded this as the large lode on Lease No. 32 which assayed 3 dwt of gold per ton.

At Kulumadau, the main lode is exposed in the old open cut as a shear-zone about 100 feet wide, trending  $170^{\circ}$  and dipping almost vertically. The shear-zone contains fragments of carbonated volcanics in a matrix of blue pug with abundant pyrite; the gold appears to be concentrated in the pug. The footwall of the lode consists of carbonated volcanic rock.

J.M. Newman, reporting on the Kulumadau (Woodlark Island) Gold Mining Company's mine in 1912, recorded that the main Kulumadau lode is 700 feet long and ranges from 18 inches to 20 feet wide and that it was worked to a depth of 400 feet. The lode strikes north and dips  $80^{\circ}$  east. Sampling on No. 4 level indicated an average gold content of 14 dwt per ton for 140 feet over an average width of 6 feet. Towards the north end of the lode, a gold-enriched zone over 100 feet long adjoining a fault was also noted by Newman.

Stanley (1912) and Mining Warden's Reports (1910-1919) give details of production from the Kulumadau mine. The available but probably incomplete records indicate that between 1901 and 1912 the company produced about 40,000 ounces of gold from about 40,600 tons of ore, by crushing and cyaniding. The total production from the mine between 1901 and 1918 was about 69,000 ounces of gold from about 110,000 tons of ore. When the mine closed the Mining Warden (1918) considered that it could be profitably worked as a low-grade proposition, though ore reserves are quoted as only 8000 tons. The shafts at Kulumadau have collapsed and the underground workings are no longer accessible.

G.J. Gray, consultant mining engineer, visited the mine in 1952 and sampled exposures of the lode and the surrounding country rock. Gray concluded that the reserves of low-grade ore in the vicinity of the mine, and the large quantities of tailings and leached ore at the surface, might justify a revival of mining on a large-scale low-grade basis.

### Busai

The Busai mining centre is about 3 miles south-east of Kulumadau, at the west end of a large outcrop of volcanics extending north-west from the north end of the Okiduse Range.

The lodes mapped by Stanley (1912) and the large open cut on the Murua United lease are obscured by rubble and bracken. The party did not locate any lodes at Busai, but Messrs Neate and Darsen have since sampled reefs on the Federation and Vulcan leases.

Pyritic shear-zones are common in both the granite and volcanic rocks exposed in creeks at Busai and in Reillys Creek nearby. Stanley described one blue quartz lode and lodes of blue sulphide-bearing pug veined with quartz and calcite. Most of the lodes at Busai probably occur in shear-zones similar to those at Kulumadau and Karavakum.

### McKenzies Creek

At McKenzies Creek, 1 3/4 miles south-east of Busai, Stanley (1912) described a lode of ferruginous quartz, 15 feet wide, with rich pockets of gold in the lode and in the surrounding decomposed porphyry.

### Bonivat/Karavakum

Bonivat and Karavakum are located on a broad low rise extending about 1 1/2 miles north-west from the north-western flank of the Okiduse Range. Exposures are mainly intermediate porphyry with a network of granite dykes and numerous inclusions of volcanic rocks.

The gold mines were mapped and described by Stanley (1912) when they were most active. Lode mining began at Karavakum in 1910 and by 1917 most of the mines had been developed and possibly worked out down to the water-table, about 70 feet below the crest of the rise. The problem of dewatering was tackled with some success at the Woodlark King mine at Bonivat, and production continued from shallow levels in this mine until 1942.

During this survey a few of the lodes mapped by Stanley were recognized in creeks at Karavakum. Though weathered, they are evidently shears in granite, porphyry, and metamorphosed volcanics. They are grey pug zones containing rock fragments and in places have a soft calcitic matrix. The lodes range from 1 to 4 feet in width and trend about 170°.

Stanley (1912) recorded lodes, up to 20 feet wide, composed of fault breccia with quartz, calcite, iron oxide, manganese oxide, and sulphides. The lodes of the Karavakum area trend between 160° and 180°, and the Woodlark King lode at Bonivat trends 140°. All the lodes dip steeply. Gold-bearing leaders and quartz veins are commonly associated with the lodes.

Between 1910 and 1912, the Little McKenzie mine at Karavakum yielded 1048 ounces of gold from 612 tons of ore. At the Woodlark King mine 2000 tons of ore averaged 3 oz of gold per ton.

