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GEOLOGY OF BOUGAINVILLE AND BUKA ISLANDS,
TERRITORY OF PAPUA AND NEW GUINEA.

by

D.H. Blake and Y.Miezitis

The information contained in this report has been obtained by the Department of National Development, as part of the policy of the Commonwealth Government, to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

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SUMMARY

Bougainville and Buka Islands, politically part of the Territory of New Guinea, are the northernmost islands of the Solomon group, a north-westerly aligned island chain on the south-western border of the Pacific Ocean. The Solomons are mostly formed of Cainozoic volcanic rocks, sedimentary rocks derived from volcanics, and subordinate organic limestones.

Bougainville Island is 127 miles long and up to 39 miles wide. It has a mountainous interior consisting of the Emperor, Crown Prince, and Deuro Ranges, the active Mount Bagana volcano, the dormant volcanoes of Mount Balbi (8505 feet) and Loluru, and a number of extinct volcanoes, including Billy Mitchell, Mount Takuan (7385 feet) and Mount Taroka (7240 feet): crater lakes occur in the centres of Loluru and Billy Mitchell volcanoes.

The much smaller Buka Island, 35 miles long and up to 9 miles wide, consists of a low range of hills, the Parkinson Range, in the south-west, and a raised reef complex to the north and east.

The oldest rocks exposed in the area are probably Upper Oligocene to Lower Miocene. These are the Kieta Volcanics, which form the Crown Prince and Deuro Ranges of southern Bougainville, and the Buka Volcanics, which form the Parkinson Range on Buka. They consist of subaerial intermediate and basic lavas, agglomerates, tuffs, a basic pillow lava, and waterlain sedimentary rocks composed of volcanic material.

In central Bougainville the Kieta Volcanics are locally overlain by a Lower Miocene ('e' stage) reef limestone, the Keriaka Limestone, which contains a rich foraminiferal fauna. This limestone forms a south-westerly tilted plateau on the southern side of Mount Balbi. The Keriaka Limestone is overlain by undifferentiated volcanics of probable Miocene to Pliocene age.

The younger volcanic rocks on Bougainville, which crop out over the greater part of the island, form the Bougainville Group, of (?)Pliocene to Recent age. This group consists of predominantly andesitic lavas, agglomerates, tuffs, and derived sediments, and it includes nine formations, each of which comprises the products of a readily identifiable volcano or volcano group. From north to south these formations are the Tore, Balbi, Numa Numa, Billy Mitchell, Bagana, Reini, Bakanovi, Takuan, and Taroka Volcanics. Also included are the Emperor Range Volcanic Beds, which are the products of unspecified volcanic centres.

A Pleistocene reef complex, the Sohano Limestone, forms most of Buka and also crops out on the north coast of Bougainville. Recent alluvium is mainly confined to low-lying coastal areas.

Dioritic intrusions, commonly surrounded by narrow metamorphic aureoles, occur within the outcrops of the Kieta Volcanics, undifferentiated volcanics, and Emperor Range Volcanic Beds; some of these intrusions may form the cores of deeply eroded volcanic centres.

Three major structural directions are apparent: a north-west trend, which is that of Bougainville Island and of the alignment of most of the Pleistocene and Rècent volcanoes on the island; a north-north-west trend, that of Buka Island and of the Parkinson Range: and a west to west-north-west trend, that of the Crown Prince and Deuro Ranges and of most of the lineaments visible on the air photographs. There is no evidence of strong folding and little evidence of large scale faulting, although small faults are common.

The known gold and copper mineralisation on Bougainville is associated with two porphyritic microdiorite bodies intruding agglomerate belonging to the Kieta Volcanics agglomerate. The gold occurs in quartz stockworks within "porphyry copper" deposits. Small quantities of alluvial and eluvial gold have also been found. Titaniferous magnetite is concentrated in many of the beach sands around the coast of Bougainville.

GEOLOGY OF BOUGAINVILLE AND BUKA ISLANDS, T.N.G.

INTRODUCTION

A geological survey of Bougainville and Buka, the northernmost islands of the Solomon group (Fig. 1), was carried out between April and July, 1965, by a Bureau of Mineral Resources party consisting of D.H. Blake, Y. Miezitis, D.D. Middleton, and F.S. Chong (Colombo Plan Fellow). The main object of the survey was to determine the geological setting of the gold and copper mineralisation on Bougainville.

Bougainville Island, the largest of the Solomon Islands, is 127 miles in length and has a maximum width of 39 miles: Buka Island is 35 miles long and 9 miles wide. The total area of these two islands is 3475 square miles (Speight, in press, b).

The Solomon Islands lie on the south-western margin of the Pacific Ocean, and form part of the 'circum-Pacific gridle of Fire'. They are made up mostly of Tertiary and Quaternary volcanic rocks and derived sedimentary rocks, but also include some organic limestones. Pre-Tertiary 'basement' rocks, mainly schists and plutonic rocks, crop out on the islands of Santa Ysabel, Guadalcanal, Choiseul, Nggela and perhaps San Cristobal (Coleman et. al. 1965).

Quaternary volcanic rocks are dominant on Bougainville, where there is one active volcano (Mount Bagana), two dormant volcanoes, and a number of extinct volcanoes. Extensive outcrops of Tertiary volcanic rocks are only found in southern Bougainville. Organic limestones of Lower Miocene and Pleistocene ages also occur on the island. Volcanic rocks of (?)Oligocene age and Pleistocene organic limestone occur on Buka.

Bougainville and Buka Islands come within the Administrative district of Bougainville and are part of the Territory of New Guinea. The present administrative centre is at Sohano, a small island at the south-western end of Buka Passage, south of Buka. There are patrol posts on Buka at Hanahan and Hutjena, and on Bougainville at, from north to south, Tinputz, Konua, Wakunai, Kieta (the pre-1941 administrative centre), Boku, Konga, and Buin.

Access

There are four airfields in the area and each airfield is served regularly from Rabaul by Trans Australia Airlines: these are the Buka Passage airport (suitable for D.C.3 and Fokker Friendship aircraft) on Buka, and the Wakunai, Kieta (Aropa), and Buin airfields (suitable for D.C.3 aircraft) on Bougainville. A weekly air service operates between Rabaul, Buka Passage, and Honiara (British Solomons Islands Protectorate).

A number of small coastal vessels ply between Rabaul and the two islands, calling at many of the good anchorages that are found on the west coast of Buka and on the north and east coasts of Bougainville, between Soraken and Tonolei Harbour. There are no anchorages on the east coast of Buka, and only one good anchorage (at Torokina) on the west coast of Bougainville, south of Soraken.

In the Bougainville District there are over 600 miles of vehicular roads. Good roads are found on Buka along the north and east coasts, and on Bougainville between Arawa Plantation, Kieta, and Iwi Plantation, and around Buin and Boku. Most of the other roads are short, serving patrol posts, missions, and plantations. Many of the roads on Bougainville become impassable in times of flood.

Most of Bougainville is well served by foot tracks which link native and European settlements. However few tracks exist in uninhabited mountainous areas in the interior of the island, making these areas relatively inaccessible (Fig. 3). In upland areas tracks tend to follow the tops of ridges.

Field Method

A 50-foot ocean going launch, the 'Tropic Seas', from Cairns, Queensland (V. Vlasoff, owner-captain), was chartered during the survey and was used as a mobile base camp. This enabled survey parties to be put ashore and picked up at various points along the coast with the minimum of delay.

During the last month of the field season a helicopter was used for dropping and picking up survey parties, for examining some of the more inaccessible exposures, either on the ground or from the air, and for general reconnaissance. Suitable helicopter landing spots were found in many native villages, on sand banks in rivers, and on most beaches, but landing spots are almost non-existent in uninhabited mountainous areas.

Survey parties consisted of one or two geologists, up to ten locally hired native carriers, and sometimes a police boy. Walking traverses of two to five days duration were made into the interior of Bougainville Island, with overnight stops at Administration rest houses ('haus kiaps') where possible. Traverses generally followed native walking tracks, as river traverses were normally not practicable; the rivers are swift flowing and subject to frequent and sudden flooding. Most of the coastal exposures were examined using a dinghy with an outboard motor.

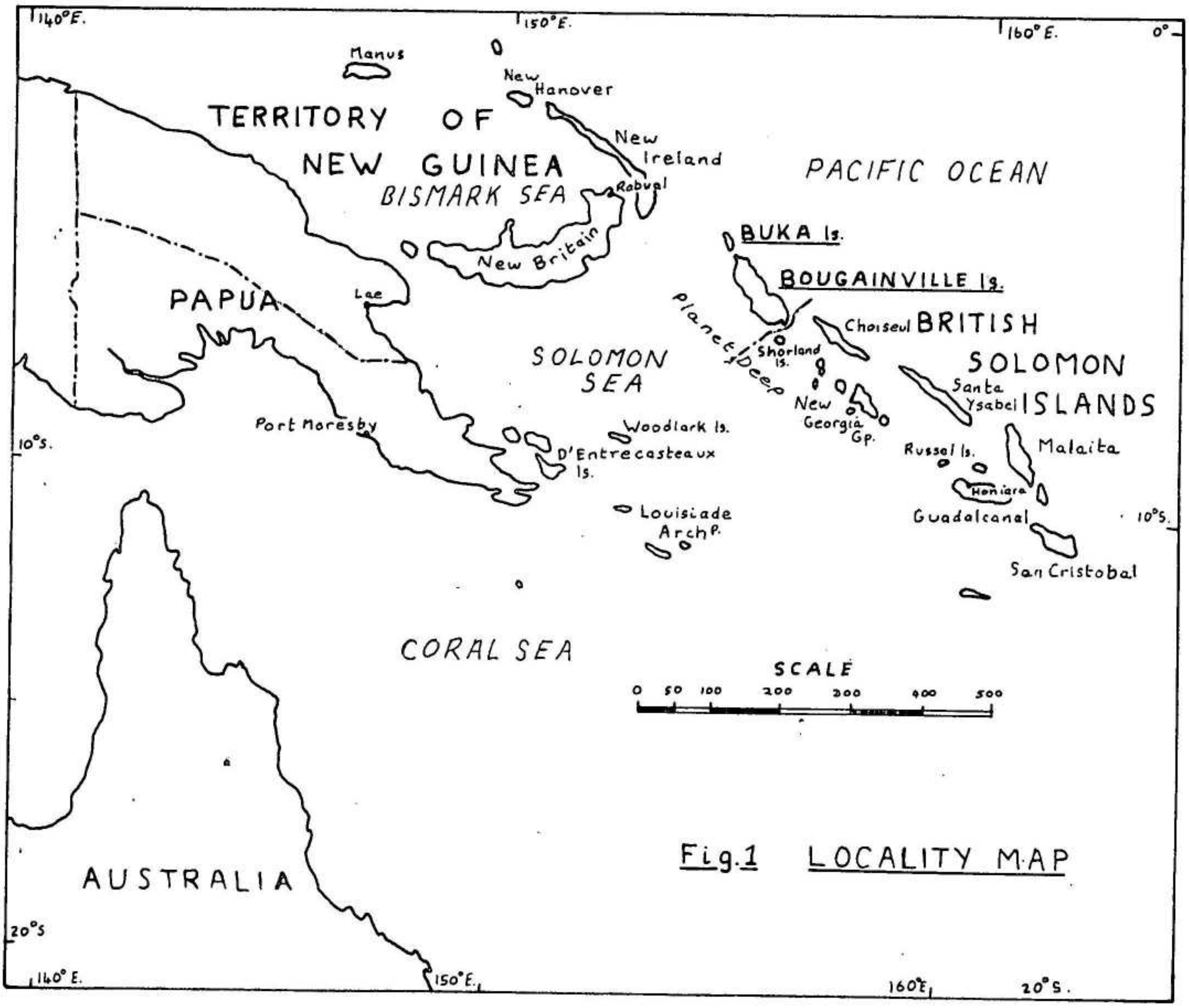


Fig.1 LOCALITY MAP

Fresh rock exposures are mostly confined to areas where rapid down-cuttings is taking place, such as wave cut platforms, cliff faces, river beds and gorges. The depth of weathering is greatest on the tops of ridges, where only residual boulders are normally found.

Most of Bougainville and Buka is covered by vertical air photographs, taken in 1962, and field observations where plotted directly on these. Later vertical air photographs, taken in 1963, cover some of the gaps and cloud obscured areas of the 1962 photographs. A list of available air photographs is given in Table 1, and flight diagrams are shown in Fig. 2. Field observations were also plotted on military one-mile maps. The geological map was compiled using both the one-mile maps and the air photographs.

TABLE 1. AIR PHOTOGRAPHS OF BOUGAINVILLE AND BUKA

Sortie	Scale	Print Numbers	Date
543A/320	1:66,000	3-38	4. 7. 62
543A/322	1:60,000	2-27	5. 7. 62
543A/332	1:60,000	2-39, 41-58, 60-64, 67-70, 74, 77-79	12. 7. 62
543A/336	1:62,000	130-138	14. 7. 62
543A/339	1:57,600	20-28, 43-48, 59	18. 7. 62
543A/349	1:60,000	4-24, 28-57, 64-83, 96	26. 7. 62
543A/351	1:60,000	85-92, 106-121, 131-139	27. 7. 62
543A/363	1:60,000	128-136	9. 8. 62
543A/418	1:60,000	6-7, 8-34, 36-83	24. 6. 63

Photogeologic interpretation supplemented by ground information proved possible on a broad scale. In particular, young lava flows and most limestone areas show up clearly on the air photographs.

Population and Industry

About 520 Europeans and Chinese, and 62,000 indigenes live on Bougainville and Buka (Commonwealth of Australia, 1965), the main centres of European population being at Sohano and Kieta. Native villages are scattered throughout most of the area lying below 3,000 feet above sea level, but much of the mountainous interior of Bougainville Island is uninhabited (Fig.3). The majority of the inland villages are situated on tops of ridges.

Each village group has its own native language or dialect, although most of the natives speak pidgin English, the lingua franca of the area, and a few also speak English. The majority of the natives are Christians, and a number of Roman Catholic (Marist Society), Methodist, and Seventh Day Adventist missions run by European missionaries are located in the area.

The Administration maintains hospitals at Sohano, Wakunai, Kieta, Buin, and Boku. A hansenide colony at Torokina is run by the Marist Society.

The main industry is copra production. European-owned coconut plantations are situated on the west coast of Buka, on Madehas Island, and on the northern and eastern coasts of Bougainville from Konua in the north-west to Toimonapu in the south-east. In addition most of the missions and some of the native villages have their own coconut plantations. Cocoa is becoming increasingly important and is now grown on most European and native coconut plantations.

Conzinc Rio Tinto of Australia Exploration Pty Ltd, who are prospecting for copper on Bougainville, employed over 100 natives in 1965.

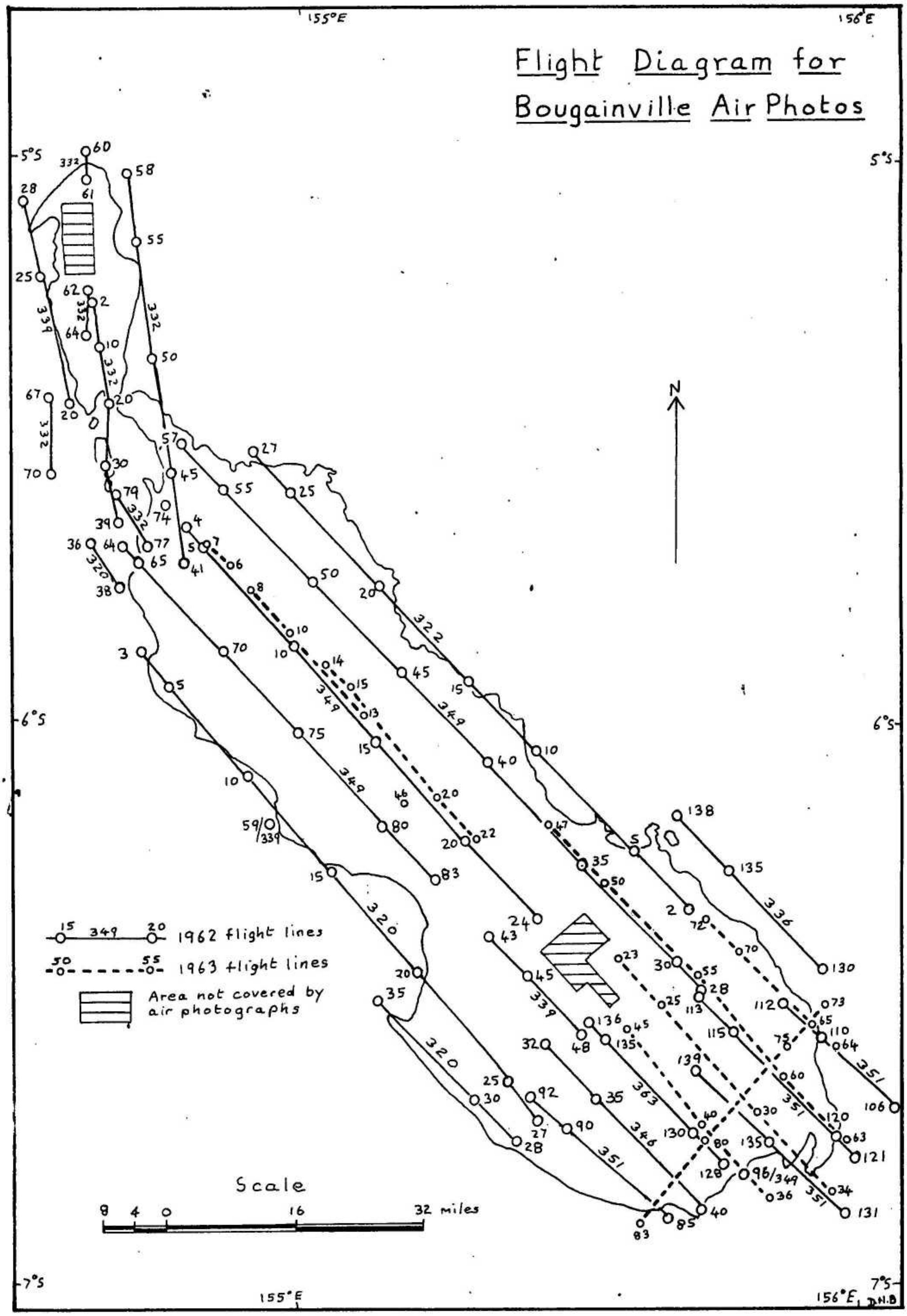
Minor industries include the making of baskets, bows and arrows, and wood carvings for sale overseas. The well known Buin baskets are made in southern Bougainville.

Most of the natives still practice subsistence farming, but this is generally supplemented by cash crops such as coconuts, oranges, pineapples, potatoes, and tomatoes. These are sold either at the native markets at Buka Passage and Kieta, or to the local Chinese and European trade stores.

Climate

Bougainville and Buka have a tropical equatorial climate and, as the islands are aligned parallel to the north-west and south-east trade winds, have no well defined wet season. The only rainfall figures available are those recorded for Kieta, on the east coast, which has an average rainfall of 10 inches for each month of the year (Department of National Development, 1951). The rainfall is much higher in the mountains, where it rains most afternoons.

Around the coast and lowlands it is usually hot and humid; Kieta, for instance, has a temperature range of 73° to 90°F. (Tudor, 1964). The mountains are generally cloud covered by 9 o'clock in the morning and are relatively cool throughout the year.



Flight Diagram for Bougainville Air Photos
155°E
156°E
5°S
6°S
7°S
N
1962 flight lines
1963 flight lines
Area not covered by air photographs
Scale
8 4 0 16 32 miles

Flora and Fauna

The greater part of Bougainville and Buka Islands is covered by tropical rain forest. This grades into moss forest on the highest mountains on Bougainville, and into swamp forest in low-lying, poorly drained areas. The undergrowth in the rain forest is sufficiently thin, except in areas of secondary growth, to enable fairly easy penetration.

Some small areas of grassland are present, notably on the Kunai Hills on the north coast of Bougainville.

Mangrove swamps occur in many inlets and river mouths around the coast.

The Bougainville District is reputed to have no venomous snakes. Leeches are said to occur in swampy areas around Tonolei Harbour in southern Bougainville but none were seen. Mosquitoes and scrub ticks are common locally and malaria is still a hazard. Salt water crocodiles were once plentiful but have been mostly shot out, and they are now found only in certain isolated coastal areas.

Previous Investigations

The earliest published geological observations of Bougainville are those of H.B. Guppy (1887), who reported that Mount Bagana was the only active volcano on the island in 1882.

In 1908 Sapper and Lauterbach recorded the occurrence of limestones of older Tertiary and younger Tertiary ages on Bougainville and Buka (Stanley, 1923). Mawson and Chapman (1935), Crespin (1951), Kicinski (1955), and Terpstra (1965) have since identified Lower Miocene foraminifera in limestone specimens collected from Bougainville by C.C. Deland, J.G. Best, A.K. Edwards and G.A. Taylor, and J.G. Speight respectively.

Gneisses were reported from the Crown Prince Range south-west of Kieta by a German expedition before the First World War (Stanley, 1923). This occurrence has not been confirmed.

Gold, with associated copper, was discovered on Bougainville in 1930 and two mines were opened up. Reports on these mines were made by Fisher (1936) and Thompson (1962).

The first detailed account of the Mount Balbi and Mount Bagana volcanoes was by Fisher (1939); later accounts have been given by Taylor (1956), Best (1956), Fisher (1954, 1957) and Branch (1965a and b). The petrology of some of the lavas from Mount Bagana was described by Baker (1949). The dormant volcano of Lake Loloru has been described by Best (1951), Reynolds (1955a), Fisher (1957) and Branch (1965b).

The heavy mineral sands around the coast of Bougainville were investigated by Thompson (1961).

In 1964 the Land Research Division of the C.S.I.R.O. visited Buka and Bougainville and carried out a regional survey of soils, vegetation, geomorphology, and geology (C.S.I.R.O., in press): J.G. Speight was in charge of the geological and geomorphological investigations during this survey (Speight, 1965, and in press a and b). In 1964 Conzinc Rio Tinto of Australia Exploration Pty Ltd began an intensive geochemical prospecting programme covering most of Buka and Bougainville.

Topography and Drainage

Bougainville is a long and relatively narrow island elongated in a north-west direction. It is dominated by a backbone of high mountains consisting of, from north to south, the Emperor Range, the Keriaka Plateau, a group of volcanoes in central Bougainville, the Crown Prince Range, the Mount Takuan and Mount Taroka groups of volcanoes, and the Deuro Range (Fig.3).

The Emperor Range consists mainly of rugged mountains between 4000 feet and 7000 feet high, but it also includes Mount Balbi, a dormant volcano 8500 feet high, the highest point on the island. South of Mount Balbi an elevated limestone platform, the Keriaka Plateau, dips gently westwards from over 4000 near the centre of the island to less than 100 feet on the west coast.

A group of four volcanoes in central Bougainville separate the Emperor Range from the Crown Prince Range. These are Mount Bagana, an active volcano 5730 feet high, Billy Mitchell, an extinct volcano in the centre of which is Billy Mitchell crater lake, and two unnamed extinct volcanoes, here called the Numa Numa and Reini volcanoes. From Mount Bagana the rugged Crown Prince Range extends south-eastwards for 50 miles; Mount Negrohead, 5212 feet, is the highest point on this range.