The Okiduse mine, about 1 mile south of Bonivat on the north-west flank of the Okiduse Range, is close to a contact between volcanic rocks and a large granite body. Stanley (1912) reported ferruginous lodes trending  $125^{\circ}$  and dipping  $80^{\circ}$  south-west in grey porphyry. This mine is now completely overgrown and no exposures could be located.

#### Wonai

The exact position of the Wonai lodes is not known. From Stanley's description they probably occur in sedimentary or volcanic members of the Loluai Volcanics which are intruded by dolerite. Stanley suggested that the lodes occupy fault zones which strike  $165^{\circ}$  and dip  $75^{\circ}$  north-east. Pyritic quartz veinlets with visible gold have also been recorded from Wonai.

#### Loluai and Norac

Stanley recorded auriferous quartz leaders at both localities, but they were not located in 1960.

### Gold Mineralization

Except at Wonai, all the productive gold lodes occur in the Okiduse Volcanics or in rocks intruding them.

At the surface, the gold-bearing lodes occupy shear-zones ranging from a few inches to 100 feet wide; they all dip steeply and with few exceptions trend between  $160^{\circ}$  and  $180^{\circ}$ . The shear-zones contain blue pug with rock fragments. Pyrite, both fresh and oxidized, is usually abundant in the pug, and fine galena is visible in some lodes. Calcite and less commonly quartz occur as gangue in pockets or in thin irregular veins.

The lodes in the underground workings at Kulumadau were interpreted as shear-zones by Newman (1912). The Mining Warden (1918) reported a pug seam in the Kulumadau mine which broadened into an ore vein 14 feet thick. Pyrite, galena, sphalerite, manganese oxide, and traces of copper minerals were recorded in the deeper levels. Stanley (1912) and Newman (1912) both noted that the calcite veins and quartz veins with visible galena have a high gold content.

Edwards (1954) described a sample of ore from the 400-foot level in the Kulumadau mine as massive and medium-grained to coarse-grained, and consisting of sphalerite, galena, pyrite, chalcopyrite, quartz, and calcite. He noted that pyrite, the least abundant sulphide, is corroded where in contact with the other sulphides and that gold, associated with most minerals, has been introduced with the latest-deposited galena.

The gold, sulphides, quartz, and calcite in the shear-zone lodes are probably concentrations of minerals deposited from solutions migrating up or along the shear-zones in the late hydrothermal stage of volcanic activity. The gold-bearing lodes are usually located in shears in the younger volcanic rocks, which were presumably in direct connexion with the centres of dying volcanic activity.

### Pyrite Mineralization

Pyrite is common to abundant in all the volcanic and intrusive rocks and in all the Tertiary sediments except the Nasai Limestone. The pyrite is generally disseminated as large and small clusters, or as individual crystals. Veins of pyrite are less common. In the Tabukui Beds, pyritic layers are represented by thin beds of massive limonite.

The pyrite mineralization is attributed to widespread permeation of the lower levels of the volcanic pile by sulphur-bearing solutions, particularly during eruptive phases.

### Manganese Mineralization

A small lode of manganese oxides was found on the seaward side of an islet in the mangrove swamp at Wasilas Point. The lode is vertical, about 4 feet wide, and trends  $180^{\circ}$ . It is composed of weathered brecciated rock and black earthy manganese oxide; a typical specimen assayed 41 percent manganese.

Thin layers of black manganese oxides are common in the weathered Tabukui Beds exposed along the west shore of Suloga Harbour, below Makete Hill. The black films on the boulders of volcanic rock in Loluai Creek were found to contain manganese as well as iron. Abundant manganese was recorded by Stanley (1912) in the Little McKenzie gold lode. The manganese was probably introduced in a late hydrothermal phase of volcanic activity, but is less widely distributed than the gold and sulphide mineralization.

### Copper and Iron Deposits

The magnetite outcrops at Loluai and Norac on the Suloga Peninsula have been described in detail by Thompson (1960), and Fricker & Trail (1961) have discussed a geochemical investigation of the copper mineralization at Loluai.

In addition to the extensive outcrops of magnetite at Lolua and Norac, magnetite and hematite boulders are found within half a mile of the old Loluai workings, at Sililoi, Watsons, and Watavai Creeks. At Watavai Creek the iron oxide boulders are near an outcrop of cupriferous skarn. Boulders of magnetite with quartz, pyrite, and possible chalcopyrite occur on Mapas Island, and boulders of hematite with malachite were seen in the headwaters of Sigebai Creek, 300 yards north of Suloga Point. Stanley (1912) recorded micaceous hematite in a shaft on the saddle 600 yards north of Suloga Point.

### Loluai

At Loluai there are four or five iron-bearing lodes, commonly ranging in width from 4 to 30 feet, and possibly up to 50 feet. The dips range from steep to vertical and, except for one lode, they strike north-north-west. Magnetite and hematite constitute about 60 percent of the lodes, malachite occurs patchily as a surface coating and in veinlets, azurite is rare, and pyrite occurs in places. The gangue minerals are garnet, epidote, and quartz. The magnetite bodies at Loluai are mainly within the outcrop of the skarn, and a geochemical investigation has indicated that copper mineralization is confined to the skarn.

Magnetite and hematite boulders are scattered over a broad zone from Loluai Creek for about 800 yards north to the headwaters of Sililoi Creek. This zone extends beyond the skarn outcrop, and near Sililoi Creek the copper content of the soil around the magnetite boulders is lower than in the skarn.

Magnetite boulders in Watavai Creek, 700 yards north-east of Loluai, overlies a small outcrop of cupriferous skarn. A lode of magnetite may continue northwards under the outcrop of the Wonai Hill Formation to the headwaters of a tributary of Watsons Creek, where magnetite boulders lie on soil with a low copper content.

Partial analyses of samples taken by Thompson (1960) at Loluai from the sorted dumps of magnetite and copper ore are :

Sample from dump with:	SiO <sub>2</sub>	Fe	Cu	Mn	TiO <sub>2</sub>	S	P <sub>2</sub> O <sub>5</sub>
Abundant copper minerals	5.0	55.8	12.3	0.05	0.1	tr	tr
Visible copper minerals	9.2	49.4	9.2	0.04	-	0.35	tr
No visible copper minerals	4.5	62.5	0.67	0.12	-	tr	tr

Arsenic and gold not determined

A geochemical investigation of Loluai, described by Fricker & Trail (1961), revealed that the soil overlying the extensive skarn outcrop at Loluai has an abnormally high copper content, and large areas contain more than 1000 ppm of copper. Previously, the copper has been regarded as an associate of the magnetite lodes, but the geochemical results indicate that it is also disseminated in the skarn beyond the magnetite lodes.

The secondary copper minerals malachite and azurite have been seen in the skarn and in the magnetite bodies only at the old workings low on the steep hillside behind Loluai. This may be the exposure of a zone of secondary copper enrichment in the skarn near the water-table.

### Norac

The magnetite deposits at Norac have been mapped and described in detail by Thompson (1960). They lie within a skarn outcrop at the foot of the steep slope of Tabukui Hill. The skarn and magnetite outcrops are partly concealed by boulders derived from the overlying Tabukui Beds.

Thompson (1960) recorded six magnetite lodes at Norac, but only two are sufficiently large for consideration as orebodies. The lodes strike about due north and dip about 60° west. One lode is 30 feet wide; the other 50 feet wide. They are separated by 40 feet of cupriferous skarn. The lodes are mainly hematite at the surface and are locally stained with malachite. Native copper is also present.

Analyses of grab samples taken by Thompson from the dumps adjacent to the lodes at Norac gave the following results:

Sample from:	SiO <sub>2</sub>	Fe	Cu	Mn	TiO <sub>2</sub>	S	P <sub>2</sub> O <sub>5</sub>
50-ft lode (no visible copper minerals)	4.6	65.7	0.25	0.25	-	-	tr
50-ft lode (visible copper carbonates)	6.6	55.2	4.3	0.06	-	-	tr
30-ft lode (visible copper carbonates)	6.7	56.3	3.2	0.06	-	-	tr

Arsenic and gold not determined

Thompson (1960) estimated that 420,000 tons of iron ore may be available above sea level in the two main lodes at Norac.

The magnetite lodes at Norac appear to lie entirely within a skarn outcrop about 2000 feet long and up to 400 feet wide. The skarn is probably a concordant lens, possibly altered Suloga Limestone, about 100 feet thick, which may extend into the hillside under the Tabukui Beds.