The Mount Takuan and Mount Taroka groups of volcanoes are situated in the central part of southern Bougainville on the south-west side of the Crown Prince Range. The volcanoes occur in two north-westerly aligned rows,

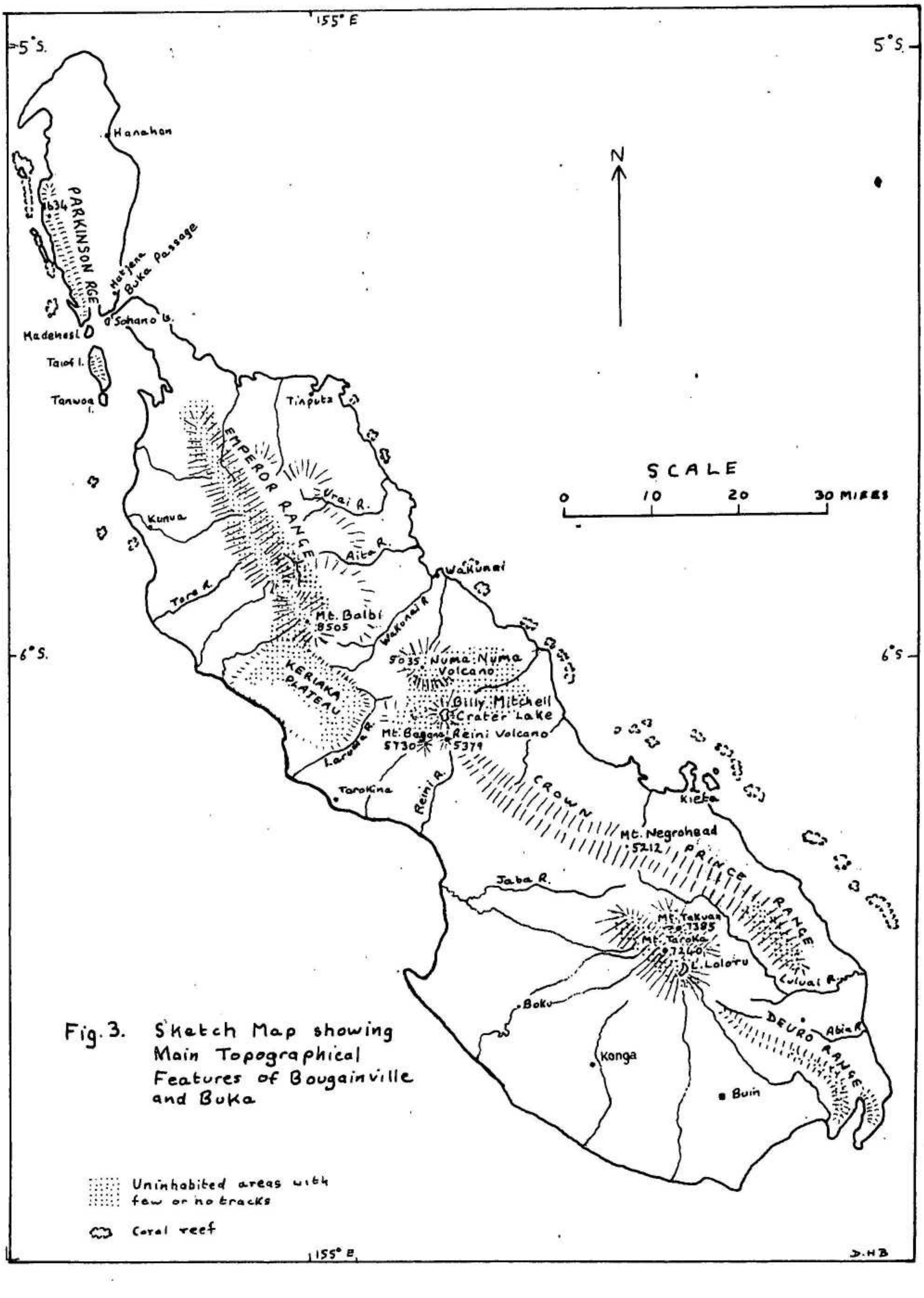


Fig. 3. Sketch Map showing Main Topographical Features of Bougainville and Buka

the highest points of which are Mount Takuan, 7385 feet, and Mount Taroka, 7240 feet.

The Deuro Range, in the extreme south-east of the island, consists of a range of hills less than 2500 feet high.

The low-lying areas of Bougainville consist mainly of alluvial plains and fans flanking the mountains; these are most extensively developed in the south, around Buin. Swamps occur in many places particularly near the coast. A raised coral reef occurs along the north coast of the island.

The rivers of Bougainville are generally short and swift. The longest is the Luluai River, 45 miles long, in the south-east of the island. In the mountains the rivers flow in deep valleys, and gorges and waterfalls are common.

The smaller island of Buka has a north-north-west elongation. It consists of a range of low hills in the south-west, the Parkinson Range, which rises to a maximum height of 1600 feet, and a raised reef complex to the north and east. The raised reef forms cliffs up to 300 feet high along the east coast of the island, and also forms Sohano Island at the south-western entrance of Buka Passage. The southerly extension of the Parkinson Range can be traced south of Buka on the small islands of Madehas, Taiof, and Tanwoa.

Coral reefs abound in the seas around Bougainville and Buka Islands. They are best developed off the west coast of Buka, in Matchin Bay south of Sohano, and along the east coast of Bougainville; here fringing reefs, patch reefs, and discontinuous barrier reefs occur.

<u>Topographical Names and Heights</u>

Most of the topographical names and heights are taken from the following maps:

No.3059 Bougainville Island North 4-mile series,

No.3313 Bougainville Island South 4-mile series.

These maps, drawn and printed in 1945 by the Australian Survey Corps, are the only available 4-mile topographical maps of the area.

<u>ROCK NOMENCLATURE</u>

In this report the following nomenclature for igneous, pyroclastic, and sedimentary rocks is used. This nomenclature is based on macroscopic and microscopic features. A general petrographic description of andesite, the most common igneous rock on Bougainville, is also given here.

Igneous rocks (modified after Morgan, 1964)

ANDESITE: this is a porphyritic rock with an average groundmass grain-size of less than 0.05mm. The most common phenocrysts are plagioclase, augite, hypersthene, hornblende, magnetite, and apatite. The phenocrysts make up 20 to 60 percent of the rock and lie in a very fine-grained and commonly vesicular groundmass which may be entirely crystalline but generally contains some glass or altered glass; the groundmass has a colour index of less than 30. The andesites are subdivided, according to the main ferromagnesian minerals they contain, into the following types: augite andesite, hypersthene-augite andesite, biotite-augite andesite, augite-hornblende andesite, hornblende-augite andesite, and hornblende andesite.

The plagioclase phenocrysts in the andesites have a euhedral, equant to elongate, tabular habit, and range up to 5mm in length. They are twinned on Carlsbad, albite, and sometimes pericline laws, and show oscillatory, normal, and reverse zoning of both gradational and discontinuous types (Baker, 1949); patchy zoning (Vance, 1965) may also be present. The compositions of the zones have been determined in thin section by the combined Carlsbad-albite twin method (Kerr, 1959); they range from bytownite to oligoclase. Many of the plagioclase phenocrysts contain inclusions. These inclusions are of three main types: irregularly shaped groundmass inclusions; fine dust inclusions confined to one or more zones; and vermiform, formerly liquid inclusions which form a honeycomb type of structure (Kuno, 1950).

The augite phenocrysts are euhedral to subhedral, and commonly have a slightly elongate habit. They are pale to very pale green, generally weakly pleochroic, and may show colour zoning. Simple twinning on 100 is common. Some augite phenocrysts have cores of hypersthene or, more rarely, hornblende.

The hypersthene phenocrysts are euhedral and have an elongate prismatic habit. They are distinctly pleochroic from pale greyish green to pale pink. Some hypersthene phenocrysts have cores of augite.

The phenocrysts of hornblende are euhedral to subhedral, elongate prismatic. Two main varieties occur; a green hornblende and a brown to reddish brown basaltic hornblende (Deer, Howie & Zussman, 1962). Very commonly the hornblende phenocrysts are surrounded by reaction rims.

Titaniferous magnetite, the main opaque mineral, forms euhedral to anhedral equant phenocrysts up to 0.5mm in diameter. It is associated with hematite, which occurs as lamellae within and as rims around the magnetite phenocrysts, and with minor amounts of maghemite, ilmenite, and an unidentified opaque mineral (see Appendix A).

Apatite occurs as stout prismatic phenocrysts less than 0.5mm long. These commonly appear pleochroic, due to innumerable minute parallel pleochroic inclusions of an unidentified mineral.

In the glassy or very fine-grained groundmass crystallites of plagioclase, pyroxene, and magnetite can generally be identified. Plagioclase occurs as minute microlites which are normally too small for their compositions to be determined in thin section. The most common pyroxene is hypersthene, distinguished by its rod-like habit, moderate to high relief, very low birefringence, and straight extinction. Less common is clinopyroxene with a stubby habit, moderate birefringence, and oblique extinction. The crystallites lie in an interstitial matrix of cryptocrystalline felsitic material (altered glass) or clear to dusky, colourless to pale brown, isotropic glass (refractive index less than 1.54).

Primary tridymite and cristobalite, and secondary zeolites and chlorite minerals occur in vesicles. (The identification of tridymite and crystobalite in thin section is described by Kuno, 1950, and by Deer, Howie, & Zussman, 1962).

TRACHYANDESITE: a fine-grained andesitic rock containing sparse phenocrysts of plagioclase (andesine), augite, and green hornblende. The groundmass is subtrachytic and consists of elongate plagioclase laths, pyroxene and magnetite granules, and altered glass.

DACITE: a rock generally similar to andesite, but with a lower groundmass colour index (less than 10) and containing quartz phenocrysts.

BASALT: this rock is generally coarser-grained than andesite and has a higher groundmass colour index. It contains phenocrysts of plagioclase (bytownite-labradorite), pale brownish augite, and pseudomorphs after olivine. The groundmass consists of plagioclase laths up to 1mm long, and interstitial augite, opaque minerals, and altered glass.

GRANODIORITE: a rock with an average grainsize greater than 1mm containing more than 10 percent quartz; alkali feldspar forms 10-40 percent of total feldspar.

DIORITE: a rock with an average grainsize greater than 1mm containing less than 10 percent quartz; alkali feldspar forms less than 40 percent of total feldspar.

MICRODIORITE: the medium-grained equivalent of diorite, having an average groundmass grainsize of 0.05-1mm; this rock is normally porphyritic.

MONZONITE: similar to diorite except that alkali feldspar forms 40-60 percent of total feldspar.

SYENITE: similar to diorite except that alkali feldspar forms more than 60 percent of total feldspar.

GRANOPHYRE: a leucocratic rock containing micrographic quartz and alkali feldspar.

Pyroclastic Rocks (Wentworth & Williams, 1932; R.V. Fisher, 1961).

AGGLOMERATE: a rock mostly made up of sub-angular to rounded fragments greater than 32mm in diameter, the rounding of the fragments being due to volcanic action.

LAPILLI TUFF: a rock made up of consolidated volcanic ejecta 4-32mm in diameter.

TUFF: a rock made up of consolidated volcanic ejecta less than 4mm in diameter.

ASH: unconsolidated volcanic ejecta less than 4mm in diameter.

WELDED TUFF: a tuff in which the fragments were partly or completely welded together during deposition.

Sedimentary Rocks

Two main types of sedimentary rocks crop out on Bougainville and Buka; organic LIMESTONE, and volcaniclastic sedimentary rocks. The latter have been formed by the weathering, erosion, and redeposition (by mudflows, landslides, and water) of igneous and pyroclastic rocks, and generally contain little or no quartz; they consist of SILTSTONE, SANDSTONE, and CONGLOMERATE.

STRATIGRAPHY

The stratigraphy of Bougainville and Buka is summarised in Table 2 and the distribution of rock units is illustrated in Plate 18. The two islands are part of a complex volcanic pile rising 8500 feet above sea level and 37,000 feet above the floor of the Planet Deep south-west of Bougainville. The oldest rocks in the area, the Kieta Volcanics and the Buka Volcanics, consist of highly dissected intermediate and basic volcanics and derived sediments; they are probably Upper Oligocene to Lower Miocene. The Kieta Volcanics are locally overlain unconformably by Lower Miocene ('e' stage) Keriaka Limestone, a massive organic limestone formation. This in turn is overlain by undifferentiated volcanics and also by some of the volcanic formations which make up the Bougainville Group. The Sohano Limestone, of Pleistocene age, and Recent alluvium complete the stratigraphy.

TABLE 2: STRATIGRAPHY OF BOUGAINVILLE AND BUKA ISLANDS

AGE	GROUP	FORMATION	MAXIMUM THICKNESS	LITHOLOGY
Quaternary		Alluvium	Probably over 1000 feet	Alluvium, coral sand.
Pleistocene		Sohano Limestone	290 feet	Massive coralline and shelly limestone.
Recent to Pliocene(?)	BOUGAINVILLE GROUP	Tore Volcanics	Probably over 4000 feet	Andesite lava, agglomerate, tuff, derived fan deposits.
		Balbi Volcanics	About 6000 feet	Agglomerate, tuff, andesite lava, derived fan deposits.
		Numa Numa Volcanics	About 4000 feet	Agglomerate, tuff.
		Billy Mitchell Volcanics	About 5000 feet	Tuff, agglomerate, derived fan deposits.
		Bagana Volcanics	About 5000 feet	Andesite lava, tuff, agglomerate, derived fan deposits.
		Reini Volcanics	About 5000 feet	Andesite lava, derived fan deposits.
		Bakanovi Volcanics	About 1500 feet	Tuff, agglomerate, andesite lava.
		Takuan Volcanics	About 6000 feet	Andesite and dacite lava, tuff, agglomerate, derived fan deposits.
		Taroka Volcanics	About 7000 feet	Tuff, agglomerate, andesite lava, derived fan deposits.
		Emperor Range Volcanic Beds	Probably at least 6000 feet	Andesite and basalt lava, agglomerate, tuff, derived fan deposits.
Pliocene(?) to Miocene(?)		Undifferentiated volcanics	Unknown	Andesite basalt and dacite lava, agglomerate, tuff
Lower Miocene ('e' stage)		Keriaka Limestone	At least 4000 feet	Foraminiferal, shelly, coralline, and algal limestone.
Undifferentiated		Diorite		Microdiorite, diorite, monzonite, granodiorite, syenite, granophyre.
Lower Miocene(?) to Oligocene(?)		Buka Volcanics	At least 1600 feet	Sandstone and siltstone composed of volcanic material, tuff, agglomerate, basalt lava.
		Kieta Volcanics	At least 5000 feet	Sandstone, siltstone and conglomerate composed of volcanic material, agglomerate, tuff, andesite and basalt lava, pillow lava, welded tuff.

LOWER MIOCENE(?) TO OLIGOCENE(?)

Kieta Volcanics (New Name)

The Kieta Volcanics, which comprise the oldest rocks exposed on Bougainville Island, form the Crown Prince and Deuro Ranges in southern Bougainville, and crop out over an area of about 950 square miles. They are named after the port of Kieta, on the east coast of Bougainville. The formation consists of conglomerate, sandstone, and siltstone composed of volcanic material; agglomerate and tuff; and andesite, basalt, and trachy-andesite lava. Most of the lavas and pyroclastic rocks were probably erupted sub-aerially, and pillow lavas have only been found at one locality.

The type area of the Kieta Volcanics is Rankama Point, three miles west of Kieta. Here unbedded agglomerate, over 100 feet thick, is overlain by a hypersthene-augite andesite lava flow which is in turn overlain by flat-lying thin-bedded siltstones.

The maximum thickness of the formation is not known, as the base is nowhere exposed, but it is probably greater than 5000 feet in the central part of the Crown Prince Range.

Sedimentary rocks within the Kieta Volcanics are exposed at numerous localities (Fig.4). They are particularly well exposed in coastal sections between Cape Pui Pui and Pok Pok Island, near Kieta, where they consist of poorly sorted conglomerate and sandstone beds composed of volcanic debris (Plate 1, Fig.2; and Plate 2, Fig.1). The individual beds here dip at low angles in a general northerly direction; they are commonly less than 6 feet thick and have transitional upper and lower contacts. The conglomerate beds are made up of sub-angular to rounded fragments, mostly less than 1 foot in diameter, enclosed in a matrix of buff-coloured sandstone identical to that of the interbedded sandstones. Most of the fragments in the conglomerate are of andesite, but sandstone, tuff, and pumice also occur. The interbedded sandstones, some of which show cross bedding, are medium to coarse-grained, and consist of angular to sub-angular volcanic debris: they very commonly contain scattered pebbles and boulders. These conglomerates and sandstones are interpreted as 'fanglomerate' deposits (Lawson, 1925), laid down in alluvial fans adjacent to a high land mass to the south. Further exposures of fanglomerate, apparently similar to those near Kieta, occur in the cliffs on the north-east side of Mount Negrohead (Plate 1, Fig.1).

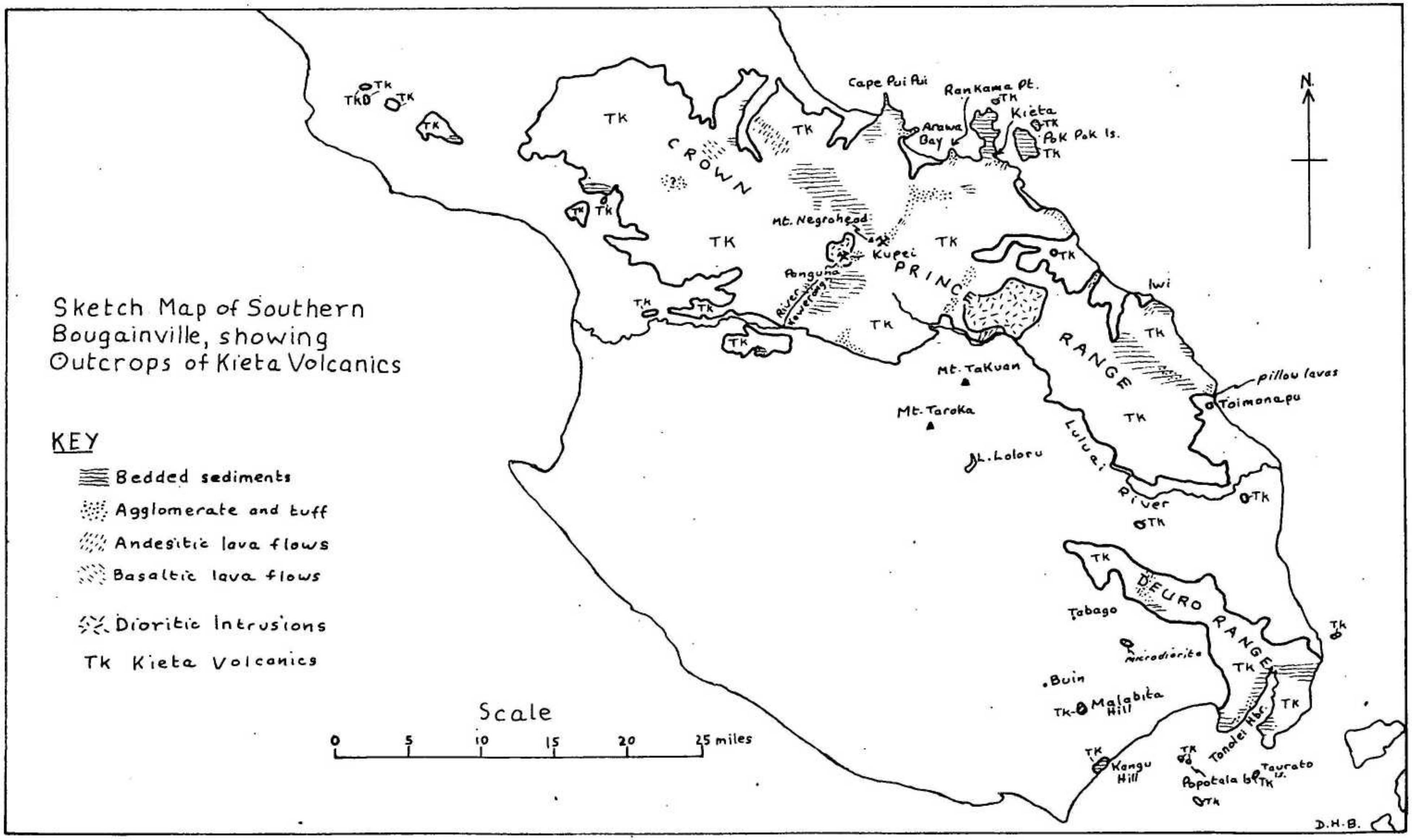
Elsewhere within the Kieta Volcanics the sedimentary rocks mostly consist of thick and thin-bedded sandstone and siltstone, with some interbedded conglomerate. Some limestone pebbles containing the foraminifera '<u>Linderina</u>' sp., a Lower Miocene form (Terpstra, 1966) have been found in a conglomerate cropping out between Iwi and Toimonapu plantations on the south-east coast of Bougainville. This indicates that the conglomerate cannot be older than Lower Miocene. No other fossils have been found within the Kieta Volcanics.

The sedimentary rocks are moderately well indurated except at a few localities, namely on Kangu Hill near Buin and near Tabago on the south side of the Deuro Range, where poorly consolidated sand and silt, apparently unfossiliferous, are exposed.

The most extensive exposures of agglomerate are in the area between Kieta, Panguna Mine, and the headwaters of the Luluai river (Fig.4). Good exposures also occur on either side of Arawa Bay east of Kieta, and on the west side of Tonolei Harbour. The agglomerate is generally well indurated, unsorted, and unbedded. It contains angular to rounded boulders, some more than 6 feet in diameter, enclosed in a tuffaceous matrix (Plate 2, Fig.2; Plate 3, Fig.1). The majority of the boulders are porphyritic pyroxene andesite. Less common are boulders of sandstone, tuff, pumice and microdiorite: the microdiorite boulders occur in an agglomerate exposed in the Kawerong river, south-west of Panguna mine. Some of the agglomerate is probably vent agglomerate.

Tuff made up of lithic and crystal fragments is mostly associated with the agglomerate, into which it commonly grades, but tuff also occurs interbedded with sandstone in the Tonolei Harbour area, and here there are probably all gradations between sub-aerial tuff and aqueous sandstone formed of reworked tuff. One undoubted sub-aerial tuff occurs as a bed 3 feet thick on Popotala Island, south-west of Tonolei Harbour. This tuff is made up of 'pisoliths', or 'petrified raindrops',up to 6mm in diameter: the pisoliths probably resulted when high flung ash particles formed coherent spherical aggregates while falling to the ground (Rittmann, 1962, p.75).

Lava flows have a relatively restricted distribution (Fig.4), although the sedimentary and pyroclastic rocks of the Kieta Volcanics are made up almost entirely of lava fragments. Andesite is the most abundant, but basalt, commonly partly propylitised, also occurs. A basaltic pillow lava crops out at Toimonapu (Plates 3, Fig.2). A trachyandesite flow and dyke are exposed at Iwi, south-east of Kieta.



Bureau of Mineral Resources, May 1966

To accompany record 1966/62

B56/A/8

Fig. 4

The andesites are subdivided according to the main ferromagnesian phenocrysts they contain into the following types (in order of abundance): hypersthene-augite andesite, augite andesite, and hornblende andesite. Olivine(which is invariably pseudomorphed by chloritic material) and hornblende occur as rare phenocrysts in some pyroxene andesites, and rare phenocrysts of augite and biotite occur in some hornblende andesites. The groundmass is normally very fine-grained and consists of feldspar microlites, pyroxene (clinopyroxene and/or hypersthene), magnetite, and interstitial felsitic material, or, rarely, clear glass. Modal analyses of some typical andesites are given in Table 3. The plagioclase phenocrysts occur as euhedral to subhedral zoned laths ranging in length from less than 0.5mm to an average maximum of 5mm: the laths have an average composition of labradorite or calcic andesine. Augite forms pale greenish euhedral to subhedral equant phenocrysts generally larger than those of plagioclase: some augite phenocrysts have cores of hypersthene. The hypersthene phenocrysts are generally smaller than those of augite and have a more elongate habit. The phenocrysts of green or brownish green hornblende range up to 1cm or more in length; they may be surrounded by reaction rims.

The basalt lavas are porphyritic, containing phenocrysts of calcic plagioclase, pale brownish augite and, in some specimens, olivine pseudomorphed by calcite and serpentine.

A number of microdiorite and diorite intrusions occur within the outcrop area of the Kieta Volcanics. Some of the intrusions are dyke-like and may represent feeder channels for the andesite lavas, but others are larger and stock-like. These larger intrusions are surrounded by metamorphic aureoles up to a quarter of a mile wide in which the lavas, and pyroclastic and sedimentary rocks have been hornfelsed. Other areas of hornfelsed rocks, at the northern end of Tonolei Harbour and between Arawa Bay and Kupei Mine, indicate that diorite probably occurs just below the present land surface.

Calcite and zeolites commonly occur as amygdale and vein minerals except within the thermal aureoles. The zeolites heulandite, chabazite, mordenite, and laumontite were identified in the field and were confirmed by X-ray diffraction studies (M. Morgan, pers.comm.). All four zeolites occur in the lava and agglomerate at Rankama Point, the type locality of the formation.

The Kieta Volcanics are considered to be the products of a number of ancient volcanoes, the eroded cores of which are represented by some of the agglomerates and dioritic intrusions that occur within the Kieta Volcanics outcrop area (Fig.4). The volcanoes were probably initially submarine and became sub-aerial later, when they formed volcanic islands. The Crown Prince and Deuro Ranges may be the eroded remnants of these islands. During repeated volcanic eruptions the central parts of the volcanoes were built up mainly by lavas and pyroclastic material, while derived terrestrial and/marine sedimentary rocks, including the fanglomerates, were deposited on the flanks.

The age of the Kieta Volcanics is uncertain, as the only identified fossils found within the formation are Lower Miocene foraminifera which occur in some limestone pebbles of a conglomerate bed cropping out south of Iwi Plantation. On the north-east side of the Crown Prince Range andesite flows belonging to the Kieta Volcanics are unconformably overlain by isolated outcrops of Lower Miocene ('e' stage) Keriaka Limestone. The Kieta Volcanics are also overlain by volcanics of the Bougainville Group. It is suggested, therefore, that most of the rocks included within the Kieta Volcanics are Lower Miocene to Upper Oligocene, although some, such as the unconsolidated sediments at Kangu Hill near Buin, may be younger (possibly equivalent to the Pemba Siltstone, of probable Pliocene age, described by Coleman, 1962, from Choiseul, B.S.I.P.).

<u>Buka Volcanics (New Name)</u>

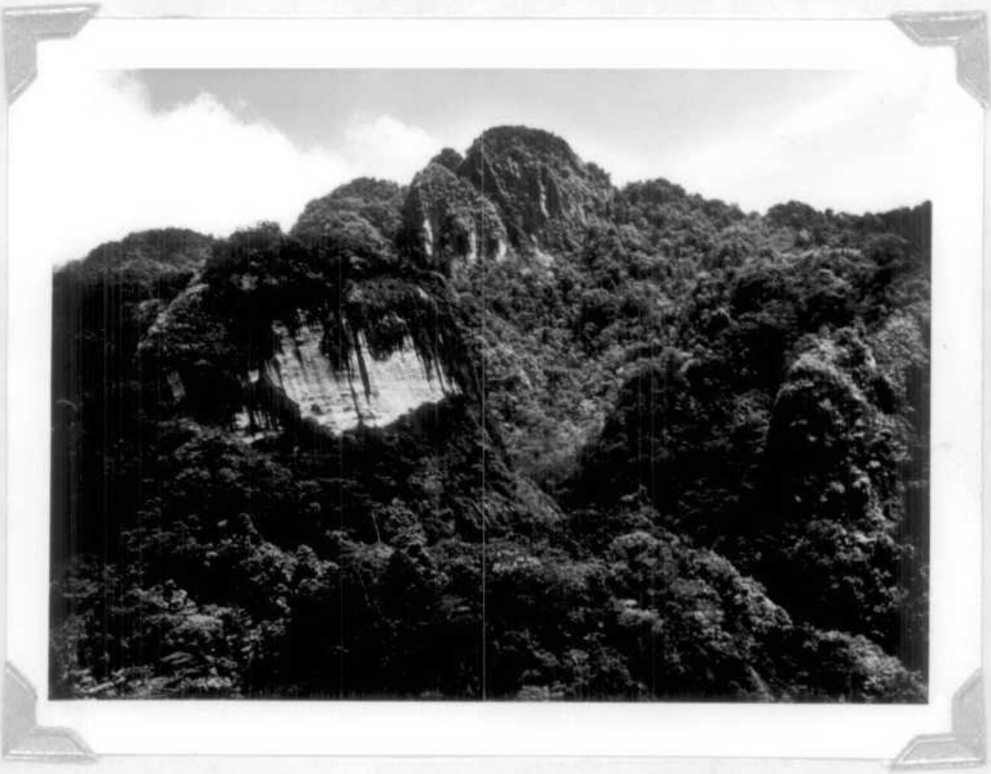
The Buka Volcanics are named from Buka Island. The formation forms the Parkinson Range in south-western Buka and the hilly areas of Madehas, Taiof, and Tanwoa Islands to the south, and has a total outcrop area of about 64 square miles. It consists chiefly of sandstone and siltstone composed of volcanic material with subordinate agglomerate, tuff and basalt lava flows.

The sandstone and siltstone are generally well bedded and locally show current bedding, graded bedding, and slump structures. The individual beds are generally less than 1 foot thick. Dips are mostly shallow (less than 20°) and strikes have a general northerly trend, parallel to the main axis of the Parkinson Range.

Agglomerate occurs underlying bedded sandstone on Madehas Island. The agglomerate is made up mostly of sandstone fragments but also includes some unfossiliferous limestone boulders, up to 18 inches in diameter; these fragments are enclosed in a tuffaceous matrix.

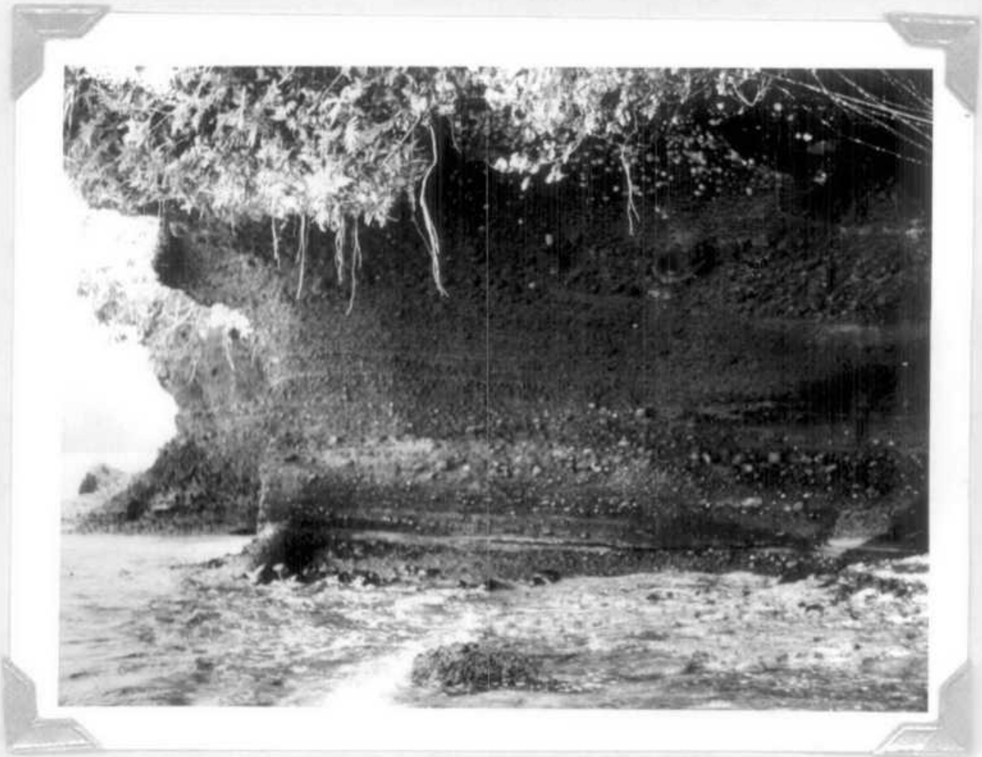
Lava flows of amygdaloidal basalt occur near Nonavek at the southern end of the Parkinson Range, on Madehas Island, and at the southern tip of Taiof Island. Under the microscope the basalt is seen to consist of abundant bytownite and sparse augite phenocrysts lying in a fine-grained matrix of labradorite laths, interstitial pale brown augite, magnetite, and altered (chloritic) glass: chlorite, green hornblende, alkali feldspar, and zeolites

PLATE 1.



Neg.G/8862 (Photo D.H.Blake)

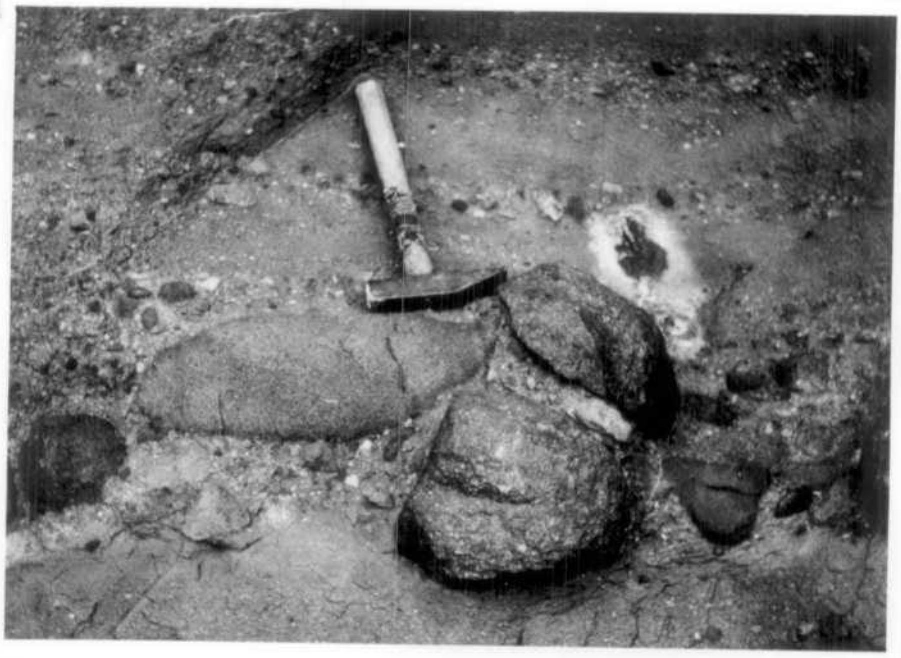
Fig.1. Cliffs on the north side of Mount Negrohead, Crown Prince Range, showing exposures of bedded 'fanglomerates' belonging to the Kieta Volcanics.



Neg.G/8667 (Photo F.S.Chong).

Fig.2. Bedded fanglomerates of the Kieta Volcanics on the east coast of Tautsina Island, north-east of Kieta.

PLATE 2.



Neg.G/8863 (Photo,D.H.Blake)

Fig.1. Bedded fanglomerate containing boulders of andesite,Kieta Volcanics. A coastal exposure on the north-west side of the Kieta Peninsula.

Neg.G/9051 (Photo F.S.Chong)

Fig.2. Pyroxene crystals in the tuffaceous matrix of an agglomerate, Kieta Volcanics. A coastal exposure on the east side of Cape Pui Pui.

PLATE 3.

Neg.G/8864 (Photo.F.S.Chong)

Fig.1. Massive agglomeratic tuff on the east side of Cape Pui Pui, Kieta Volcanics.

Neg.G/9034 (Photo D.H.Blake)

Fig.2. Basaltic pillow lava, north side of Toimonapu Plantation, Kieta Volcanics.

occur as alteration products of the plagioclase and augite. The amygdales are infilled with zeolites, chlorite, calcite, and actinolite.

The type locality of the Buka Volcanics is half a mile east of Bei (lat. 5°14'S, long. 154°34'E) on the west side of Buka Island. Here over 100 feet of well bedded sandstone and siltstone are exposed in a cliff face.

The formation probably has a maximum thickness greater than 1600 feet (the height of the Parkinson Range). Its base is not exposed.

The Buka Volcanics are apparently unfossiliferous, and their age is uncertain. The formation is overlain by the Pleistocene Sohano Limestone, indicating a pre-Pleistocene age, while a Miocene or older age is suggested by the topography of the Parkinson Range. This range appears to be in a much older stage of erosion than the Emperor Range of northern Bougainville, which is formed of post-Miocene volcanic rocks. The Buka Volcanics are therefore considered to be Lower Miocene to Upper Oligocene, comparable with the Kieta Volcanics on Bougainville Island.

LOWER MIOCENE ('e' stage)

Keriaka Limestone (New Name)

'Keriaka' is both the name of the census district and of the native language of the area where the main outcrop of the Keriaka Limestone occurs - a roughly rectangular area of about 100 square miles on the western side of Bougainville, between latitudes 6°00'S and 6°11'S. Small isolated outcrops of the Keriaka Limestone have also been found on the eastern side of Bougainville between latitudes 5°56'S and 6°12'S.

In the Keriaka census district the limestone occurs as an uplifted reef complex which forms a gently tilted plateau dipping at about 5° to the west-south-west. This plateau has a maximum height near its eastern margin of 4400 feet, where it is bounded by high cliffs, and here the limestone has its maximum thickness of at least 4,000 feet: its base is not exposed. The top of the plateau appears to correspond roughly with the original top of the reef complex, although the surface features of the plateau are entirely erosional. Speight (in press a) considers that the western part of this plateau has been lowered by erosion more rapidly than the eastern part, and that the deduced top of the uplifted reef complex dips at only 3° to the west-south-west.

The surface features of the plateau are described by Speight (in press, a) as follows: 'The typical landscape is a karst of very closely spaced dolines, grading into valleys of intergrated drainage and separated by a reticulate system of saw-tooth ridges about 400 feet high. The slopes tend to be concave and very steep. In some areas on the periphery of the former atoll pyramidal hills tend to be more conspicuous than conical dolines, resulting in a fine textured type of kegel karst perhaps approaching the pyramid-and-doline karst of Jennings and Bik (1962). The landscape is at present mantled with many feet of ash and the development must have been influenced by this to some extent.'

The outcrops of Keriaka Limestone on the eastern side of Bougainville occur at heights varying from near sea level at Mantai Mission to over 2,500 feet near Sisivi. The largest of these outcrops, just west of Mantai Mission, has a well developed 'Kegelkarst' (Jennings and Bik, 1962) topography, unlike the smaller limestone outcrops, where karst topography is not readily apparent on the air photographs.

The type area of the Keriaka Limestone is on the west coast of Bougainville, south-east of Cape Moltke, where the limestone forms cliffs up to 100 feet high.

The Keriaka Limestone is generally a massive organic limestone and bedding could rarely be determined. It ranges from pale buff to pale grey, and is locally partly recrystallised and veined by calcite.

Fossils preserved in the Keriaka Limestone (Mawson and Chapman, 1935; Crespin, 1951; Kicinski, 1955; Terpstra, 1965, 1966) are Algae, including Halimeda sp., Lithothamnium sp., ; Bryozoa; Corals; Echinoid Spines; Mollusca; and the following Foraminifera: Amphistegina sp., Austrotrillina sp., Borelis sp., Cycloclypeus sp., Dentalina sp., Elphidium sp., Flosculinella sp., Globigerina sp., Gypsina sp., Heterostegina sp., Lepidocyclina (Nephrolepidina and Eulepidina) sp., 'Linderina' sp., Marginopora sp., Miogypsina sp., Miogypsinoides sp., Operculina sp., Quinqueloculina sp., Sorites sp., Spiroclypeus sp., Textularia sp., Triloculina sp.. The faunas indicate that the limestone was formed under marine conditions generally not exceeding 75 to 100 feet in depth. The foraminiferal faunas are closely related to those found and described by C.G. Adams (1965) in the upper Te beds of the Melinau Limestone, Sarawak, and they indicate that the age of the Keriaka Limestone is Lower Miocene, 'e' stage. The Keriaka Limestone is older than the biostromal Mount Vasu Limestone on Choiseul, B.S.I.P., which is Lower Miocene f1-2, and is of similar age to the Kamanga Grit (Coleman, 1963).

The Keriaka Limestone is overlain by Bakanovi Volcanics near Mantai Mission, by undifferentiated volcanics, Balbi Volcanics, and Numa Numa Volcanics in the Sisivi - Wakunai River area, and by Balbi Volcanics at the northern end of the Keriaka Plateau. The base of the formation was seen only near Boira, on the north-east side of the Crown Prince Range, where it unconformably overlies andesite lava belonging to the Kieta Volcanics.

PLIOCENE(?) TO MIOCENE(?)

Undifferentiated volcanics

In the northern part of central Bougainville outcrops of volcanic rocks of uncertain age have been mapped as undifferentiated volcanics. These outcrops occur (1) between Mount Bagana and Laruma River, (2) south of Sisivi, and (3) on the north side of the lower part of the Wakunai River. They have a total area of about 38 square miles.

The undifferentiated volcanics form erosional hills which are distinct from the adjacent outcrops of the Lower Miocene Keriaka Limestone and the Pleistocene to Recent volcanics of the Bougainville Group. They consist of lava, agglomerate, and tuff. The lavas are basalt, augite andesite, hypersthene-augite andesite, hornblende andesite, and dacite. The few lava specimens examined under the microscope could not be distinguished petrographically from either the lavas of the Kieta Volcanics or the lavas of the Bougainville Group. Some lavas contain zeolites.

South of Sisivi the undifferentiated volcanics have been intruded and locally hornfelsed by small microdiorite intrusions.

From both their location and erosional state the undifferentiated volcanics could be comparable in age to either the older members of the post-Miocene Emperor Range Volcanic Beds or the mostly pre-Miocene Kieta Volcanics. They are partly overlain by the Pleistocene to Recent Balbi, Numa Numa, Billy Mitchell and Bagana Volcanics. Their contacts with the Lower Miocene Keriaka Limestone were not seen.

RECENT TO PLIOCENE(?)

Bougainville Group (New Name)

The Bougainville Group comprises the younger volcanic rocks of Bougainville and cover more than half the inland. These volcanics consist of lavas, pyroclastic rocks, and derived sedimentary rocks, and have a maximum thickness of about 8000 feet. They range from Pliocene or possibly Miocene to the present day.

The formations which make up the Bougainville Group are the products of several readily identifiable volcanoes or groups of volcanoes located along the central axis of Bougainville Island (Plate 4, Fig.1), and as such they are partly distinguished from one another on geomorphological evidence. The ages of the volcanoes can be estimated from their present eroded form (Kear, 1957, 1959). The constituent formations are the Tore, Balbi, Numa Numa, Billy Mitchell, Bagana, Reini, Bakanovi, Takuan, and Taroka Volcanics. In addition there are other volcanic rocks within the Bougainville Group which are the products of unspecified volcanic centres and these are grouped together as the Emperor Range Volcanic Beds.

Tore Volcanics (New Name)

The Tore Volcanics are the products of a previously unnamed volcano, here called the Tore volcano, which is situated in northern Bougainville immediately north-west of Mount Balbi. The name is taken from the Tore River, which has its headwaters on the south-west flank of the volcano.

The formation crops out over an area of about 75 square miles, mostly on the western side of the Emperor Range. It consists of andesite lava flows, pyroclastic rocks and derived sediments, and has a probable maximum thickness greater than 4000 feet. The type area is the headwaters of the Tore River.

Tore Volcano is a densely forested and apparently extinct strato volcano rising eastwards from sea level on the west coast to about 7000 feet on the Emperor Range watershed. It does not form a major topographic feature by itself as it is part of the chain of extinct volcanoes north-west of Mount Balbi. There is no record of either historic eruptions or thermal activity associated with the volcano.

The summit area of the Tore Volcano (Fig. 5) consists of an erosional pyramidal peak (a possible spine), an adventive ash cone 2 miles to the north-west (Plate 4, Fig.2), and a flattish area in between. Two cirque-like valleys occur north-east of the pyramidal peak. On the south-west flank of the volcano a group of well preserved 'aa' lava flows (Cotton, 1944) descend from the northern part of the summit area. The largest flow is 9 miles long, locally more than 1 mile wide, and is probably over 100 feet thick. Near the summit area the flows have convex cross profiles and have transverse arcuate furrows facing up-slope on their upper surfaces, whereas lower down on the flanks of the volcano they have marginal levees similar to those found on lava flows on Ngaurohoe volcano, New Zealand (Gregg, 1956). Derived fan deposits extend from the steep fronts of the lava flows down to sea level.