Most of the soil samples taken over the Norac skarn outcrop were found to contain more than 1000 ppm of copper; the highest value recorded was 7000 ppm. As at Loluai, the presence of secondary copper minerals in the old Norac workings may indicate a zone of secondary copper enrichment of unknown extent.

#### Other Deposits

Magnetite, hematite, and limonite boulders with traces of malachite were seen on the Loluai Volcanics near the head of Sigebai Creek north of Suloga Point. The copper-iron mineralization is probably associated with the dolerite sill which forms Uskweilele Hill. No skarn is exposed.

A small area on Mapas Island is occupied by small boulders of magnetite and hematite containing quartz, brassy pyrite, and possible chalcopyrite. The mineralization is probably associated with the dolerite of Mapas Island, and the mineralized boulders may be near the contact of dolerite and a remnant of Loluai Volcanics.

Magnetite boulders reported by former prospectors from the Wasilas area, probably in Loluai Volcanics, were not located in 1960.



## Copper-Iron Mineralization

The copper-iron mineralization is attributed to the intrusion of dolerite sills comagmatic with the volcanic rocks of Woodlark Island. Fugitive metallic constituents of the dolerite magma were concentrated in the porous skarn rocks formed by the metasomatic alteration of limestone. The magnetite occupied north-trending tension fissures, mainly in the skarn, and in dolerite and volcanic rocks. The copper disseminated through the skarn may have been redistributed and concentrated by groundwater in a zone of secondary enrichment.

## CONCLUSIONS AND RECOMMENDATIONS

The geochemical investigation at Loluai has indicated a previously unsuspected dispersed copper content in weathered skarn rock which, as recommended by Fricker & Trail (1961), warrants further delineation by diamond drilling. Diamond drilling is also recommended to prove the extent and grade of the cupriferous skarn at Norac, and to test the possibility of an extension of the magnetite lodes beneath the Tabukui Beds.

Further geological and geochemical exploration for copper should begin in the Loluai Volcanics and gabbro at Suloga Point, Mapas Island, and the Wasilas area.

Further investigations at Busai and Bonivat-Karavakum, where near-surface gold values were high, should be directed towards determining the grade of the known lodes below the water-table. This can only be done by drilling. If high gold values persist, the water problem which caused the closure of the old mine could probably be solved with modern pumping equipment. Systematic sampling of the Kulumadau open cut and the sand and slime dumps may offer encouragement for reopening the Kulumadau area as an open-cut low-grade gold mine. Possible extensions of the Kulumadau lode laterally and in depth can only be tested by drilling.

Payable alluvial gold may exist in the conglomerate lenses in the blue marine clays exposed in the banks of the Sinkurai River east of the Okiduse Range, and also in the flats south of Busai.

## ACKNOWLEDGEMENTS

I gratefully acknowledge the unlimited hospitality and assistance provided by Mr & Mrs R.C Neate and Mr and Mrs D.B. Neate. I am particularly indebted to Messrs R.C. and D.B. Neate for supplying the party regularly during a two-months' stay on Suloga Peninsula, and for providing accommodation for the party at Kulumadau. The assistance of Mr A. Dawkins, who provided accommodation at Bonivat, is also acknowledged.

Discussions with Mr H.J. Ward, consulting geologist, assisted greatly the planning and interpretation of the geological and geochemical work.

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## APPENDIX

### Further Investigations

Since 1960, geological and geophysical investigations have been carried out at Woodlark Island by members of the Department of Lands, Surveys, and Mines of the Territory of Papua and New Guinea. The results of these investigations have been compiled in detail by L. Hamilton (1964) and this appendix summarizes parts of Hamilton's unpublished report.

#### Loluai

After a ground magnetometer survey by Mr I.A. Wood and a detailed geological investigation by P.W. Pritchard (1962), 10 diamond drill-holes, between 90 feet and 300 feet long, were put down in 1961 to test in depth the exposed copper mineralization at Loluai and the geochemical anomalies located by Fricker & Trail (1961).

Core recovery was poor. Only low-grade mineralization was found. The highest value of copper in any core was 3.7 percent, and values of about 0.2 percent ranging up to 0.6 percent were more common in skarn, hornfels, and magnetite. A typical specimen of weathered chloritized dolerite contained only 0.06 percent copper. No blanket type of secondary copper deposit was encountered. Hamilton points out that sea level in Quaternary times has fluctuated through 400 feet, but no zoning attributable to this fluctuation could be detected.