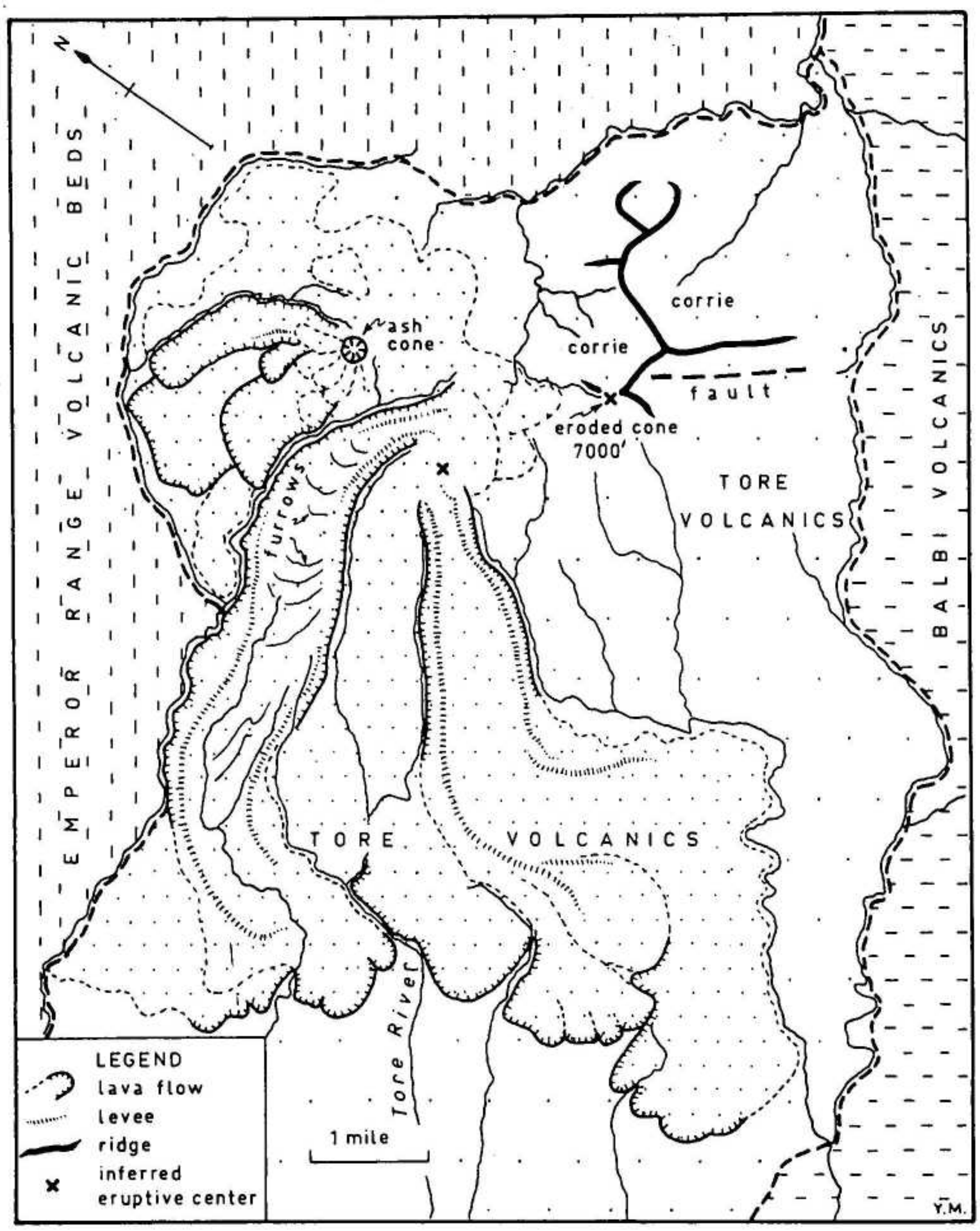
PLATE 4.

Neg. G/9043 (Photo D.H.Blake)

Fig.1. View looking south-eastwards along the central axis of Bougainville Island, Part of the Emperor Range is shown in the foreground, with Mount Balbi (8505') in the middle distance on the right. Twin peaks representing the Mount Takuan (left) and Mount Taroka (right) lines of volcanoes can be seen in the far distance on the left, behind Numa Numa Volcano. Mount Bagana is almost completely hidden by cloud on the far side of Mount Balbi.

Neg.G/8866 (Photo.D.H.Blake)

Fig, 2. Adventive ash cone covered by dense jungle on the summit of Tore volcano, Emperor Range.



Sketch map of Tore Volcano
showing Recent Lava Field

TABLE 3 - Modal Analyses (Vol.%) of Andesites and Dacites from Bougainville

	Formation	Phenocrysts										Groundmass	
		Pl	Au	Hy	Ol	BH	GH	Bi	Ma	Qz	Ap	Gr	Constituents
1	Kieta Volcanics	25	9	-	-	-	-	-	3	-	<1	63	Pl, Cp, Ma, Fst
2	" "	31	8	2	-	-	-	-	1	-	-	58	Pl, Hy, Ma, Fst
3	" "	23	23	2	-	-	-	-	1	-	-	51	Pl, Cp, Ma, Gl.
4	" "	34	11	4	-	-	-	-	1	-	-	50	Glass
5	" "	22	-	-	-	-	17	-	<1	-	<1	61	Pl, Ma, Fst
6	Tore Volcanics	23	5	<1	-	1	-	3	1	-	<1	67	Pl, Cp, Ma, Fst
7	Balbi Volcanics	32	12	1	1	-	-	-	4	-	<1	50	Pl, Hy, Ma, Gl
8		35	5	2	-	-	-	<1	5	-	-	53	Pl, Hy, Ma, Gl
9	Numa Numa Volcanics	29	6	<1	-	4	-	-	3	-	-	58	Pl, Hy, Ma, Gl
10		27	3	2	-	5	-	-	2	-	<1	61	Pl, Hy, Ma, Fst
11	Billy Mitchell	28	<1	-	-	-	13	-	1	-	<1	58	Pl, Ma, Fst
12	Volcanics	24	<1	-	-	11	-	-	2	-	<1	63	Pl, Ma, Fst
13	Bagana Volcanics	26	6	<1	1	<1	-	-	1	-	-	66	Pl, Hy, Ma, Gl
14		35	8	<1	1	<1	-	-	3	-	-	53	Pl, Hy, Ma, Gl
15		35	6	1	-	1	-	-	2	-	-	54	Pl, Hy, Ma, Gl
16		37	6	<1	1	1	-	-	2	-	-	53	Pl, Hy, Ma, Gl
17	Reini Volcanics	22	7	-	-	3	-	-	3	-	-	65	Pl, Hy, Cp, Ma, Fst
18	Bakanovi Volcanics	25	-	-	-	-	16	-	1	-	<1	58	Pl, Ma, Fst
19		27	-	-	-	-	10	-	1	-	<1	62	Pl, Ma, Fst
20	Takuan Volcanics	30	8	<1	-	6	-	-	2	-	<1	54	Pl, Hy, Ma, Fst
21		36	14	<1	-	-	-	-	2	-	-	47	Pl, Cp, Hy, Ma, Fst
22		22	14	-	-	5	-	-	4	-	<1	55	Pl, Hy, Ma, Gl.
23	(Luluai dome)	31	<1	-	-	6	-	<1	<1	6	<1	56	Pl, Ma, Fst
24	(Damu dome)	35	1	-	-	8	-	-	1	<1	<1	59	Pl, Af, Cp, Ma, Fst
25	Taroka Volcanics	39	5	-	-	6	-	-	3	-	<1	47	Pl, Cp, Ma, Fst
26		30	5	-	-	4	-	-	2	-	-	58	Pl, Cp, Ma, Fst
27		40	3	-	-	6	-	-	<1	-	<1	51	Pl, Cp, Ma, Fst
28		25	6	-	-	4	-	-	2	-	<1	62	Pl, Cp, Ma, Fst
29	Emperor Range	20	2	<1	-	<1	-	<1	1	<1	<1	77	Pl, Cp, Hy, Ma, Fst
30	Volcanic Beds	34	6	-	1	-	-	-	2	-	<1	57	Pl, Ma, Fst
31		23	8	1	5	-	-	<1	1	-	<1	62	Pl, Cp, Ma, Gl
32	Undifferentiated volcanics	18	1	-	-	11	-	<1	<1	2	<1	68	Pl, BH, Ma, Fst

Key to symbols: Pl: plagioclase; Au: augite; Hy: hypersthene; Ol: olivine; BH: brown and basaltic hornblende; GH: green hornblende; Bi: biotite; Ma: magnetite; Qz: quartz; Ap: apatite; Gr: groundmass (does not include vesicles); Cp: clinopyroxene; Fst: felsitic or cryptocrystalline material; Gl: glass; Af: alkali feldspar.

Key to Analyses 3

1. Augite andesite (65490036A)* lava flow; Taurato Island, south of Tonolei Harbour.
2. Hypersthene-augite andesite (65490044), Malabita Hill, near Buin.
3. Hypersthene-augite andesite (65490135); lava flow, Rankama Point.
4. Hypersthene-augite andesite (65490184A); lava bomb in agglomerate, near Koro, N.N.E. of Boku.
5. Hornblende andesite (65491125); lava flow near Korpei, west of Kieta.
6. Biotite-augite andesite (64490126-4); boulder from Potua River, south of Konua.
7. Olivine-hypersthene-augite andesite (8B/14786); lava flow near Togarau, south-east flank of Mount Balbi.
8. Hypersthene-augite andesite (65490599); lava bomb, summit of Mount Balbi.
9. Hornblende-augite andesite (65490164A); boulder in creek, Old Leikaia, near Wakunai.
10. Hypersthene-augite-hornblende andesite (65491221); boulder on hillside, Sisivi.
11. Hornblende andesite (65490162C); boulder in Pukarobi River, east flank of Billy Mitchell volcano.
12. Hornblende andesite (65490162D); boulder in Pukarobi River, east flank of Billy Mitchell volcano.
13. Augite andesite (65490121); front of 1965 lava flow, northernmost arm, Mount Bagana.
14. Augite andesite (65490122); 1952 lava flow, south-west side Mount Bagana.
15. Augite andesite (65490148); pre-1946 lava flow, south-east flank, Mount Bagana.
16. Augite andesite (65490151); 1946-1947 lava flow, east flank, Mount Bagana.
17. Hornblende-augite andesite (65490149B); lava flow, western flank of Reini volcano.
18. Hornblende andesite (65491106); ?lava flow, Bakanovi River.
19. Hornblende andesite (65491195); ?lava flow N.E. of Korpani.
20. Hornblende-augite andesite (65490562); lava flow, N.E. flank, Mount Takuan.
21. Augite andesite (65491212B); boulder on valley side, Poenga River.
22. Hornblende-augite andesite (65491213); boulder on top of lava flow, north-east flank of volcano.
23. Hornblende dacite (65490160); dome on north side of Luluai River, 14 miles east-south-east of Mount Takuan.
24. Hornblende andesite (65491165); dome near Damu, 3 miles north-west of Mount Takuan.
25. Augite-hornblende andesite (R5160); Loloru dome, Lake Loloru.
26. Hornblende-augite andesite (R5166); Loloru dome, Lake Loloru.
27. Augite-hornblende andesite (65491022A); boulder in creek near Konga.
28. Hornblende-augite andesite (65491022B); boulder in creek near Konga.

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*Specimen number

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29. Augite andesite (65490171); lava flow, tributary creek of Aita River.
30. Olivine-augite andesite (65490199B); lava flow on shore south of Soraken.
31. Hypersthene-olivine-augite andesite (65491090); Banui River.
32. Hornblende dacite, Torokina River, 6 miles N.E. of Torokina (65490120).

The upper part of the Tore volcano between the lava flows and Mount Balbi, and including the pyramidal peak, has been extensively eroded and little, if any, of the constructional surface of the volcano has been preserved. This part of the volcano has long been extinct and is probably Pleistocene, whereas the well preserved adventive ash cone and lava flows are considered to be Recent.

The Tore Volcanics abut against Balbi Volcanics to the south and overlie Emperor Range Volcanic Beds to the north and east.

Petrography

Two pebbles of biotite-augite andesite collected by J.G. Speight from near the front of one of the Tore lava flows have been examined in thin section. The andesite contains phenocrysts less than 5mm long of plagioclase, augite, biotite, magnetite, hypersthene, hornblende and apatite (Table 3). The phenocrysts are enclosed in a fine-grained matrix composed of feldspar microlites, clinopyroxene and magnetite granules, and interstitial cryptocrystalline material.

The plagioclase phenocrysts are of weakly zoned labradorite (An50-67). Hypersthene occurs in the cores of some augites and also as separate phenocrysts. The phenocrysts of reddish brown biotite and yellowish brown hornblende have opaque reaction rims.

Balbi Volcanics (New Name)

The Balbi Volcanics occupy an area of over 200 square miles and consist of andesite lava, agglomerate, tuff, ash and derived fan deposits. They were erupted from the now dormant Mount Balbi volcano, a complex strato volcano rising to a height of 8502 feet at the south-eastern end of the Emperor Range, north-west Bougainville (Plate 4, Fig.1). The type area of the formation is the eastern flank of Mount Balbi, where lava flows are interlayered with pyroclastic deposits. The maximum thickness of the formation is probably greater than 6000 feet.

The Balbi Volcanics are considered to range in age from Recent to late Pleistocene. They unconformably overlie Keriaka Limestone, undifferentiated volcanics and Emperor Range Volcanic Bed, and abut against the Tore Volcanics to the north-west and the Numa Numa Volcanics to the south-east.

Balbi Volcano has been described by Fisher (1939, 1954, 1957), Taylor (1956), and Branch (1965a). It is made up of a number of coalescing volcanic cones which are roughly aligned in a north-west direction. The flanks of the volcano are covered by dense tropical rain forest up to 4000 feet, bamboo and moss forest between 4000 feet and 7500 feet, and alpine rush above 7500 feet (Branch, 1965a).

The summit area comprises a solfatara field and a number of ash cones, craters, and domes (Plate 5, Figs. 1 & 2; Plates 6 & 7). The best preserved craters are referred to as A', A, B, C, D, E, and F by Fisher (1957) and Branch (1965a). Craters A' to E occur in a line 2 miles long trending north-north-west, and crater F lies in an ash cone, the highest point of Mount Balbi, just over 1 mile south-west of crater C. The solfatara field lies between craters B and F. There are sulphurous fumeroles with temperatures of over 110°C. in this field, and also inside crater B. Two prominent domes, which were not examined on the ground, occur south and south-east of crater A.

Three large amphitheatre-headed valleys have been formed on the flanks of Mount Balbi. The largest valley is on the north side of the volcano; it is 4½ miles long, up to 2 miles wide, and over 2000 feet deep, and is similar to the amphitheatre-headed valleys on Manam volcano, New Guinea, which Taylor (1958) considers to have been formed by very rapid erosion. During the development of this valley eruptive vents on the north side of Mount Balbi were obliterated: the approximate positions of these vents can be found by projecting upwards the volcanic constructional surfaces on either side of the valley. The two other valleys, on the north-east and south sides of Mount Balbi, resemble in shape the amphitheatre-headed valleys on the extinct Piton des Neiges volcano, Reunion Island, where narrow gorges on the lower slopes of the volcano pass upwards into roughly circular amphitheatres. Upton and Wadsworth (1965) consider that the valleys on Reunion are also due to rapid erosion, but the circular amphitheatres of the two valleys on Mount Balbi are thought more likely to be old explosion craters: it is probably significant that fumeroles occur in the amphitheatre on the north-east side of Mount Balbi.

The upper part of Balbi volcano is mostly covered by ash on which a fine-textured pattern of ridges, spurs and narrow ravines has developed. The occurrence of volcanic bombs within the ash suggests that most of the ash is probably air fall material. However, some of the ash appears from the air to

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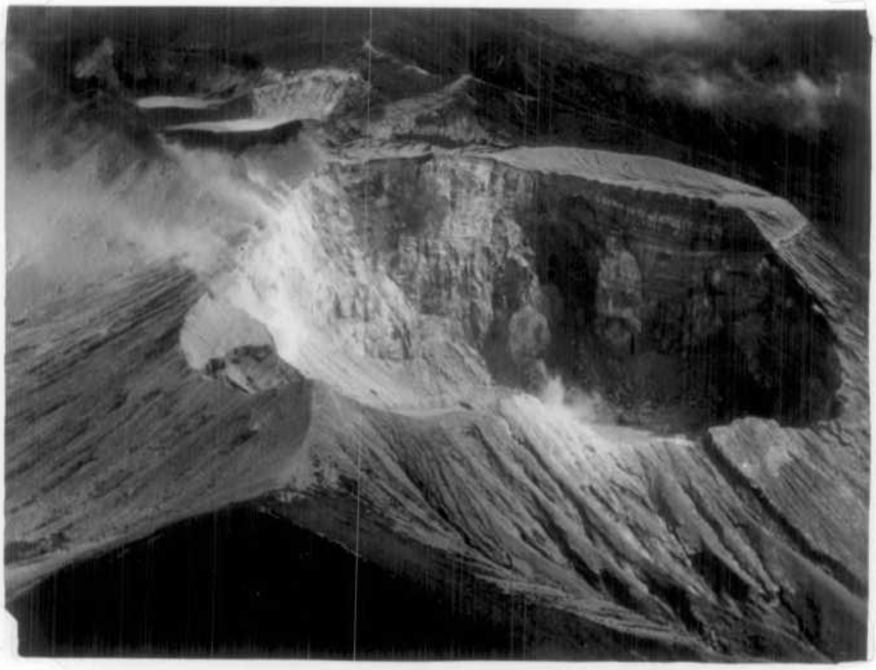
PLATE 5.

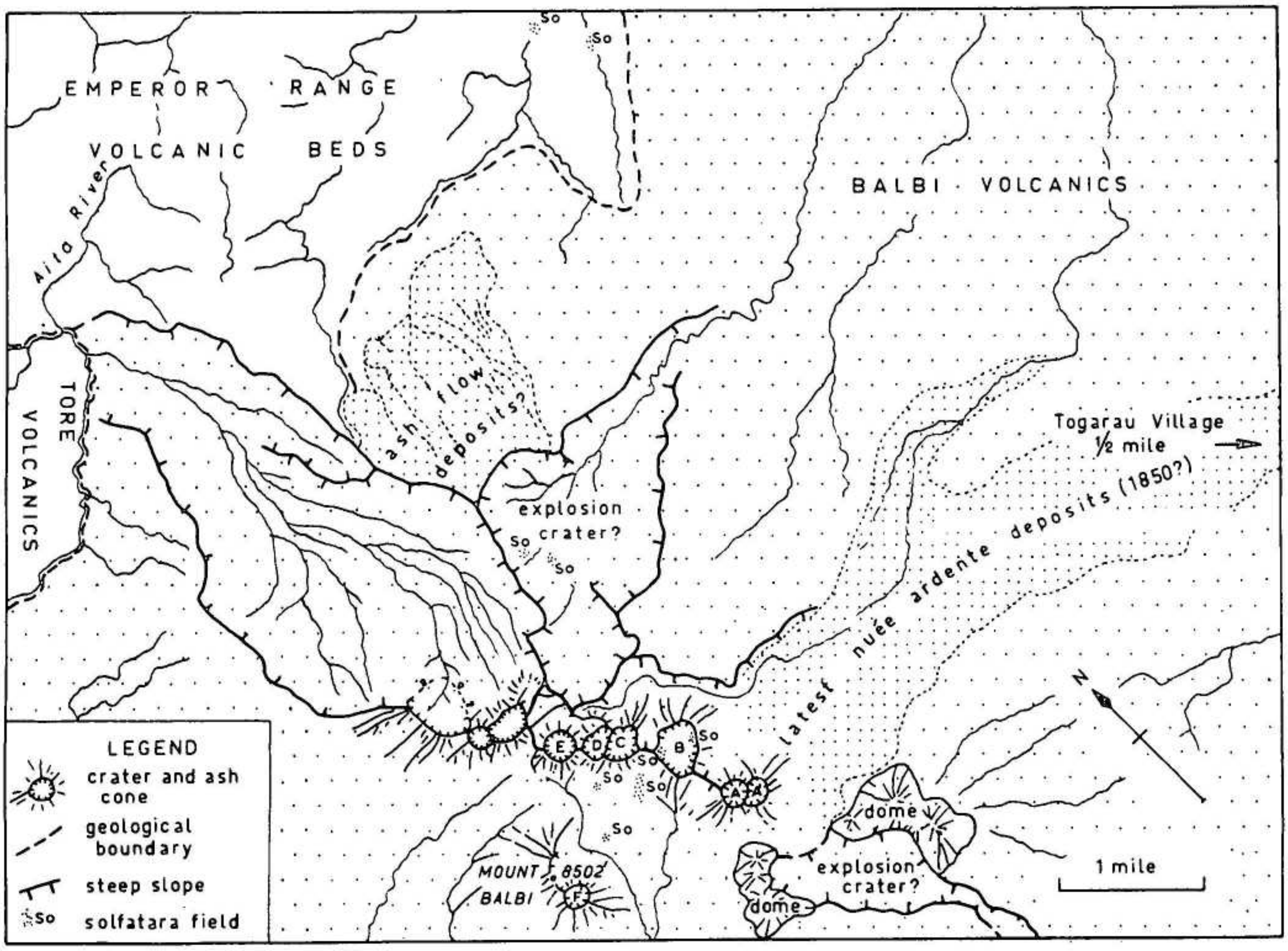
Neg.G/9042 (Photo, D.H.Blake)

Fig. 1. Summit area of Mount Balbi volcano, from the south-east. Craters A and A' are in the foreground, in front of crater B; craters C. D. and E are behind crater B; crater F is just off the photograph, to the left. The main solfatara field can be seen in the left middle distance. The Emperor Range is in the background.



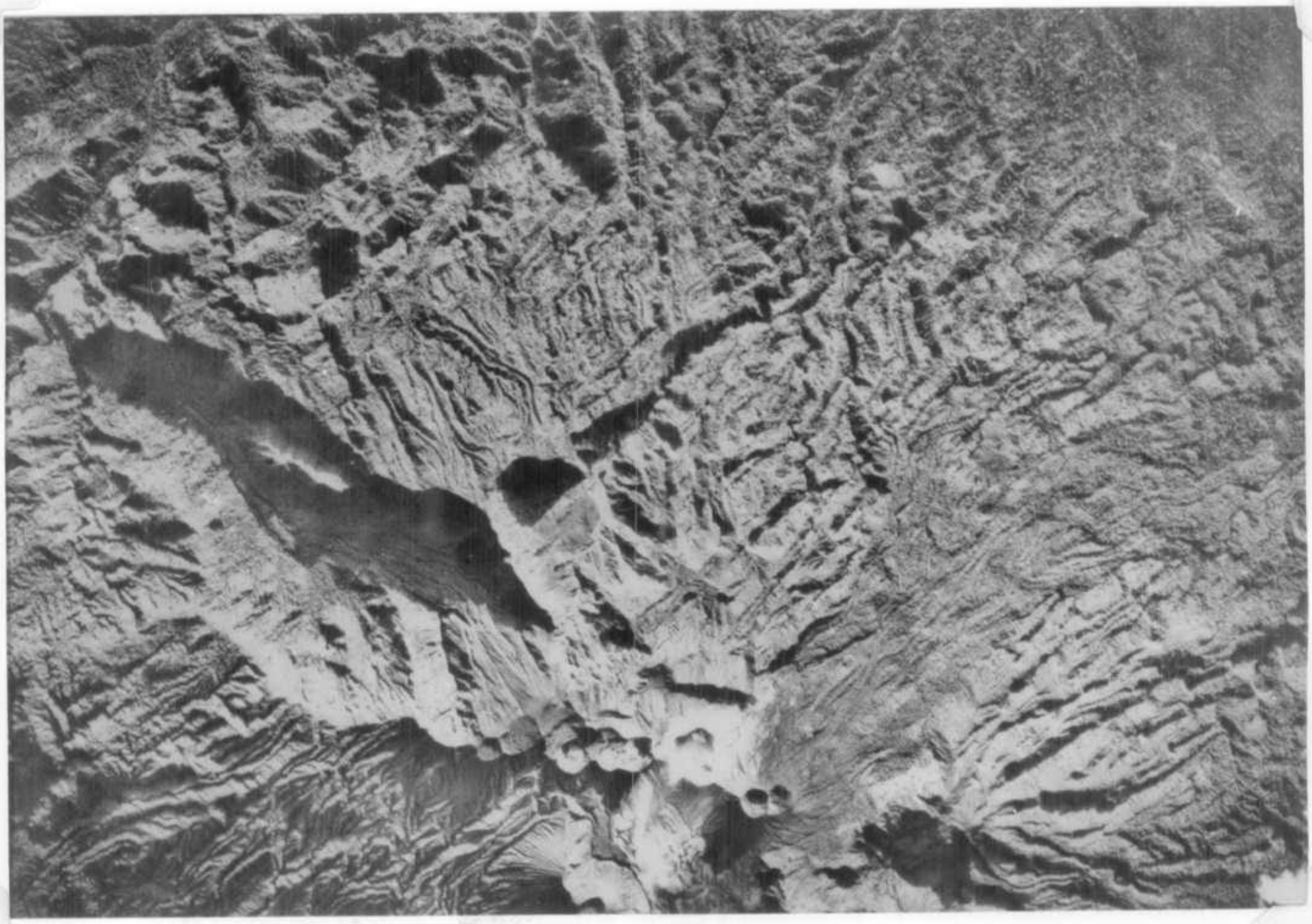
Neg. G/9049 (Photo, F.S.Chong)

Fig. 2. Mount Balbi volcano, crater B, from the south-east. Craters C and D are shown in the left background.



Mount Balbi Volcano (overlay for Plate 6)

PLATE 6.



Neg.G/9093

Vertical air photograph mosaic of Mount Balbi volcano
(See Plate 6).
R.A.F. photographs; sortie 543A/418. Nos.11 & 12. 24th June,1963.

form slightly elevated sinuous flows which may be of nuée ardente or lahar origin (Plates 6 and 7).

Lava flows and interlayered agglomerate and tuff are exposed beneath the ash in gorges and waterfalls on the upper slopes of the volcano: some of the lavas show columnar jointing. The lower part of the volcano, below about 2000 feet, consists mostly of agglomerate and tuff which probably represent nuée ardente and lahar deposits.

The last eruption from Mount Balbi is reputed to have occurred some time between 1800 and 1850 (Branch, 1965a) and is said to have killed a number of natives. During the eruption nuée ardentes were emitted, probably from crater B, and descended the south-eastern flank of the volcano: their course can be clearly seen on air photographs (Plates 6 and 7). The present activity of the volcano is confined to the fumeroles in the summit area and in the north-eastern amphitheatre, and to hot springs on the flanks (Branch, 1965a). The volcano is considered potentially active, and nuée ardentes are likely to be emitted during its next eruption (Branch 1965a).

<u>Petrography</u>

The lava flows and the rock fragments in the agglomerates on Mount Balbi are andesitic. All the specimens examined in thin section are of hypersthene-augite andesite containing small phenocrysts of plagioclase, augite, hypersthene, and magnetite; most specimens also contain phenocrysts of apatite, and some contain olivine phenocrysts. In addition sparse phenocrysts of basaltic hornblende and brown biotite occur in some specimens. The phenocrysts lie in a very fine-grained groundmass made up of plagioclase microlites, hypersthene rods, magnetite granules, and interstitial pale brownish isotropic glass ($n < 1.54$) or felsite. Modal analyses of two Balbi andesites are presented in table 3.

The plagioclase phenocrysts are mostly less than 3mm long, and are invariably zoned, the zones ranging in composition from andesine (An45) to bytownite (An74). The augite phenocrysts are generally less than 2mm long, and commonly have cores of hypersthene. Hypersthene also forms separate euhedral phenocrysts which are smaller and more elongate than those of augite. The olivine phenocrysts are less than 1mm in diameter; some show marginal alteration to iddingsite. The apatite phenocrysts are euhedral, less than 0.5mm long, and are commonly crowded with minute pleochroic inclusions. The phenocrysts of hornblende and biotite have reaction rims consisting of opaque material and small hypersthene crystals.

Numa Numa Volcanics (New Name)

These are the products of a previously unnamed extinct volcano, here called the Numa Numa volcano, which is situated south-east of Mount Balbi (Plate 4, Fig.1). The formation covers an area of about 175 square miles and is named after Numa Numa River, which flows down the north flank of the volcano to Numa Numa Plantation, on the north-east coast of Bougainville.

The Numa Numa Volcanics consist very largely of andesitic agglomerate, tuff, and ash, and no undoubted lava flows were seen. The pyroclastic rocks, well exposed in deep gullies cut in the flanks of the Numa Numa volcano, include both nuée ardente and lahar deposits (Plate 8, Fig.2). The type area is the north flank of the volcano. The formation is probably about 5000 feet thick in the central part of the Numa Numa volcano.

Most of the Numa Numa Volcanics are probably Pleistocene. The formation overlies Keriaka Limestone to the west and undifferentiated volcanics to the south-west; it abuts against Balbi Volcanics to the north-west, and is overlain by Billy Mitchell Volcanics to the south-east.

Numa Numa Volcano is a densely forested, complex strato volcano which has a shield-like topographical form (Plate 8, Fig.1). The summit area consists of an erosion caldera, a dome, and a deeply eroded volcanic cone (Plate 9). The erosion caldera is over 1000 feet deep and more than 2 miles wide, and has been formed by the hollowing out of the central part of the volcano by a system of branching valleys: the highest point of the volcano (5035 feet) is on the southern rim of this caldera. The lava dome, which is about 1 mile in diameter and appears from the air photographs to partly fill an old crater, occurs just south of the caldera and 1 mile north of the eroded volcanic cone. On the gently sloping flanks of the volcano deep gullies separated by sharp ridges extend radially outwards from the summit area. Because of the amount of erosion that has taken place on the flanks, where little if any of the constructional surface of the volcano is preserved, the Numa Numa volcano is considered to be Pleistocene.

Petrography

In thin section the andesite fragments in the agglomerate are seen to contain small phenocrysts of plagioclase, basaltic hornblende, augite, magnetite, apatite, and, in some specimens, olivine and hypersthene (Table 3). These phenocrysts lie in a very fine-grained matrix made up of feldspar microlites, hypersthene needles, magnetite granules, and interstitial felsitic material. Most of the specimens have vesicles containing tridymite and cristobalite.

PLATE 8.

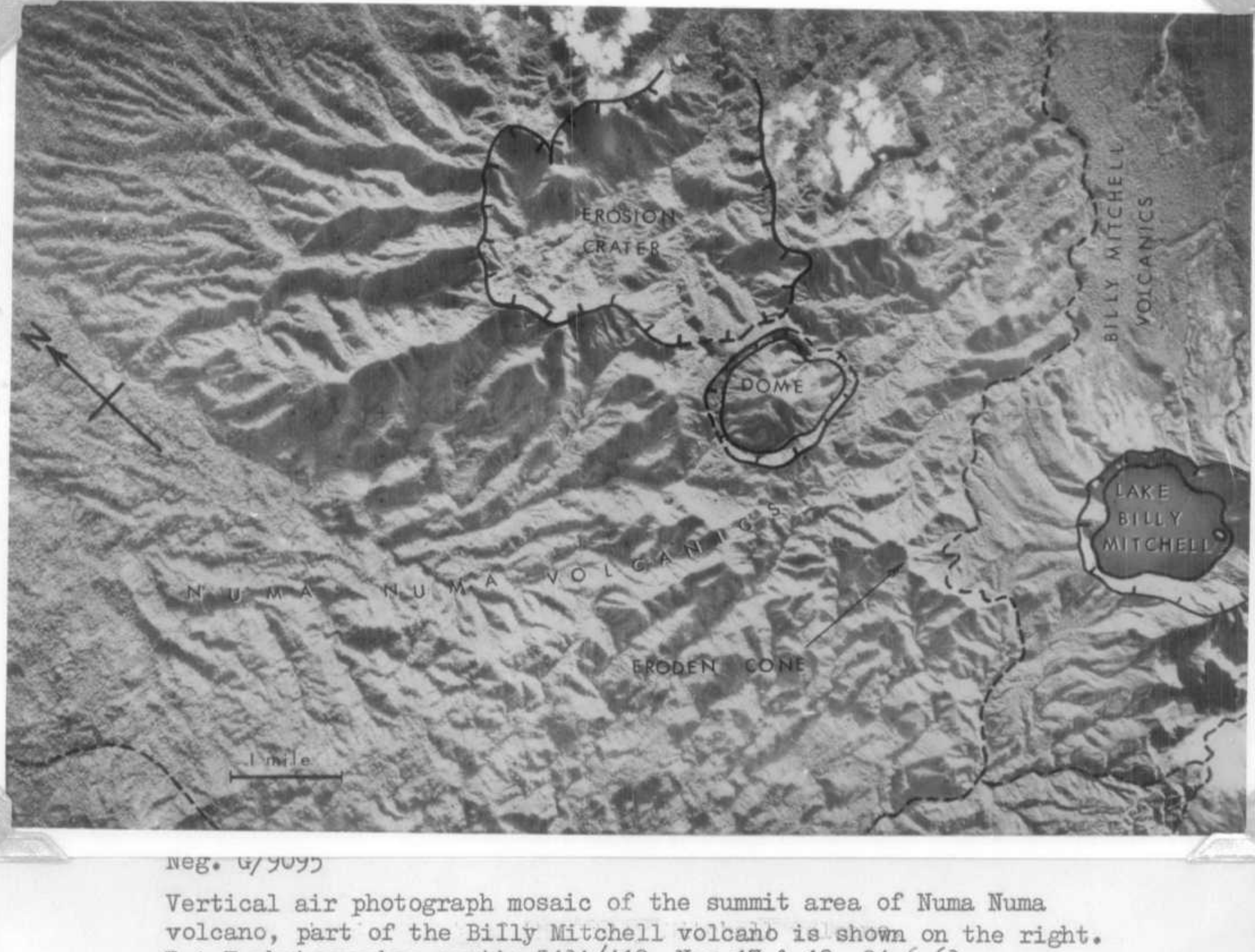
Neg.G/8858 (Photo D.H.Blake)

Fig. 1. The extinct Numa Numa volcano from the north.

Neg.G/8871 (Photo, D.H.Blake)

Fig. 2. Lahar deposits from Numa Numa volcano overlying beach gravels, Wakunai beach.

PLATE 9.



Neg. G/9095

Vertical air photograph mosaic of the summit area of Numa Numa volcano, part of the Billy Mitchell volcano is shown on the right. R.A.F.photographs: sortie 543A/418, Nos.17 & 18, 24.6.63.

Plagioclase forms zoned phenocrysts ranging in length from less than 0.1mm to more than 2mm: most of the zones are of calcic labradorite but the marginal zones are generally more sodic; the measured compositions range from An85 to An20. The augite and basaltic hornblende phenocrysts are between 0.5 and 2mm long. Those of basaltic hornblende are various shades of brown and red, and are normally surrounded by opaque reaction rims: in some specimens they also show replacement by augite and feldspar.

Billy Mitchell Volcanics (New Name)

The Billy Mitchell Volcanics comprise both the rocks which were erupted from the extinct Billy Mitchell Volcano and the fan deposits derived by erosion of the eruptive rocks. The formation covers an area of about 80 square miles in central Bougainville and consists of pumice tuff, agglomerate, and sand. No undoubted lava flows were identified although some are thought to be present near the eruptive centre of the volcano. The formation and the parent volcano take their name from Lake Billy Mitchell, the crater lake in the centre of the volcano.

The type area of the Billy Mitchell Volcanics is north-east of the crater lake, in the headwaters of the Pukarobi River, where a massive unconsolidated pumice tuff is exposed in cliffs 300 feet high around amphitheatre-headed gorges (Plate 10, Fig.1). The pumice tuff is a pale grey, unbedded and unwelded ash flow deposit containing scattered large pumice and andesite lava fragments. It probably represents the final phase of explosive activity of the Billy Mitchell volcano, being deposited by nuées ardentes which swept down the flanks of the volcano when the crater now occupied by the crater lake was formed. Also in the type area water-lain pumiceous sands derived from the pumice tuffs form narrow discontinuous terraces up to 30 feet high along the sides of the gorges. The stream beds here contain rounded andesite lava fragments.

The only other exposures of Billy Mitchell Volcanics examined were further north, in the lower reaches of the Tekan River, where the same ash flow deposit crops out. At this locality pumice and lava fragments are more abundant than in the type area.

The Billy Mitchell Volcanics have a maximum thickness of about 5000 feet. They overlie Kieta Volcanics, Keriaka Limestone, undifferentiated volcanics, Numa Numa Volcanics, and Reini Volcanics, and they are unconformably overlain by some of the Bagana Volcanics.

Billy Mitchell Volcano is an extinct strato volcano north-east of Mount Bagana made up predominantly of pyroclastic material. The highest and steepest parts of the volcano are covered with kunai grass and scattered trees, while tropical rain forest covers the lower flanks. In the centre of the volcano Billy Mitchell crater lake (Plates 11 and 12) occupies a well formed crater 1.5 miles in diameter (Fisher 1957). A small island occurs near the southern shore of the lake. The highest point on the rim of the crater is 5028 feet, and the water level of the lake is at about 3500 feet: the maximum depth of water in the lake is not known. The eastern flank of the volcano descends smoothly for 14 miles to the sea, but the other sides of the volcano have irregular surfaces and are much less extensive.

The activity of Billy Mitchell volcano is thought to have culminated in a paroxysmal eruption during which the present crater was formed, mainly by explosive activity but possibly also partly by collapse (Williams 1941); at the same time nuées ardentes descended the flanks of the volcano. It seems likely, from the well-preserved state of the crater and the small amount of erosion suffered by the nuée ardent deposits, that this paroxysmal eruption took place only a few thousand years ago. However the volcano was probably built up mostly during the late Pleistocene.

Petrography

Hornblende andesite from the Billy Mitchell Volcanics contains abundant phenocrysts of plagioclase and hornblende, and sparse phenocrysts of magnetite, apatite, and augite; these phenocrysts are set in a vesicular, cryptocrystalline groundmass (Table 3).

The plagioclase phenocrysts are up to 6mm long, and are distinctly zoned, varying in composition from An45 to An70 (average An60).

Hornblende forms phenocrysts up to 3mm long: in some of the andesite specimens these phenocrysts are of green hornblende surrounded by opaque reaction rims, and in others they are of dark reddish brown, basaltic hornblende without reaction rims. The rare augite phenocrysts generally have cores of hornblende.

Bagana Volcanics (New Name)

The Bagana Volcanics crop out over about 40 square miles in central Bougainville and are the products of the active strato volcano Mount Bagana, which rises 5730 feet above sea level, 12 miles north-east of Torokina. The formation consists of dark grey andesite lava flows, subordinate tuffs and agglomerate, and derived alluvial fan deposits.

PLATE 10.

Neg. G/9040 (Photo.D.H. Balek)

Fig. 1. The main amphitheatre-headed gorge of the Pukarobi River, on the eastern flank of Billy Mitchell Volcano. About 300 feet of a massive ash deposit (white) are exposed here in cliff faces.

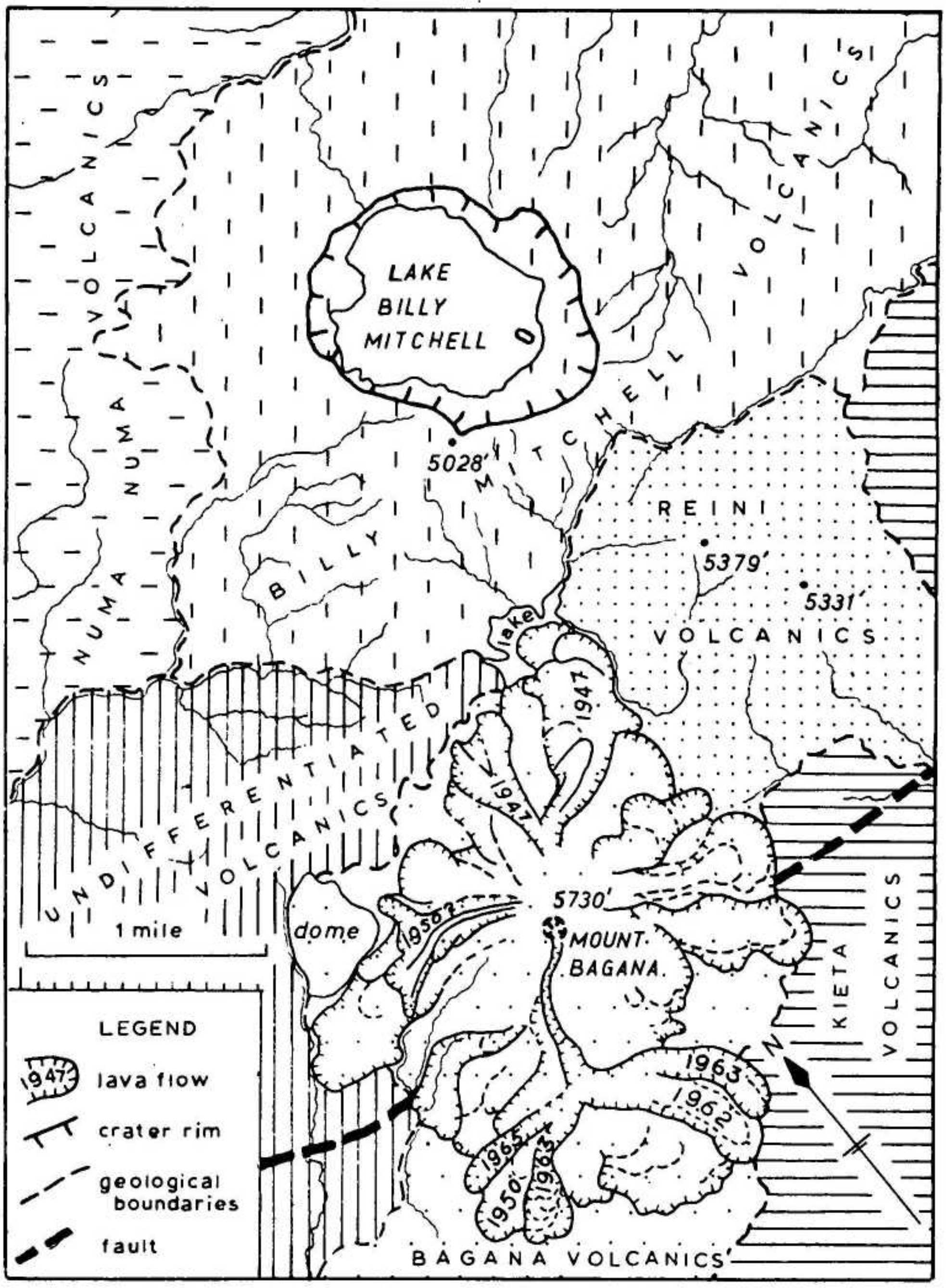
(Photo. G.A.Taylor).

Fig.2. Lake Loloru from the south, a crescentic-shaped crater lake in the centre of Loloru volcano, at the south-east end of the Taroka line of volcanoes. Lake Loloru is situated between the crater wall to the right (east) and an andesite dome partly filling the crater to the left (west).

PLATE 11.

Neg. G/9094.

Vertical air photograph of the active Mount Bagana volcano and the extinct Billy Mitchell and Reini volcanoes (see Plate 12.) R.A.F. photograph: sortie 543A/349, No. 17. 26th July, 1962.



Mount Bagana, Billy Mitchell and Reini Volcanoes

(overlay for Plate 11)

Lava flows are confined to the flanks of Mount Bagana, the type area of the formation, where they are associated with scree deposits, fanglomerates, and pyroclastic material. Derived alluvial fan deposits extend 8 miles south-west from the base of the volcano to the sea at Empress Augusta Bay. The maximum thickness of the formation is probably about 5000 feet.

The Bagana Volcanics are of Recent age. They unconformably overlie Kieta Volcanics, undifferentiated volcanics, and Billy Mitchell Volcanics, and abut against Reini Volcanics.

Mount Bagana Volcano and its activity have been described by Fisher (1939, 1954, 1957), Taylor (1956), Best (1956), and Branch (1965b). The volcano is a symmetrical cone about 4500 feet high which has been built up predominantly of andesite lava flows (Plates 11, 12 and 13). The summit area consists of a solfatara field with a poorly defined crater about 440 yards across. From this crater a series of viscous blocky aa lava flows have been erupted and have flowed down the flanks of the volcano. The individual flows are steep-sided, up to 150 feet thick, and locally have marginal levees and transverse furrows (cf. the lava flows on Tore volcano, page 20): the flows are less than 100 yards wide near the crater but become much wider towards the base of the cone. Interspersed with the flows are some steep scree slopes and alluvial fans made up of lava debris and pyroclastic material. A small lava dome is situated on the north side of the cone (Plate 12).

Mount Bagana is the most active volcano in the New Guinea area (Fisher 1954, 1957) and may well have been entirely built up since the end of the Pleistocene. Its activity was recorded by Guppy (1887), who visited the Solomon Islands in 1882, and it has probably been more or less continuously active ever since. The most recent manifestations of activity include powerful explosive eruptions between 1948 and 1952, when numerous nuées ardentes (first described by G.A. Taylor in a monthly report for May, 1950) descended the flanks of the volcano, and the emmision of lava flows in 1946-1947, 1952 and 1963-1965 (Plate 12). When examined in June, 1965, the youngest lava flow was still moving down the south-west side of the volcano. Half way down the volcano this lava flow has split into four arms; two arms flow west and two south. The fronts of these arms have reached the base of the cone and are now advancing at the rate of 1 foot or less a day. The post 1946 lava flows are the sites of innumerable active fumeroles. Several hot springs issue from the base of the cone.

Petrography

Samples of five lava flows, including the 1946-1947, 1952, and 1963-1965 flows, have been examined in thin section. These lavas are of highly vesicular augite andesite which contains abundant plagioclase, augite, and magnetite phenocrysts and sparse basaltic hornblende and hypersthene phenocrysts; some lava flows also contain phenocrysts of olivine (Table 3). The groundmass of the andesite consists of clear brown isotropic glass, plagioclase microlites, hypersthene rods, and magnetite granules. Tridymite and crystobalite occur in some vesicles.

Plagioclase forms phenocrysts of all sizes up to 3mm; these show intermittent and continuous normal zoning from cores of bytownite (An70-80) to margins of sodic labradorite (An46-57). (The oscillatory zoned plagioclase phenocrysts described by Baker, 1949, as coming from Mount Bagana occur in hornblende andesite pebbles which probably came not from Mount Bagana but from an older, unidentified, volcanic center.). Pale greenish augite phenocrysts have a maximum length of 3mm. Hypersthene occurs in the cores of some augites and also forms separate phenocrysts. The phenocrysts of basaltic hornblende are reddish brown and are surrounded by reaction rims of opaque granules, hypersthene rods, and, in some cases, subordinate clinopyroxene granules. Olivine phenocrysts are less than 1.5mm long and are commonly rimmed by small hypersthene rods.

Reini Volcanics (New Name)

These are the products of an unnamed extinct volcano, here called the Reini volcano, on the east side of Mount Bagana and at the north-western end of the Crown Prince Range, central Bougainville. The formation and the volcano are named after the Reini River, which flows south-west from the flanks of Reini volcano into Empress Augusta Bay.

The Reini Volcanics occupy an area of about 4 square miles, and consist of andesite lava flows, derived fanglomerates, and probably, although not seen in outcrop, tuffs and agglomerates. The type area is the western flank of Reini volcano, and the maximum thickness is probably about 5000 feet. The flank deposits of the volcano overlie Kieta Volcanics to the south, and are partly overlain by the flank deposits of Billy Mitchell volcano. The Reini Volcanics are considered to be Pleistocene.