#### Kulumadau

Following a reconnaissance ground magnetometer traverse by Mr I.A. Wood, a ground magnetometer survey by Hamilton in 1961 over an area 2700 feet by 1200 feet, immediately north of the No. 2 shaft of the Kulumadau mine, revealed irregular northerly trends, containing anomalies of about 1000 gammas. Hamilton attributes the anomalies to the distribution of magnetite.

In 1962, two short vertical diamond drill-holes were put down on the largest negative magnetic anomaly, one on the adjacent positive anomaly, one on the largest positive anomaly and one on its western side. The holes caved and circulation was maintained with difficulty. The holes reached an average depth of less than 50 feet; overall core recovery was 30 percent and the core was recovered in small fragments. The cores were split and assayed at 5-foot or 10-foot intervals. Where no core was recovered sludge samples were assayed.

In approximately half the samples assayed gold was not detected. Only two of the remaining samples contained more than a trace of gold, and these held less than 1 dwt per ton.

The core is composed of andesite and andesite breccia, commonly weathered, and pug. Since the gold probably occurs in the soft cement of the breccia, Hamilton believes that the determination of the gold is not reliable where core recovery is poor.

In a costean 85 feet long and averaging  $2\frac{1}{2}$  feet deep, traces of gold were found in channel samples taken at localities corresponding to the highest and lowest points on the magnetic profile. No gold was detected in the other channel samples, taken at 5-foot intervals.

In 1963, two drill-holes near the Kulumadau mine passed through barren andesite and andesite breccia. The holes were abandoned at 68 feet and 114 feet respectively. Two samples from one hole assayed a trace of gold and a few pennyweights of silver per ton.

Hamilton located the Bosocalo lode at Kulumadau, possibly a lode on Lease 31 recorded by Stanley (1912). It is composed of grey pug and lies in porphyritic andesite and andesite breccia, which have been altered near the lode. The lode is exposed for 250 feet and dips  $30^{\circ}$  south-west. Its southern part is a zone 6 inches to  $2\frac{1}{2}$  feet wide composed of a stockwork of veinlets,  $1/10$  inch to 1 inch wide, of galena, sphalerite, pyrite, and possible chalcopryite in a matrix of dolomite(?). The northern part of the lode is a patchy dark grey and light grey stiff pug, about 6 inches wide, containing disseminated pyrite. It is richer in gold than the southern part. Gold values in samples from the lode range from a trace to 23.5 dwt per ton. Hamilton recommends this lode for further investigation.

### Busai

Hamilton examined in detail the Federation and Open Cut mines at Busai in 1962, in preparation for diamond drilling.

The Greentree shafts on the Federation lease appear to be located in a shear-zone occupied by tough breccia, which contains sphalerite and pyrite; one specimen assayed 43 dwt of gold per ton. Pyrite and galena occur in quartz veins in altered andesite in the exposed workings.

The main Federation shaft is sunk on altered andesite with disseminated pyrite and quartz veins containing sphalerite and galena. The lode strikes about north-north-west and prominent joints, possibly parallel to the footwall, dip  $75^{\circ}$  eastwards.

A diamond drill-hole, designed to test the southern part of the lode below old workings, intersected an 8-inch zone, a sample of which assayed 152.8 dwt of gold per ton. This zone is distinct from the surrounding altered andesite and is composed of silicified rock with slickensides, and mineralized pug with galena, pyrite, sphalerite, and possible chalcopryite, disseminated and in veinlets. Above the zone, 7 feet of core assayed 0.2 dwt of gold per ton, and below the zone, 4 feet of core assayed 3.3 dwt of gold per ton. Another hole drilled at the same locality yielded core assaying 9.9 dwt of gold per ton where it penetrated the hangingwall, composed of altered andesite with veinlets and disseminated crystals of pyrite, galena, sphalerite, quartz, and calcite.

A hole which intersected the Greentree shear-zone revealed that the zone lacks mineralization and probably cuts the Federation lode.

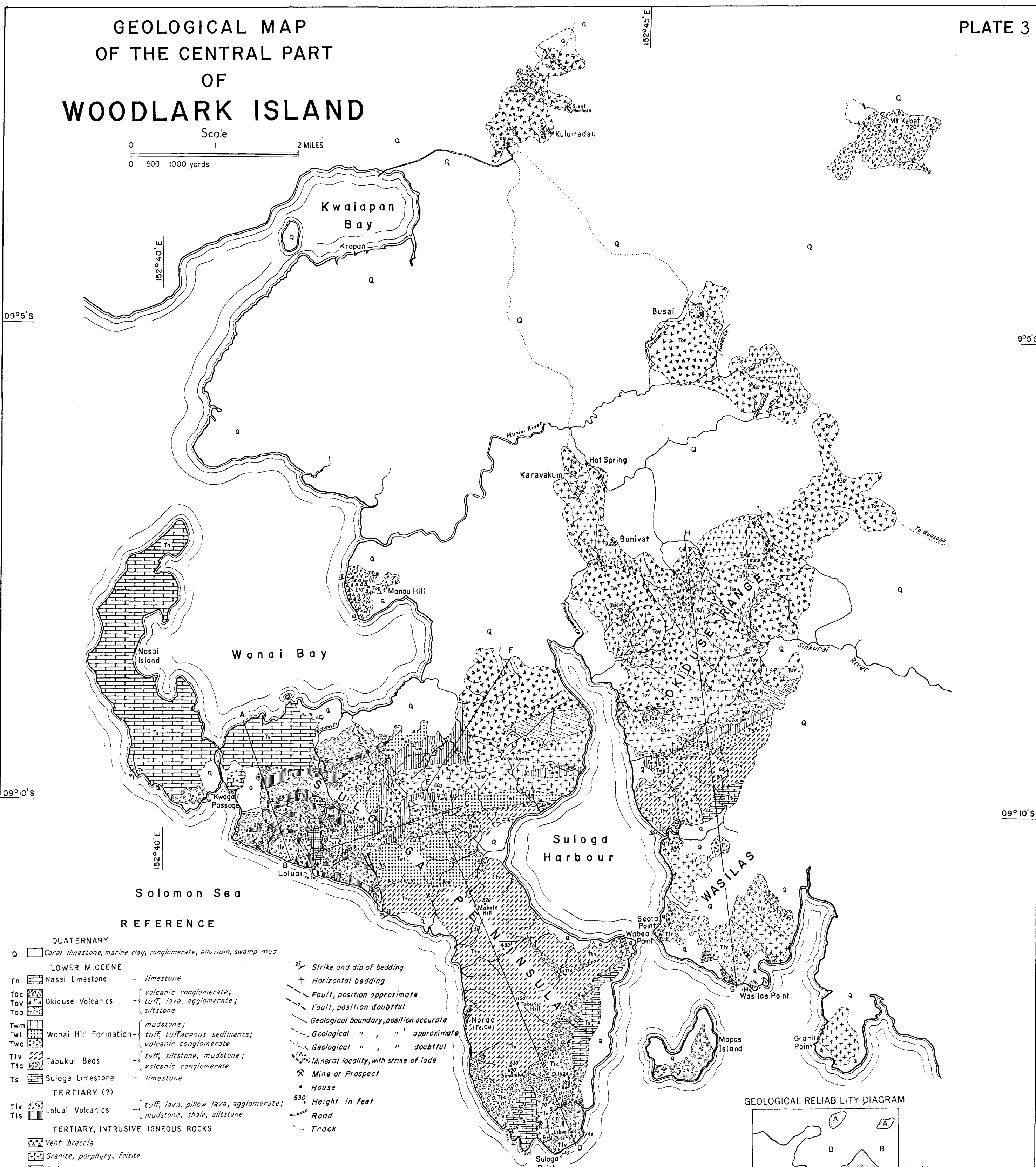
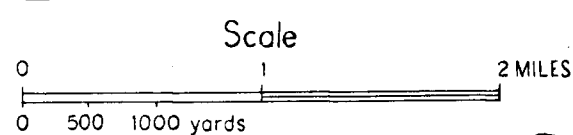
Hamilton concluded that the appearance of several mineralized zones in the drill-holes, which cannot be correlated, suggests that the gold at the Federation mine is erratically distributed in lenses within steeply dipping shear-zones striking north-north-west. These zones are characterized by calcite, quartz veinlets, and disseminated pyrite in altered country rock. The richer zones contain galena, sphalerite, and pug. A profitable unworked lode may exist at the south end of the Federation mine.