Reini volcano is a deeply serrated and eroded cone with twin peaks rising to 5379 feet and 5331 feet above sea level (Plates 11 and 12). The surface of the volcano is covered with kunai grass. The cone appears to be made up largely of lava flows, but the individual flows do not form distinct topographical features, unlike the lava flows on Tore, Mount Bagana, and Mount

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PLATE 13.

(Photo,G.A.Taylor)

Fig.1. The active volcano Mount Bagana, 23 May,1960, from the north-east. One of the 1946-7 lava flows is shown on the extreme left of the photograph.

Neg.G/9031 (Photo. C.D.Branch)

Fig.2. Mount Bagana, 7th October,1964, from the south. The 1964/5 lava flow, darker in colour than the older flows, is shown descending the western flank of the volcano. About half way down the flank this flow has divided into four main arms, two of which flow to the west and two to the south (see Plates 11 and 12).

Takuan volcanoes. Because of this, and the amount of erosion that has taken place on the flanks, it is considered that Reini volcano is of Pleistocene age.

Petrography

Only one andesite specimen from Reini volcano has been studied in thin section. This is a hornblende-augite andesite containing phenocrysts of plagioclase, augite, basaltic hornblende, and magnetite (Table 3) enclosed in a groundmass of plagioclase microlites, hypersthene rods, granules of magnetite and subordinate clinopyroxene, and very pale glass.

The plagioclase and augite phenocrysts are less than 1.5mm long. Those of plagioclase show normal zoning from cores of bytownite to margins of labradorite (An_{85} to An_{58}); some also show weak oscillatory zoning. The basaltic hornblende phenocrysts, up to 2.5mm long, are reddish brown and have opaque reaction rims.

Bakanovi Volcanics (New Name)

The Bakanovi Volcanics consist of tuff, agglomerate, and andesite lava. They crop out over about 5 square miles on the north-east side of the Crown Prince Range, 10 miles east of Mount Bagana, and are the products of a small, long extinct volcanic center, here called the Bakanovi volcano. The name is taken from the Bakanovi River which flows north-east from the Crown Prince Range to Vito on the east coast of central Bougainville; this river marks the northern limit of the Bakanovi Volcanics. The type area is a quarter of a mile east of Korpani village; here andesite lavas are exposed. Further east, tuff and agglomerate crop out on an eastward-facing arcuate ridge rising 1500 feet above the surrounding land (and 2000 feet above sea level). The formation has a maximum thickness of about 1500 feet, and it unconformably overlies Kieta Volcanics and Keriaka Limestone.

Bakanovi volcano is a deeply eroded crescentic-shaped remanant of a former volcanic cone. It has a maximum relief of 1500 feet. Because of its poor state of preservation it is thought to be of Pleistocene or even Pliocene age.

Petrography

The Bakanovi lavas are hornblende andesites. They contain phenocrysts of plagioclase and green hornblende up to 6mm long, and much smaller phenocrysts of magnetite and apatite (Table 3); the phenocrysts are enclosed in a very fine-grained feldspathic matrix. Zeolites occur in vesicles. The phenocrysts of both plagioclase and hornblende (which do not have reaction rims) show well marked oscillatory zoning; the plagioclase is mostly sodic labradorite (average about An_{55}).

Takuan Volcanics (New Name)

The Takuan Volcanics crop out over 40 square miles in the central part of southern Bougainville. They are the products of three closely spaced extinct strato volcanoes the highest of which, Mount Takuan (7385 feet), gives its name to the formation. The volcanoes are situated along a line trending north-west, parallel to the Crown Prince Range to the north-east, and to the Mount Taroka range of mountains to the south-west. In addition to the three volcanoes two small dome-like bodies, each about 500 feet high occur on the same general line, and these are also tentatively included in the Takuan Volcanics. One dome is near Damu, 3 miles north-west of Mount Takuan (Plate 14, Fig. 1), and the other is on the north-east side of the Luluai River, 14 miles east-south-east of Mount Takuan (Plate 14, Fig. 2).

Andesite lava, alluvial fan deposits, tuff, agglomerate, and dacite lava make up the Takuan Volcanics. The type area is Mount Takuan, which consists predominantly of andesite lava, and the maximum thickness of the formations is probably about 6000 feet.

The Takuan Volcanics unconformably overlie Kieta Volcanics, and interfinger with the Taroka Volcanics to the south and west. Both the Takuan and Taroka volcanics are considered to be Recent to Pleistocene.

The three volcanoes from which the Takuan Volcanics have been erupted are covered by dense forest. Of these volcanoes only Mount Takuan has been named, and in the following account the other two are called volcano 'B' and volcano 'C' (Plates 15 and 16).

Mount Takuan is a volcanic cone about 5000 feet high built up largely of lava flows. The summit area has been partly modified by the intersection of two large steep-sided valleys on the sides of the cone, and it now consists of a semicircular ridge 3000 feet in diameter. Part of this ridge probably represents the walls of an old crater. Originating from the summit area and forming the flanks of the volcano are lava flows of similar size and form to those of Mount Bagana. Two small domes occur on the lower northern and north-eastern slopes of the volcano.

Volcano B, immediately south-east of Mount Takuan, is a slightly smaller cone which has been breached on its south-west side, probably during a paroxysmal eruption. A large dome partly fills this breach and extends for 1 mile further to the south-west. Well preserved lava flows which were extruded before the cone was breached, occur on the other sides of the volcano.

PLATE 14.

...Neg.G/9032 (Photo D.H.Blake)

Fig. 1. The dacite dome near Damu, looking south. The north-western flank of Mount Takuan is behind the dome. The Mount Taroka line of volcanoes is shown in the right background.

Neg.G/9048 (Photo. D.H.Blake)

Fig. 2. The dacite dome on the north bank of the Luluai River, 14 miles south-east of Mount Takuan. The Crown Prince Range is in the the background.

Volcano C, south-east of volcano B, is not as high as the other two volcanoes and has been much more extensively eroded. The lower slopes of this volcano are overlapped to the north-west by lava flows from volcano B and to the south-west by pyroclastic rocks from the Taroka group of volcanoes.

Although now extinct, the well preserved nature of the lava flows on Mount Takuan and volcano B indicate that these two volcanoes have probably been active in post-Pleistocene times. The last major activity was probably a paroxysmal eruption from volcano B, during which part of the cone of this volcano was blown away and a large dome was extruded. From the aerial photographs it appears that the pyroclastic material produced during this eruption may have formed nuées ardentes which flowed north-west down the valley between the Takuan and Taroka lines of volcanoes and then curved north-eastwards into the Luluai valley, around the north-west flank of Mount Takuan.

Volcano C, on the other hand, is in an advanced stage of erosion and is most likely entirely Pleistocene.

Petrography

Of the five lava specimens from the Takuan group of volcanoes that have been examined in thin section, four are hornblende-augite andesite, and one is an augite andesite (Table 3). The andesites contain phenocrysts of plagioclase, augite, magnetite, and, with one exception, hornblende: some also contain apatite phenocrysts. The groundmass is made up of plagioclase microlites, hypersthene rods, magnetite granules, and interstitial glass or felsitic material. Tridymite occurs in some of the vesicles.

The phenocrysts of hornblende range up to 7mm long, but those of plagioclase and augite are generally less than 3mm long. The plagioclase phenocrysts show distinct normal zoning from cores of labradorite-bytownite (av. An70) to margins of oligoclase-andesine (av. An30). The hornblende phenocrysts have prominent reaction rims; in one specimen the hornblende is greenish brown and in the others it is a reddish brown basaltic hornblende.

The dome near Damu and the dome on the north side of the Luluai River are made up of hornblende dacite containing abundant phenocrysts, up to 4mm long, of plagioclase and hornblende. Rounded quartz phenocrysts are common in the dacite of Luluai dome but rare in that of Damu. Also present as phenocrysts are augite, magnetite, apatite, and, in the Luluai dome dacite, biotite and sphene. The groundmass of the dacite is very fine-grained and leucocratic. In both dacites two varieties of hornblende occur as phenocrysts; one is a dark brown basaltic hornblende, largely replaced by opaque material, and the other is a pale greenish brown hornblende; the basaltic hornblende in both dacites and the greenish brown hornblende in the dacite of the Damu dome have opaque reaction rims. The plagioclase phenocrysts are mostly andesine and show prominent oscillatory zoning.

Taroka Volcanics (New Name)

The Taroka Volcanics comprise the products of a line of both dormant and extinct volcanoes 9 miles long in southern Bougainville. These volcanoes rise to over 7000 feet above sea level and form a north-west striking range which runs parallel to the Mount Takuan line of volcanoes immediately to the north-east. Lake Loloru, in the crater of the dormant Loloru volcano (Fisher 1957), is at the south-eastern end of the range. The formation is named after Mount Taroka (7240 feet), an extinct volcano and the highest point of the range, situated 3½ miles north-west of Lake Loloru.

The Taroka Volcanics crop out over most of southern Bougainville, occupying an area of more than 800 square miles. They consist predominantly of andesitic tuff, agglomerate (made up of andesite lava and pumice fragments), and derived waterlain sand and gravel. Good sections are exposed in deep gorges cut into the flanks of the volcanoes. Only two extrusive bodies of lava have been identified; one of these forms a dome occupying most of the summit crater of Loloru volcano, and the other forms a lava flow on the south-eastern flank of the same volcano.

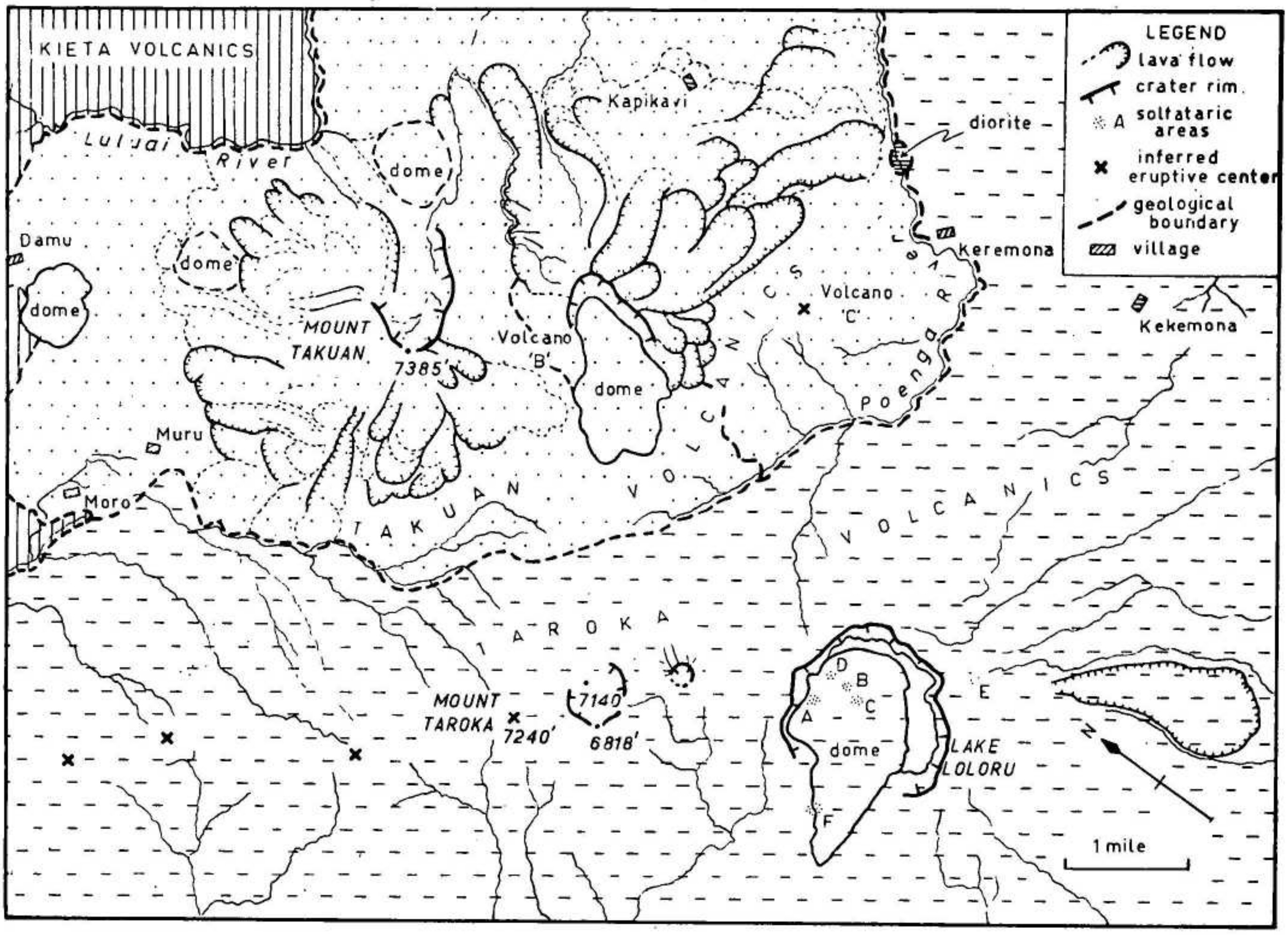
Agglomerate is mostly confined to the upper parts of the volcanoes, and the best exposures seen were on the almost vertical eastern wall of Loloru crater. Soft and generally unbedded pumice tuff containing scattered boulders of pumice and andesite lava occur on the flanks of the volcanoes above the 500 foot contour: most of these tuffs are interpreted as ash-flow deposits. Below the 500-foot level alluvial sands form extensive apron deposits. Coarse gravels made up of andesite fragments occur in stream beds.

The type area for the Taroka Volcanics is on the southern flank of Loloru volcano, near Kugugai, where ash-flow tuffs over 400 feet thick overlie unconsolidated river gravels.

The formation has a probable maximum thickness of about 7000 feet. It overlies Kieta Volcanics to the north and east, and interfingers with the Takuan Volcanics to the north-east.

The Taroka Volcanics are considered to be Recent to Pleistocene.

The Taroka group of volcanoes comprise a number of closely spaced strato volcanoes, including Mount Taroka and the dormant Loloru volcano, all situated along a line striking north-west (Plates 15 and 16). These volcanoes,



Mount Takuan and Mount Taroka lines of volcanoes

(overlay for Plate 15)

Bureau of Mineral Resources, May 1966 To accompany record 1966/62 B56/A/13

PLATE 15.

Neg. G/9096

Vertical air photograph mosaic of the Mount Takuan and Mount Taroka lines of volcanoes (see Plate 16). R.A.F.photographs; sortie 543A/418 Nos. 23-25. 24/6/1963.

like most of the other volcanoes on Bougainville, are covered by dense jungle.

Loloru was first recognised as a potentially active volcano by G.A. Taylor in May, 1951. The summit area consists of a crater just under 1½ miles in diameter which is partly filled by a dome. This dome has overflowed through a breach in the south-west wall of the crater. On the opposite side of the crater a crescentic-shaped lake, Lake Loloru, has been formed between the dome and the eastern crater wall (Plate 10, Fig. 2; see also Fisher 1954, fig. 9). The water level of this lake is at about 4500 feet, and the top of the dome, the highest point on the volcano, is 6215 feet. The smooth flanks of the volcano are dissected by a number of deep gorges radiating outwards from the summit area. A well preserved lava flow occurs on the south-eastern flank, one mile south-east of Lake Loloru.

Six solfataric areas, labelled A to F, on the summit area of Loloru volcano are described by Best (1951), Reynolds (1955a), Fisher (1957), and Branch (1965b). These areas are shown in Plate 16. Hot springs have been recorded from the lower eastern flank of the volcano.

The extinct volcanoes north-west of Loloru are extensively eroded, especially in their summit areas (Plate 15), and few craters are preserved. However there appear to be at least six major eruptive centers here, including that of Mount Taroka, and the probable positions of these are shown in Plate 16. The constructional surfaces of the extinct volcanoes is only preserved on the lower flanks where they occur as 'planezes' (Cotton, 1944, p.365) between steep-sided, deeply eroded valleys. As on Loloru volcano, these valleys radiate outwards from the centers of the volcanoes.

The very young aspect of the dome in Loloru crater and the presence of active solfatara fields here indicate that this dome was extruded within the last few hundred years. The Loloru volcano is therefore considered potentially active. The deeply eroded appearance of the other volcanoes, on the other hand, indicates that these volcanoes are extinct and are mostly of Pleistocene age.

Petrography

The lava dome in Loloru crater and the lava fragments in the agglomerates and river gravels are of grey augite-hornblende and hornblende-augite andesite. The andesite contains prominent phenocrysts, generally less than 4mm long, of plagioclase, hornblende, augite, and, in one specimen (a pebble from a stream bed in the north-western part of the formation), quartz. Some of the andesite fragments contain dark cognate inclusions. Modal analyses are given in Table 3.

The plagioclase phenocrysts range from oligoclase-andesine (An30) to labradorite (An60) and show prominent oscillatory zoning. The amphibole phenocrysts are either of dark brownish green hornblende or brown to reddish brown basaltic hornblende; in most specimens they are surrounded by opaque reaction rims.

The groundmass consists mostly of plagioclase microlites and glass or devitrified glass: small crystals of hornblende, pyroxene, and magnetite are also commonly present. The groundmass is generally vesicular. Tridymite occurs in some of the vesicles.

The one cognate inclusion examined in thin section consists of phenocrysts of basaltic hornblende (without reaction rims), augite, and plagioclase enclosed in pale brown glass: the darker colour of the inclusion is due to an abundance of hornblende in relation to plagioclase, as compared with the host andesite.

Emperor Range Volcanic Beds (New Name)

In northern Bougainville a large area of volcanic rocks have been erupted from a number of extinct and mostly deeply eroded volcanic centers situated along the Emperor Range north of Mount Balbi and Tore volcanoes. These volcanic rocks are grouped together as the Emperor Range Volcanic Beds, and they crop out over more than 500 square miles.

The Emperor Range Volcanic Beds consist of andesite and basalt lava flows, tuff, agglomerate, and derived sediments. The outlines of andesite lava flows can be seen on air photographs of the northern and north-western parts of the Emperor Range; some of these flows reach the coast near Konua, Soraken, and Baniu Bay. Tuffs and agglomerates, interpreted as nuée ardente and lahar deposits, form gently sloping flank deposits on the north-east side of the range and reach the coast near Tinputz and Teop. Agglomerate, tuff, and both andesite and basalt lava crop out in the headwaters of the Ramazon, Uruai, and Aita rivers. Sediments derived from the lavas and pyroclastic rocks occur in some coastal areas.

Six miles north-east of Mount Balbi some small fumeroles were discovered in two tributary valleys of the Aita River (Plate 6 and 7). Here there is a strong smell of H_2S and the rocks are sulphur stained. Two hot springs occur in the Uruai River 1½ miles east-south-east of Puspa.

Four major dioritic intrusions occur within the outcrop area of the Emperor range volcanic Beds. Two of the intrusions, near Umum and Baniu Bay on the north coast, are partly overlapped by younger volcanic rocks. The other two intrusions, at Melilup and Puspa, have intruded and thermally metamorphosed the adjacent volcanic rocks.

The Emperor Range Volcanics Beds are considered to range from Pleistocene to Pliocene or possibly Miocene. The relatively well preserved lava flows in the north and north-west outcrop areas and the nuées ardentes and lahar deposits near Tinputz are probably Pleistocene. These were erupted from a group of volcanoes situated on the main watershed of the Emperor Range, along a line striking north-north-west. Most of the volcanic rocks further south, on the eastern side of the range, are probably pre-Pleistocene, and they appear to have been erupted from volcanic centers on the eastern side of the main watershed. The sites of some of these centers may be represented by the dioritic intrusions.

In the southern part of their outcrop area the Emperor Range Volcanic Beds are overlain by Tore Volcanics and Balbi Volcanics; in the north they abut against Sohano Limestone.

Petrography

The andesite contains phenocrysts of plagioclase (generally within the labradorite range), augite and magnetite; many also contain phenocrysts of olivine, hypersthene, apatite, basaltic hornblende, biotite, and rare partly resorbed quartz (Table 3). Olivine phenocrysts, largely pseudomorphed by iddingsite, occur in Pleistocene andesites near Konua, Soraken, Baniu, and Teop.

Two basalt specimens from the headwaters of the Aita River system have sparse phenocrysts of plagioclase, olivine (pseudomorphed by 'chlorite'), and pale brownish augite: the phenocrysts lie in a fine-grained intergranular groundmass consisting of plagioclase laths, granular clinopyroxene, olivine (pseudomorphed by 'chlorite'), magnetite, and interstitial altered glass. The plagioclase phenocrysts show normal zoning from bytownite cores to sodic labradorite margins.

PLEISTOCENE

Sohano Limestone (New Name)

The Sohano Limestone is named after Sohano Island, at the south-western end of Buka Passage. The formation, which consists almost entirely of limestone, crops out over northern and eastern Buka, on Sohano Island, and on the north coast of Bougainville between Teop in the east and Bonis Plantation in the west. Isolated outcrops also occur near Bei and Skotolan, on the west coast of Buka.

The type area of the formation is the east coast of Buka, and the type locality is at Iltopan, in the extreme north, where the maximum observed thickness of the formation, 290 feet, is exposed.

The Sohano limestone is an elevated reef complex forming a platform dipping at less than 1° to the south and west (Speight, in press, a). This platform terminates in cliffs along the north and east coasts (Plate 17; Figs. 1 and 2). These cliffs increase in height westwards, along the north coast of Bougainville, and northwards, along the east coast of Buka, from less than 10 feet near Teop, on Bougainville to almost 300 feet at Iltopan, on the north-eastern tip of Buka. The cliffs mark the position of a barrier reef at the edge of the reef complex, and inland from the cliffs the barrier reef limestone passes into back-reef deposits. The topography of the reef complex has been little modified by sub-aerial erosion.

The reef limestone is a massive pale whitish rock made up of corals, algae, echinoids, mollusca, and some foraminifera (Terpstra, 1965, 1966). Many of the corals and algae are in positions of growth. The limestone is unbedded but commonly shows a crude quasi-horizontal layering; the individual layers are mostly from 10 to 20 feet thick.

The Sohano Limestone contains a rich fauna of macrofossils, [illegible] corals, [illegible], and molluscs but microfossils are rare and most of those that do occur are of little stratigraphical value. Terpstra (1965, 1966), has examined a number of limestone samples for foraminifera, and has identified the following: Amphistegina sp., Quinqueloculina sp., Operculina sp., Discorbis sp., Cristellaria sp., Globigerina sp., Textularia sp.. These genera range all through the Cainozoic. In addition 'Linderina' sp., a Lower Miocene foraminifera, has been identified (Terpstra, 1966), in limestone samples taken from a ledge at the base of the cliffs at Iltopan. The larger foraminifera characteristic of the Lower Miocene Keriaka Limestone are entirely absent.

From the fossil evidence at Iltopan it would appear the the lowest exposed part of the Sohano Limestone may be Lower Miocene. Yet the lack of erosion of the raised reef complex indiactes relatively recent uplift, suggesting that at least the upper part of the Sohano Limestone is Pleistocene. A similar age is also indicated for the Sohano Limestone on the north coast of Bougainville, where it occurs as an uplifted reef fringing volcanic rocks of probable Pleistocene age. The absence of typical Miocene foraminifera in all but one of the limestone samples examined perhaps supports this view. The explanation favoured for the conflicting evidence for the age of the limestone is that the Sohano Limestone is of Pleistocene age, and that at Iltopan the top of an unknown

PLATE 17.

Neg.G/8873 (Photo D.H.Blake)

Fig.1. Undercut cliffs of Sohano Limestone, 45 feet high, on the north side of Sohano Island.

Neg.G/9045 (Photo.D.H.Blake)

Fig. 2. Cliffs of Sohano Limestonr on the north coast of Bougainville, from the west. The cliffs increase in height from about 20 feet near Tinputz, on the sky-line, to over 100feet in the right foreground.

thickness of Lower Miocene limestone is exposed underlying 290 feet of Sohano Limestone. The Sohano Limestone is probably the same age as the recently elevated reef limestones on the south coast of Choiseul (Coleman, 1962, 1963).

At only one locality have volcanic rocks been found within the Sohano Limestone. This is on the east side of Raua Bay, on the north coast of Bougainville, where a conglomerate bed, 5 feet thick, occurs near the base of the limestone cliff. The conglomerate is made up of rounded andesite pebbles and boulders, up to 1 foot in diameter, enclosed in a calcareous matrix.

The drainage on the Sohano Limestone outcrop is mostly underground, and surface streams are found only in low-lying areas on the west side of Buka. Underground rivers reach the sea in caves at Lonahan (Taema Caves) and Melasang, on the east coast of Buka.

On Buka the Sohano Limestone unconformably overlies the ?Oligocene Buka Volcanics forming the Parkinson Range. On northern Bougainville the limestone overlaps onto intrusive dioritic masses near Umum and Raua harbour, and abuts against Pleistocene Emperor Range Volcanic Beds. Over most of its ouctrop the limestone is overlain by a reddish brown tuffaceous soil (Speight, 1966).

QUATERNARY

Alluvium

Recent alluvium consisting of volcanic detritus from various sources is mostly confined to low-lying coastal areas, where it forms deltaic, swamp, and beach deposits. The greatest expanses of alluvium on Bougainville are on the west coast between the delta of the Laruma River and Motupena Point, on the east coast between Cape Mabiri and Cape Pui Pui, and on the south-east coast in the delta area of the Luluai and Abia rivers.

Beach deposits containing both volcanic and organic detritus occur around much of the coast of Bougainville and western Buka. They extend more than 2 miles inland as old strand lines at Moila Point (Jennings, 1955) on the south coast, at Motupena Point on the west coast and between Cape Moltke and Konua on the north-west coast.

Sands composed mainly of comminuted coral occur on the small coral islands off the west coast of Buka and off the north-west and east coasts of Bougainville.

Ash

Much of Bougainville and Buka is covered by deposits of andesitic ash derived from the volcanoes on Bougainville. These deposits range in thickness from less than 1 inch to several feet, and occur on volcanic rocks ranging in age from pre-Miocene to Recent and also on Keriaka Limestone and Sohano Limestone. The ash is of air fall type, and is generally best preserved on ridge tops, as it has normally been removed from steep slopes and redeposited as alluvium in the valleys. It is made up largely of euhedral to sub-hedral crystals of plagioclase, hornblende, magnetite, augite, and volcanic glass.

The ash probably ranges in age from Late Pleistocene to Recent. Large quantities of ash were undoubtedly produced during recent eruptions from Loloru, Billy Mitchell, and Mount Balbi volcanoes, and also from earlier eruptions of Numa Numa volcano, and the Takuan and Taroka groups of volcanoes. Relatively small amounts of ash have been erupted from Mount Bagana.

INTRUSIVE ROCKS

The Kieta Volcanics, undifferentiated volcanics, and Emperor Range Volcanic Beds have been intruded and locally hornfelsed by a number of high-level dioritic bodies. These intrusions range from small dyke-like or plug-like bodies to larger and more irregular masses. Some of the intrusions probably occur in the eroded cores of old volcanic centres. Most of the intrusions have some associated sulphide mineralisation.

The smaller intrusions, the majority of which are either andesite or porphyritic microdiorite, have mostly been found within the outcrop of the Kieta Volcanics. One such intrusion, a small plug-like microdiorite body, is associated with the copper and gold mineralisation at Kupei mine, 10 miles south-west of Kieta.

From north to south, the larger intrusions on Bougainville are those of Umum and the Kunai Hills, on the north coast; Melilup, 8 miles south-west of Tinputz; Puspa, 11 miles south of Tinputz; Panguna, 12 miles south-west of Kieta; and Isinai, 8 miles south of Kieta.

The Umum and Kunai Hills intrusions are older than the Sohano Limestone and Emperor Range Volcanic Beds immediately surrounding them. Both the intrusions are of porphyritic microdiorite. The Melilup, Puspa, Panguna, and Isinai intrusions, on the other hand, are made up of a variety of rock types, including microdiorite, diorite, granodiorite, monzonite, syenite, and granophyre, and they are surrounded by metamorphic aureoles up to several hundred feet wide. The limits of these last four intrusions could not be determined accurately as no actual contacts were seen in the field, and the intrusions cannot be easily distinguished from the country rocks on the air photographs. Copper and gold mineralisation is associated with the Panguna intrusion.

The intrusions probably range from Upper Oligocene to Pleistocene. The oldest intrusions are those of the Crown Prince Range, and these are thought to be comparable in age to the Kieta Volcanics which they intrude, whereas the youngest intrusions are probably those of the Emperor Range.

Petrography

Modal analyses of intrusive rocks from Bougainville are given in Table 4.

Most of the small andesite and microdiorite intrusions have a similar mineralogy to the andesitic rocks they intrude. They contain phenocrysts of plagioclase (andesine-labradorite), hornblende and/or augite, and magnetite enclosed in a fine or very fine-grained groundmass.

The porphyritic microdiorite at Kupei mine has been subjected to considerable secondary alteration. In the specimens examined the plagioclase phenocrysts show alteration to chlorite, sericite, and alkali feldspar, and the augite and hornblende phenocrysts are completely pseudomorphed by chlorite and epidote. Epidote and chlorite also occur in the groundmass which, in some specimens, has been partly silicified. Altered andesitic xenoliths are locally abundant.

A quartz diorite exposed in the Poenga River, east of Mount Takuan, contains sparse phenocrysts of hypersthene, augite, and plagioclase set in a medium to coarse-grained hypidiomorphic granular groundmass (average grain-size about 1mm) of plagioclase, alkali feldspar, green hornblende, biotite, quartz, opaque minerals, and augite.

The microdiorite forming the Umum and Kunai Hills intrusions contains phenocrysts of plagioclase, pale greenish augite, and magnetite. The plagioclase phenocrysts are zoned from sodic labradorite to oligoclase. Some pale pinkish brown biotite is associated with the magnetite.

The coarser-grained rocks of the Melilup, Puspa, Panguna, and Isinai intrusions contain the following minerals: plagioclase (laboradorite-oligoclase), alkali feldspar, quartz, augite, hypersthene, pale green or brown hornblende, brown biotite, opaque minerals, and accessory apatite and sphene; secondary minerals include chlorite, epidote, actinolite, zeolites, and calcite.

TABLE 4: Modal Analyses (Vol.%) of Intrusive Rocks from Bougainville

	A	B	C	D	E	F	G	H	I
Plagioclase	45*	45*	48	23	59	48	43	56	43+2*
Alkali feldspar	-	-	31	68	14	26	20	6	14
Quartz	-	-	1	2	12	8	23	5	3
Augite	6*	7*	3	2	3	2	-	<1	1+10*
Hypersthene	-	-	-	-	-	-	-	-	-+2*
Hornblende	-	-	9	3	8	12	5	26	11
Biotite	-	-	2	1	-	2	6	3	10
Opaque minerals	2*	1*	4	1	3	2	2	3	3
Accessories	<1	-	1	<1	1	<1	<1	1	<1
Fine-grained groundmass	47	47	-	-	-	-	-	-	-

* = phenocrysts

A. Porphyritic microdiorite (65490085), Umum intrusion.
B. Porphyritic microdiorite (65491094), Kunai Hills intrusion.
C. Monzonite (65490080), Melilup intrusion.
D. Syenite (65491064), Puspa intrusion.
E. Granodiorite (65490510), Kawerong River, Panguna intrusion.
F. Quartz diorite (65490546), Isinai intrusion.
G. Granodiorite (65490554), Isinai intrusion.
H. Diorite (65491157), Isinai intrusion.
I. Porphyritic quartz diorite, Poenga River, near Mount Takuan.

The intrusive rock associated with the copper and gold mineralisation at Panguna mine is an altered porphyritic microdiorite similar to that at Kupei mine, with which it may be connected at depth. It contains phenocrysts of plagioclase, augite, and pale green hornblende, and abundant andesitic xenoliths. Chlorite, amphibole, epidote, and quartz are characteristic secondary minerals.

SUMMARY OF IGNEOUS PETROGRAPHY

Basalt

Basalt lavas occur within the Kieta Volcanics, Buka Volcanics, undifferentiated volcanics, and Emperor Range Volcanic Beds. The basalts contain phenocrysts of calcic plagioclase and augite, and some also contain chloritic pseudomorphs after olivine phenocrysts. The phenocrysts lie in moderately fine-grained groundmass of plagioclase laths, augite, opaque minerals, and altered basic glass. All the basalts examined had suffered some secondary alteration, with the development of chlorite, serpentine, alkali feldspar and zeolites as secondary minerals.

TABLE 5. Petrography of andesites from Bougainville

FORMATION	PHENOCRYSTS											GROUNDMASS					
	Plagioclase	Quartz	Augite	Hypersthene	Olivine	Hornblende	Biotite	Magnetite	Apatite	Sphene		Plagioclase	Hypersthene	Clinopyroxene	Magnetite	Felsitic material	Glass
Kieta Volcanics (23)	—		—	c	r			—	r			—	c	c	—	c	r
	—		r			—	r	—	r			—			—	—	
Tore Volcanics (2)	—		—	—		—	—	—	—			—		—	—	—	
Balbi Volcanics (14)	—		—	—	r	r	r	—	c			—	—		—	c	c
Numa Numa Volcanics (6)	—		—	c	r	—		—	c			—	—		—	c	c
Billy Mitchell Volcanics (4)	—		c			—		—	c			—			—	—	
Bagana Volcanics (6)	—		—	—	c	—		—				—	—		—		—
Reini Volcanics (1)	—		—			—		—				—	—	—	—	—	
Bakanovi Volcanics (3)	—					—		—	c			—			—	—	
Takuan Volcanics (5)	—		—	r		c		—	c	r		—	—	r	—	c	c
Taroka Volcanics (12)	—	r	—			—	r	—	c	r		—		—	—	c	c
Emperor Range Volcanic Beds (9)	—		—	c	c	r	r	—	c			—	c	c	—	c	c

(6) = number of samples examined;

— = always present;

c = commonly present;

r = rarely present

<u>Andesite</u>

Andesite, the dominant volcanic rock on Bougainville, occurs within the Kieta Volcanics, undifferentiated volcanics, and within each formation of the Bougainville Group. It contains phenocrysts of plagioclase (characteristically showing well marked oscillatory zoning), magnetite, and one or more ferromagnesian silicate mineral; the phenocrysts lie in a very fine-grained matrix of plagioclase, magnetite, pyroxene (not always present), and interstitial glass or felsitic material. The petrography is summarised in Table 5 and modal analyses are given in Table 3. In most cases the andesite of each formation can be distinguished petrographically from andesites of other formations.

The Kieta Volcanics include both pyroxene andesite (containing phenocrysts of augite and, in some cases, hypersthene) and hornblende andesite (containing phenocrysts of hornblende). The ferromagnesian phenocrysts in these andesites tend to be much larger than the plagioclase phenocrysts, whereas in the andesites of the Bougainville Group the ferromagnesian phenocrysts tend to be either of similar size to or smaller than those of plagioclase.

Insufficient andesite specimens from the outcrops of the undifferentiated volcanics were examined to determine whether these andesites were of Kieta Volcanics or Bougainville Group type.

Four main varieties of andesite occur within the Bougainville Group. These are:

(1) Hornblende-biotite-pyroxene andesite, represented by the Tore Volcanics;

(2) Pyroxene andesite, represented by the Balbi Volcanics, Bagana Volcanics, Emperor Range Volcanic Beds, and one specimen from the Takuan Volcanics;

(3) Andesite containing both hornblende and pyroxene phenocrysts in roughly equal amounts, represented by the Numa Numa Volcanics, Reini Volcanics, Takuan Volcanics, and Taroka Volcanics;

(4) Hornblende andesite, represented by the Billy Mitchell Volcanics and Bakanovi Volcanics.

The pyroxene andesite of the Balbi Volcanics differs from that of the Bagana Volcanics in containing (a) plagioclase phenocrysts of more sodic average composition, and (b) a higher proportion of hypersthene phenocrysts.

The andesite of the Numa Numa Volcanics cannot readily be distinguished from that of the Takuan Volcanics. The andesite of both these formations differs from andesite of the Taroka Volcanics in containing hypersthene in the groundmass.

The hornblende phenocrysts in the hornblende andesite of the Bakanovi Volcanics characteristically show oscillatory colour zoning, whereas the hornblende phenocrysts in the andesite of the Billy Mitchell Volcanics do not.

Dacite

Three dacite bodies on Bougainville were sampled, one within the undifferentiated volcanics and two within the Takuan Volcanics. These dacites contain phenocrysts of plagioclase, hornblende, quartz, and subordinate augite, enclosed in a very fine-grained, leucocratic groundmass.

Intrusive rocks

The intrusive rocks include both porphyritic and non-porphyritic types. Porphyritic microdiorite is the most widespread intrusive rock: it contains phenocrysts of plagioclase, augite and/or green hornblende, and magnetite enclosed in a fine-grained and largely feldspathic groundmass. The non-porphyritic rocks are diorite, granodiorite, monzonite, syenite, and granophyre. These are made up of the following minerals, in various proportions: plagioclase, alkali feldspar, quartz, augite, hornblende, biotite, hypersthene, and opaque minerals.

Conclusions

The volcanic rocks of Bougainville belong to the calc-alkaline suite that is characteristic of the orogenic regions of continents (MacDonald, 1960).

Most of the andesites contain hypersthene in the groundmass and appear to be directly comparable to the andesites of the hypersthenic series described by Kuno (1950) from Japan. The rocks of the hypersthenic series are considered by Kuno to have been produced by fractional differentiation of basic magma accompanied by assimilation of granitic rocks. This series tends to be associated with thick geosynclinal deposits, where subsidence has taken place over a long period of time (Turner and Verhoogen, 1960). The andesites which do not contain groundmass hypersthene may be comparable to Kuno's pigeonitic series.

METAMORPHISM

Both contact and low grade regional metamorphic rocks occur on Bougainville. Contact metamorphic rocks consisting of hornfelsed volcanic and sedimentary rocks are found in the metamorphic aureoles around most of the dioritic intrusions, and also in and around the cores of eroded volcanic centres.

Low grade regionally metamorphosed lavas, agglomerates, and tuffs occur within the Buka Volcanics and Kieta Volcanics.

The majority of the rocks within the Kieta Volcanics, undifferentiated volcanics, and Emperor Range Volcanic Beds which have been affected by contact metamorphism come within the albite-epidote hornfels facies of Fyfe, Turner & Verhoogen (1958), and are characterised by the mineral assemblage alkali feldspar-epidote-actinolite-chlorite-calcite-quartz. In addition rocks of the hornblende hornfels facies (Fyfe, Turner & Vergoogen, 1958), consisting mainly of green hornblende and plagioclase, occur in the metamorphic aureole around the Isinai intrusion, south of Kieta. The original outlines of phenocrysts may be preserved in the hornfelsed rocks but the fine-grained groundmass is generally entirely recrystallised.

The Buka Volcanics, and most of the Kieta Volcanics on the north-east side of the Crown Prince Range which have not suffered contact metamorphism, come within the zeolitic facies of regional metamorphism (Fyfe, Turner & Verhoogen, 1958). The volcanic rocks of the zeolite facies contain calcite and various zeolites of which heulandite, laumontite, mordenite, and chabazite have been positively identified. This type of metamorphism is related to depth of burial (Fyfe, Turner & Verhoogen, 1958; Walker, 1960), and indicates that several thousand feet of rock have been removed by erosion from the top of the zeolite bearing rocks.

STRUCTURAL SETTING

Most of the following notes are taken from a report by Coleman (1965).

Bougainville and Buka Islands form part of the north-westerly trending Solomon Islands, a chain of oceanic islands on the south-western border of the Pacific Ocean. The Solomons are flanked to the north-east by the more or less smooth floor of the Pacific Ocean, and to the south-west by a trough, generally more than 12,000 feet deep, which includes the Planet Deep (about 29,000 feet deep).

The Solomon Islands form in part a double chain of islands separated by a narrow stretch of sea and closed at one end by Bougainville and at the other by San Cristobal (Fig. 1). The north-east side of the chain consists of Choiseul, Santa Ysabel and Malaita, which are formed mostly of pre-Pliocene marine sedimentary rocks composed of volcanic material; on the north-east flank of Santa Ysabel and on Malaita these rocks are strongly folded while on Choiseul and on the south-west flank of Santa Ysabel faulting is dominant.

On the south-west side of the chain are the Shortland Islands, New Georgia Group, Russell Islands, and Guadalcanal; except for Guadalcanal, which is formed predominantly of pre-Pliocene rocks, these islands are made up mostly of Pliocene to Recent non-marine volcanic rocks.

On Bougainville, at the north-west end of the Solomons, the two sides of the chain come together and may cross over. The pre-Pliocene sedimentary rocks of the outer Solomon Islands are represented on Bougainville and Buka by the Kieta and Buka Volcanics, and the younger volcanic rocks of the inner part of the Solomon chain are represented by the volcanics of the Bougainville Group.

STRUCTURE

Bougainville and Buka Islands consist of Tertiary and Quaternary volcanic piles around which Lower Miocene, Pleistocene, and present day reef complexes have been built. The islands are aligned roughly in a north-west direction, parallel to a submarine trench, the Planet Deep, to the south-west. They lie in a zone of intense volcanic and tectonic (seismic) activity, yet the rocks show little conclusive evidence of major faulting and no evidence of strong folding. However faults are much more prevalent than has been shown on the geological map (Plate 18), as many of the faults seen in the field could not be traced on the air photographs and other faults have been obscured by Recent volcanic rocks.

Three major lineament directions are apparent on Bougainville and Buka (Fig. 6); a north-west direction (320°), a north-north-west direction (335° - 340°), and a west to west-south-west direction (270° - 300°). The north-west trend is that of Bougainville Island itself, and of the alignment of the main eruptive centres of the Tore, Mount Balbi, Takuan and Taroka volcanoes. The north-north-west trend is shown by Buka Island, the Parkinson Range, a possible major fault off the west coast of Buka, the northern part of the Emperor Range, and by the alignment of the eruptive centres of Numa Numa, Billy Mitchell, and Reini volcanoes. The Crown Prince (in part) and Deuro Ranges, a possible major fault on the south-west side of the Crown Prince Range, and most of the minor lineaments show the west to west-north-west trend.

On the air photographs a number of lineaments are visible which represent either faults or major joints. Most of these occur within the outcrop of the Kieta Volcanics. One such lineament, trending 280°, passes beneath Mount Bagana (Plates 11 and 12). A substantial movement along a fault has only been demonstrated at Kieta, near the new overseas wharf, where a vertical fault separates agglomerate from a lava flow: this fault could not be traced inland.

Two possible major faults are shown on Fig. 6. One of these is off the west coast of Buka, trending 345°; this fault follows the straight coast line and is parallel to the Parkinson Range. The other major fault follows a strong lineament trending 300° on the south-west side of the Crown Prince Range in central Bougainville. Additional major faults may be represented by the lines along which the Pleistocene and Recent volcanoes are situated.

There is little evidence of folding on Bougainville and Buka. Dips are generally less than 15° and appear to be mostly depositional. Steeper dips occur locally but these may be due to either slumping or volcanic tilting.

Tectonic warping on Bougainville is indicated by the attitudes of both the Keriaka Limestone, which dips at about 3° to the west-south-west, and the Sohano Limestone, which dips at less than 1° to the south and west. Evidence of major subsidence and uplift during and since the Lower Miocene is indicated by the 4000 foot thickness of the Keriaka Limestone and by its present elevation of over 4000 feet above sea level.

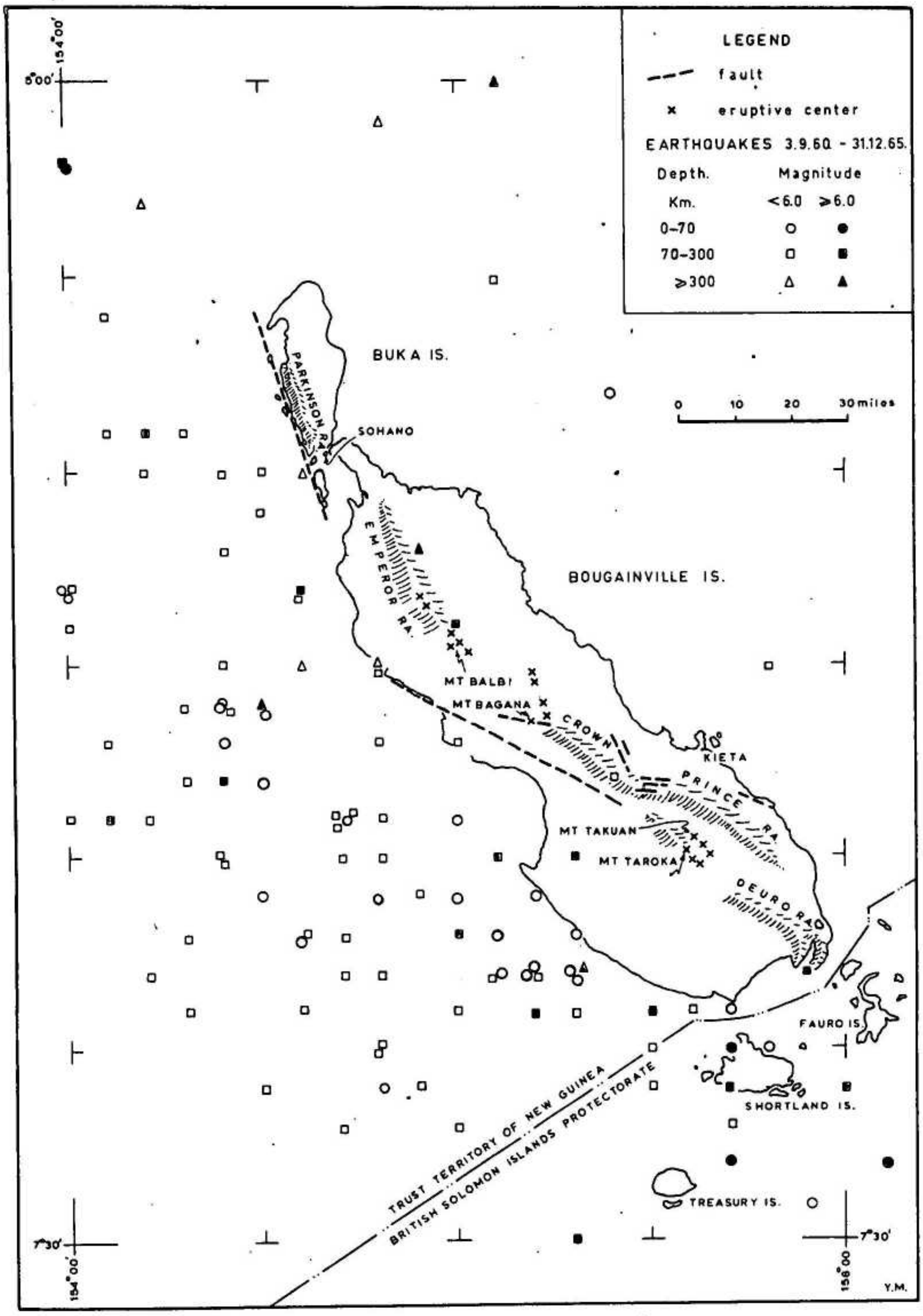
A gravimetric survey undertaken by P. St.John (pers.comm.) has shown that there is an extensive positive anomaly of more than 240 milligals in the area of the northern part of the Parkinson Range, Buka.