The country rock at the Busai open cut appears to be weathered propylitized andesite, locally intensely silicified. Eight grab samples from the cut were found to contain gold values ranging from a trace to 25.8 dwt per ton. The samples differed little in appearance. The lodes appear to be located in or near shear-zones. The abundance of very small mines and scattered shafts suggests that most of the lodes mined are probably larger members of a series of small leaders.

Four diamond drill-holes were put down to test possible lodes near the open cut, but the highest value obtained was only 4.3 dwt of gold per ton. The richer zones are generally characterized by disseminated pyrite, calcite veinlets, and pug. No relation appears to exist between gold and silver values.

# GEOLOGICAL MAP OF THE CENTRAL PART OF WOODLARK ISLAND

PLATE 3



## REFERENCE

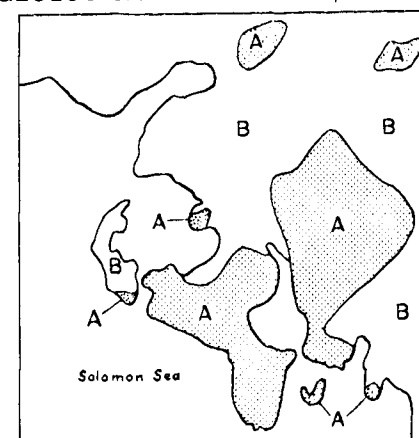
- QUATERNARY**  
Q Coral limestone, marine clay, conglomerate, alluvium, swamp mud
- LOWER MIOCENE**  
Tn Nasai Limestone - limestone  
Toc Okiduse Volcanics - volcanic conglomerate; tuff, lava, agglomerate; siltstone  
Tov  
Toc  
Twm Wonai Hill Formation - mudstone; tuff, tuffaceous sediments; volcanic conglomerate  
Twt  
Twc  
Tiv Tabukui Beds - tuff, siltstone, mudstone; volcanic conglomerate  
Tic  
Ts Suloga Limestone - limestone
- TERTIARY (?)**  
Tlv Lolui Volcanics - tuff, lava, pillow lava, agglomerate; mudstone, shale, siltstone  
Tls
- TERTIARY, INTRUSIVE IGNEOUS ROCKS**  
Vent breccia  
Granite, porphyry, felsite  
Dolerite  
Diorite, lamprophyre, basalt and ultrabasic dykes  
Magnetite (lode and boulders)
- CONTACT METAMORPHIC ROCK**  
Skarn

- 25° Strike and dip of bedding  
+ Horizontal bedding  
- Fault, position approximate  
- Fault, position doubtful  
- Geological boundary, position accurate  
- Geological " " approximate  
- Geological " " doubtful  
Mineral locality, with strike of lode  
Mine or Prospect  
House  
630' Height in feet  
Road  
Track

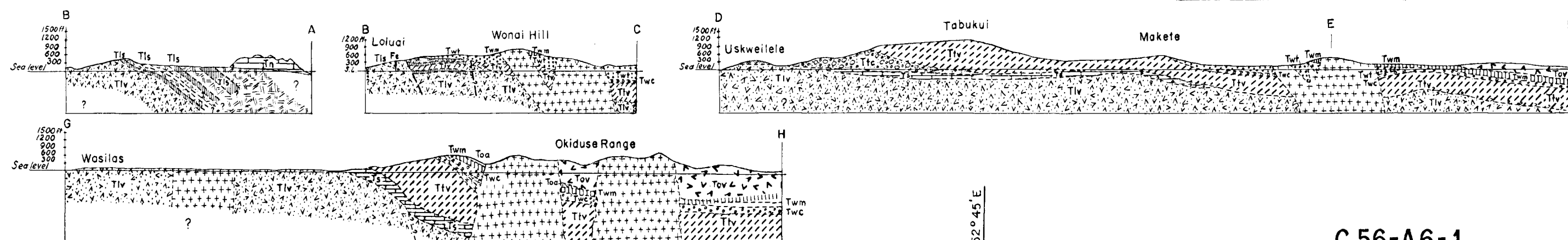
## SECTIONS

Vertical Scale = Horizontal Scale  
Quaternary sediments omitted

## GEOLOGICAL RELIABILITY DIAGRAM



A Many traverses  
B Few traverses



C 56-A6-1