SEISMICITY

Seismicity in the Solomon Islands has been discussed recently by Brooks (1965) and Coleman (1965). Grover (1960, 1965) and Brooks (1965) have presented maps showing the epicenters of the major earthquake shocks in the area up to 1962.

The Solomon Islands in general and Bougainville in particular are in a region of very high seismicity. Most of the earthquakes are shallow to intermediate in depth, with foci less than 200 kilometers deep, and deeper shocks are comparatively rare (Fig. 6). In plan most of the foci are located along an arcuate belt to the south-west of and running parallel to the Solomon Islands chain. The plane on which the foci lie is more or less vertical, and the earthquakes may be related to a single tectonic feature (Brooks, 1965). The earthquakes do not appear to be directly related to volcanic activity, although some earthquakes may help trigger off volcanic eruptions (Taylor, 1955; Reynolds, 1955b). The crustal thickness in the area is estimated by Coleman (1965) at about 15 kilometers.

Earthquakes sufficiently intense to be felt by observers are common in the southern half of Bougainville, where eight shocks with felt intensities



Map showing main structural elements of Bougainville and Buka, and epicentres of recent earthquakes between VI and VIII (Modified Mercalli scale, 1956 version) have been recorded by Brooks (1965, pl.11) for the periods 1916-1937, 1941, and 1954-1963, compared with only one similar shock for northern Bougainville over the same periods, although some earthquakes may help trigger off volcanic eruptions (Taylor 1955, Reynolds, 1959b).

GEOLOGICAL HISTORY

Volcanic activity is the dominant feature of the geological history of Bougainville and, to a lesser extent, Buka. The earliest recorded event is the eruption of andesitic and basaltic lavas and pyroclastic rocks in the Oligocene, and there has probably been more or less continuous volcanic activity in the area ever since. Reef building has alos been important, and is represented by the Lower Miocene Keriaka Limestone, the Pleistocene Sohano Limestone, and the present day reefs.

Oligocene to Lower Miocene

The Cainozoic vulcanism in the area probably commenced in the Oligocene. The first eruptions are thought to have produced a group of submarine volcanoes which built up to form small islands. Volcanic activity continued and the islands coalesced to form two main islands, now represented by the Crown Prince Range on Bougainville and Parkinson Range on Buka.

At the same time as the volcanic rocks were being erupted the following processes were taking place: (1) marine and terrestrial sediments derived by erosion of the volcanic rocks were deposited around the volcanoes; (2) dioritic intrusions, in some cases with associated copper and gold mineralisation, were emplaced within the volcanic piles, possibly in the cores of individual volcanic centres; (3) reef complexes, represented by the Keriaka Limestone, were built up offshore.

The volcanics and the derived sedimentary rocks of this period form the Kieta Volcanics of Bougainville and Buka Volcanics of Buka.

During the Lower Miocene the building up of volcanic islands and the growth of the reef complexes appears to have kept pace with a general subsidence of at least 4000 feet (the exposed thickness of the Keriaka Limestone).

Middle Miocene to Pliocene

This appears to have been a time of uplift and tilting, subdued volcanic activity, and subaerial erosion. Uplift and tilting is best shown by the Kieriaka Limestone: for example, the reef complex forming the Keriaka plateau was raised over 4000 feet at its eastern border and tilted to the west-south-west. Much of the faulting in the area probably occurred during this period.

On Bougainville the older volcanic centres of the Emperor Range and the Numa Numa and Bakanovi volcanoes may have been active in the Pliocene, but on Buka volcanic activity probably ceased in the Miocene. The diorite intrusions of northern Bougainville were possibly emplaced during the Middle Miocene to Pliocene.

Pleistocene to Recent

The Pleistocene and Recent have probably been the periods of maximum volcanic activity on Bougainville. During this time the volcanoes of Tore, Mount Balbi, Numa Numa, Billy Mitchell, Mount Bagana, Reini, Takuan, Taroka, and others of the north-western part of the Emperor Range have been active; these are all subaerial strato volcanoes. During this period the pre-Pleistocene volcanoes, where they were left uncovered by younger rocks, continued to be eroded, while reef complexes were built up offshore. In the Upper Pleistocene the Sohano Limestone on Buka and on the north coast of Bougainville was uplifted and gently tilted to the south and west.

TABLE 6. Gold Production - Bougainville Island.
(Thompson, 1962)

Year	Gold Fine oz. (approx)	Value $
1935	45	
1936	113	
1937	598	
1938	487	
1939	297	38,994
1940	217	
1941	32	
1942-1948 No production		
1949	166	
1950	126	3,760
1951	95	2,938
1952	78	2,428
1953	6	188
1954	15	480
1955	5	160
1956-1958 No production		
1959	2	72
Total	2,282 oz.	$48,020

98

ECONOMIC GEOLOGY

One of the main objects of the geological survey of Bougainville and Buka was to establish the regional setting for the gold and copper mineralisation on Bougainville. The known gold and copper deposits are associated with two porphyritic microdiorite (porphyry) intrusions in the Crown Prince Range south-west of Kieta. These deposits have previously been described by N.H. Fisher and J.E. Thompson (Fisher, 1936; Thompson, 1962; Thompson and Fisher, 1965). Small amounts of copper sulphides are also associated with some of the other diorite intrusions on Bougainville.

Alluvial and eluvial gold have been found in small quantities in the Crown Prince Range. Titaniferous magnetite is concentrated in many of the present day beach sands around the Bougainville coast.

Gold

Early in 1930 lode gold was found on the north-eastern fall of the Crown Prince Range near Kupei, about 9 miles south-west of Kieta, and the Kieta Goldfield was proclaimed in the same year. Gold was later found at Panguna (Pumkuna) and Moroni, on the south-western fall of the Crown Prince Range 3 miles west-south-west of the Kupei occurrence. Small scale gold mining was commenced in the Kupei-Panguna area in 1934, and by 1941, 1789 fine ounces of gold and 89 ounces of silver had been produced, the mine at Kupei being the largest producer. The available tonnages of gold ore were small, and the unpredictable structure of the lodes did not support expensive underground development. Eventually the mines became uneconomic and were abandoned shortly before the Japanese invasion in 1941 (Thompson, 1962).

After the end of the Second World War alluvial gold was worked near Atamo, Karato, and several other localities in the Crown Prince Range (Thompson, 1962). None of these alluvial prospects was a large producer and gold production ceased in 1959. The total gold production for Bougainville is shown in Table 5.

The Kupei gold lode (Fisher, 1936; Thompson, 1962) is perched on a steep hillside on the north-eastern fall of the Crown Prince Range. The old mine workings, abandoned in 1941, consist of an open cut and three drive levels, the lowest being 224 feet below the surface. The ore was treated at a battery situated in Kupei Creek below the mine. Plans of the workings are included in Fisher's 1936 report.

In 1936 ore reserves were estimated at 37,400 tons. About a third of this had been mined by 1941, the average grade of the ore mined being between 8 and 10 dwts Au per ton. The gold ranged in fineness from 830 to 896.

The Kupei gold lode consists of a lenticular network of closely spaced gold-bearing quartz veins cutting a copper-bearing porphyritic microdiorite which has intruded agglomerate belonging to the Kieta Volcanics. The outcrop of the lode is 231 feet long in a roughly north-south direction and up to 106 feet wide. The lode diminishes in size with depth and pinches out between 100 and 224 feet below the surface. An indefinite zone of weak gold mineralisation surrounds the lode and grades outwards into unmineralised porphyritic microdiorite. The lode is cut by several steeply dipping faults striking roughly east, most of which carry mineralised clayey or pyritic material.

The gold-bearing quartz veins in the lode are up to 3 inches wide. They contain abundant chalcopyrite and bornite, and subordinate pyrite, galena, and sphalerite. Many veins have median bands of chalcopyrite and bornite, indicating that some of the copper may be later than the quartz (Thompson and Fisher, 1965). Secondary malachite is characteristic on weathered surfaces.

The Panguna (Pumkuna) gold lode (Fisher, 1936; Thompson, 1962) is situated 3 miles west-south-west of the Kupei lode and 12 miles south-west of Kieta. It crops out on a steep valley slope on the north side of Panguna Creek, a tributary of the Kaverong River on the south-western fall of the Crown Prince Range. The old mine workings consist of two adits and a number of short drives (Thompson, 1962). In 1936 Fisher estimated that the lode contained from 15 dwts to 1oz. of gold per ton. The fineness of the gold produced at this time ranged from 904 to 946.

The lode is a fissure vein cutting porphyritic microdiorite; it strikes approximately north-west and dips north-east at 30° to 60°. In 1936 the lode outcrop was 230 feet long and up to 44 inches wide. Since that date the outcrop has been modified by mining and in 1960 Thompson could only trace the lode discontinuously for about 140 feet, the maximum thickness then being 18 inches. The lode is intersected by a number of cross-faults and has also been offset along strike-slip faults caused by movement down slope.

The lode consists mainly of quartz, with subordinate chalcopyrite, bornite and malachite, and small amounts of pyrite, molybdenite and magnetite (see Appendix B). These minerals also occur in stringers cutting the surrounding microdiorite.

At Moroni (Fisher, 1936) eluvial gold has been found in varying quantities in the surface soils, but up to 1936 no definite lode had been located. Here porphyritic microdiorite grades up into overlying agglomerate: the transition zone is silicified and cut by quartz and pyrite veins.

Copper

After the Kupei mine was abondoned in 1941 little or no prospecting was done until 1963. However in 1961 J.E. Thompson visited the Kupei area and in his report (Thompson, 1962) he strongly recommended the area for mineral search, specifying a geochemical survey and reconnaissance mapping. Subsequently, in late 1963, Conzinc Rio Tinto of Australia Pty Ltd applied for and was granted a Special Prospecting Authority. This company has since carried out a programme of geochemical prospecting covering most of Bougainville and Buka, and this work has led to the discovery of large and intense copper anomalies in the vicinity of the old gold workings at Kupei and Panguna. In September, 1964, C.R.A. commenced diamond drilling the geochemical anomalies, and the drilling has established substantial tonnages of low grade copper deposits at Panguna and similar but smaller deposits at Kupei. At both localities the deposits are of 'porphyry' type (Bateman, 1950), the copper occurring in shattered porphyritic microdiorite close to intrusive contacts with hornfelsed agglomerate; the agglomerate contains pyrite but little or no copper sulphide.

The mineralised microdiorite is considerably altered, being partly silicified and chloritised, and it commonly contains abundant dioritic and andesitic xenoliths. Exposures generally have a thick soil cover and the microdiorite is locally weathered to a depth of over 200 feet. A zone of secondary enrichment occurs at varying depths beneath the surface outcrop. Detailed geochemical prospecting of the microdiorite outcrops is complicated by localised deposits of Recent or Pleistocene ash several feet thick, which closely resemble weathered microdiorite, and also, on steep slopes, by land slip material.

The copper occurs mainly as chalcopyrite and bornite in innumerable thin cross-cutting quartz veins; these same minerals are also present in much smaller amounts in the adjacent microdiorite. Covellite and chalcocite occur as minor alteration products of chalcopyrite and bornite (Greaves, in Thompson, 1962; and Appendix B). Green malachite is prominent on most weathered microdiorite surfaces. Other minerals associated with the copper sulphides are sphalerite, molybdenite, pyrite, and traces of gold.

Sulphide mineralisation, consisting predominantly of pyrite, but including some copper sulphides, is associated with the other diorite intrusions on Bougainville. It apppears that where pyrite is abundant copper sulphides are generally absent, although the pyrite may occur as a halo around copper deposits. Sulphides, including chalcopyrite, are also present in some of the andesite lavas (see Appendix A).

Pyrite and subordinate chalcopyrite are associated with quartz in a fissure occupying a fault zone near Iwi Plantation, 15 miles south-east of Kieta (see Appendix C).

Age of the Mineralisation at Kupei and Panguna

The copper and gold mineralisation at Kupei and Panguna is considered to be Upper Oligocene or Lower Miocene. The mineralisation probably took place during or shortly after the emplacement and shattering of the host microdiorite. These microdiorite intrusions, as has been suggested earlier in this report, may represent the eroded cores of some of the volcanic centres from which the Kieta Volcanics were derived.

Beach Sands

Many of the present day beach sands around the Bougainville coast contain high concentrations of heavy minerals, and similar concentrations probably occur in many of the old strands on the coastal plains (Thompson, 1961). The heavy mineral fraction in these sands locally exceeds 95% of the total mineral content. Titaniferous magnetite containing about 4% TiO_2 (G. Greaves, in Thompson, 1961) is the predominant heavy mineral, with subordinate hematite, pyroxene, and hornblende. These minerals are derived from the andesitic lavas and pyroclastic rocks on Bougainville and have been concentrated firstly by streams and then, on reaching the coast, by current and wave action. The heavy mineral concentrations appear to be thin, as they grade downwards into pale beach sands, and they are unlikely to form economic iron ore deposits.

QW

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APPENDIX A.

Ore Mineralogy Report No. 2 File No. 65-6865
7/3/66

AN EXAMINATION OF THE OPAQUE MINERALS IN ELEVEN IGNEOUS ROCKS FROM BOUGAINVILLE ISLAND. T.P.N.G.

by

I.R. Pontifex

The samples were submitted by D.H. Blake. Most of these are andesites and all have been examined in thin section by Blake as an integrel part of his study of the geology of Bougainville Island.

The object of this report is to present an account of the opaque minerals to supplement the petrographic descriptions.

Brief descriptions of the composition of the opaque minerals in each rock is given and these are followed by a summary and conclusions.

65-49-0044. Rock type: hypersthene-augite andesite
Locality : Malabita Hill, Buin.

The opaque minerals consist predominantly of titaniferous magnetite. Almost in every grain, the magnetite, which has a characteristic brown tint, grades imperceptibly into mag-hemite with which it forms a mottled intergrowth. Commonly this latter mineral replaces the magnetite around grain boundaries. In many grains where it is the dominant mineral, replacement has obviously been more extensive, and it contains remnant inclusions of magnetite.

65-49-0121. Rock type: hyper thene-augite andesite (basaltic)
Locality : Mt. Bagana.

The opaque grains consist almost entirely of titaniferous magnetite. Some grains, particularly the smaller ones contain lamellae of hematite which frequently form a connected lattice work following the crystallographic planes of the magnetite host. The grain boundaries of magnetite are generally unaltered.

Several grains of magnetite contain extremely thin (0.002 mm.) exsolution lamellae of ilmenite.

In some grains magnetite grades imperceptibly into thin stringers of mag-hemite along fine cracks. Rare, minute inclusions of chalcopyrite (about 0.002 mm.) occur in some magnetite. Several chalcopyrite grains of this size were also seen in the groundmass.

65-49-0135. Rock type: hypersthene-augite andesite
Locality : Arawa Bay, Kieta.

The opaque minerals consist exclusively of titaniferous magnetite. There is no evidence of exsolved ilmenite or hematite or of any alteration of the magnetite, (at 500 X magnification).

65-49-0151. Rock type: hypersthene-augite andesite
Locality : Mt. Bagana.

The opaque grains consist of titaniferous magnetite. Small amounts of hematite occur as extremely fine lamellae in some grains. This appears to be a primary exsolution product.

65-49-0162D. Rock type: hornblende andesite
Locality : Billy Mitchell

The opaque grains consist predominantly of hematite. This has a distinct reflective pleochroism from mid to light grey. Some grains are associated with lamellae of titaniferous magnetite.

All grains contain bleb and rod-like inclusions of a mineral which are generally oriented along definite directions within the hematite. In some grains these inclusions form skeletal and myrmekitic intergrowths with the hematite.

This mineral, which has similar relationships with hematite in 65-49-1022A, is dark grey (c.f. hematite), and in some places has a reddish internal reflection and a weak anomalous anisotropism. Rarely it forms the greater part of a grain and it then acts as host to bleb-like inclusions of hematite which are oriented in a similar pattern to the inclusions contained in a hematite host.

In an attempt to identify this mineral the opaque minerals were separated from this rock and analysed on the X-ray diffractometer. The diffraction pattern obtained on the chart indicates the presence of hematite and lesser magnetite. Although several minor peaks could not be accounted for the pattern did not indicate the presence of significant amounts of any other mineral. On this basis it is suggested that the grey mineral, intergrown with hematite, is an iron oxide which has mineralogical affinities with hematite, and, or magnetite.

A mixture of fine-grained hematite and hydrated iron oxides extensively replace ferro-magnesian silicate minerals around the grain boundaries and along cleavage planes.

Extremely small grains of pyrite (0.002 mm.) and probable chalcopyrite are disseminated through the rock groundmass. One grain of chalcopyrite enclosed in hematite was observed.

65-49-0171. Rock type: hypersthene-augite andesite
Locality : Mt. Balbi

The opaque mineral grains are made up predominantly of titaniferous magnetite. Invariably these are partially altered to mag-hemite, generally around grain boundaries and along fractures within the grains.

Thin lamellae (0.003 mm.) of hematite are oriented along crystallographic planes of some magnetite.

65-49-1022A. Rock type: augite-hornblende andesite
Locality : Mt. Taroka

Most of the opaque minerals consist of titaniferous magnetite which is extensively replaced around grain margins and along crystallographic planes, to hematite. Much of this hematite has a distinctive, mottled reflective pleochroism, it has no red internal reflection and it is slightly darker than 'normal' hematite. It is probably a titanium rich hematite - titan-hematite. Hydrated iron-oxides partly surround some magnetite and some ferro-magnesion silicate grains.

65-49-1214. Rock type: hornblende, augite andesite
Locality : Mt. Takuan

The opaque minerals consist mainly of titaniferous magnetite which invariably contains exsolution lamellae of hematite, ilmentite, spinel, and rutile.

Hematite lamellae are the most abundant; they measure about 0.005 mm. wide and are oriented along the 111 crystallographic planes of the magnetite host.

Some lamellae of this size and orientation in magnetite contain small (0.00 X 0.003 mm.) exsolved blebs of ilmenite. The limited optical properties and the associations of these lamellae indicate that they are of rutile.

Most grains of magnetite contain abundant, extremely fine rods of spinel, oriented along the 100 crystallographic planes. These have a uniform size which measures 0.001 mm. wide and generally 0.02 mm. long. Some grains of magnetite contain thi exsolution lamellae of ilmenite.

Several opaque grains in this section consist of hematite which contains irregular blebs of, and forms a graphic intergrowth with, the dark grey mineral found in 65-49-0162D.

Summary and Conclusions

The opaque minerals generally make up about 2% of the sections examined. They have a random distribution throughout the rocks; commonly they occur as inclusions in silicate grains. Their average grain size is of the order of 0.05 mm., their maximum size is 0.5 mm..

The opaque mineral grains observed in each section are summarised in the following table.

Rock No.	mag.	hem.	unident.	maghem.	ilm.	spin.	rut.	py.	chalco.	limon.
65-49-0044	x			x						
0121	x	x		x r.	x				x r.	
0135	x									
0151	x	x r.								
0162D	x r.	x	x					x r.	x r.	x
0171	x	x r.		x				x r.	x r.	x
1022A	x	x	x							
1195	x	x			x		x r.	x r.	x	
1212A	x	x			x				x r.	
1212B	x	x r.			x					
65-49-1214	x	x	x r.		x	x	x r.			

x = present
mag. = titaniferous magnetite
hem. = hematite lamellae in or rims around magnetite grains
unident. = unidentified grey mineral
mag.hem. = mag-hemite
ilm. = exsolved blebs and lamellae of ilmenite in magnetite
spin. = spinel (un-named)
rut. = rutile
py. = pyrite
chalco. = chalcopyrite
limon. = limonite, a mixture of fine-grained hematite and hydrated iron oxides
x r. = rare

Titaniferous magnetite is the main opaque mineral in each section. It is generally associated with lesser amounts of hematite.

The hematite most commonly occurs as narrow lamellae oriented along the crystallographic planes of magnetite. The lamellae have straight well defined margins; frequently they form a connected lattice work which enclose triangular areas of magnetite.

Various textural criteria such as; (i) intersecting lamellae are not enlarged where they cross, and (ii) hematite is commonly absent from grain margins and fractures within the host; suggest that in some grains at least, the hematite is a primary exsolution product. This hematite is interpreted as having been derived by the unmixing of a solid solution of hematite and magnetite during the crystallisation of the rock.

It is noted however, that lamellar intergrowths of hematite in magnetite can also result from the alteration of magnetite. To what extent this has occurred in these rocks cannot be positively determined.

Some opaque grains consist of a myrmekitic intergrowth of hematite and a dark grey mineral. Where these are associated with magnetite-hematite grains the hematite is continuous from within the magnetite to within the myrmekitic intergrowth.

The dark grey mineral is slightly anisotropic from dark to mid-grey; in some areas it has a weak internal reflection. This is the same unidentified grey mineral as found in rock no. 0162D. Several extremely small grains of pyrite and chalcopyrite are disseminated through the matrix. Two grains of chalcopyrite were observed as inclusions in magnetite.

65-49-1195. Rock type: hornblende andesite
Locality : Bakanovi River, Kieta.

The opaque mineral grains consist mainly of titaniferous magnetite. Invariably these are partly altered around their margins and along crystallographic planes to hematite.

Many of the grains, particularly the larger ones, contain fine exsolution lamellae of ilmenite. The lamellae measure of the order of 0.003 mm. wide and some of them are intergrown with extremely small amounts of rutile.

Several grains of magnetite contain inclusions of chalcopyrite, which have a maximum observed size of 0.008 mm. Four grains of chalcopyrite of this size also occur as inclusions in silicate minerals. Some of the chalcopyrite is partly altered to covellite. One small grain of pyrite in magnetite, and one extremely small grain of ?gold in the rock matrix, were also observed. The gold was too small to be positively identified.

65-49-1212A. Rock type: quartz diorite
Locality : Mt. Takuan

The opaque minerals in this section consist mainly of titaniferous magnetite. The magnetite generally contains exsolved lamellae and blebs of ilmenite. The lamellae are commonly lined by a narrow border of hematite and fine tongues of hematite protrude from this, along adjacent crystallographic planes of the magnetite.

Small amounts of fine hematite lamellae were also observed in other magnetite grains; these appear to be a primary exsolution product.

In one part of the section, magnetite containing exsolved ilmenite, forms a graphic intergrowth texture with the silicate minerals.

One small grain (0.033 mm. across) of chalcopyrite was observed in the groundmass of the rock.

65-49-1212B. Rock type: hypersthene-augite andesite
Locality : Mt. Takuan

The opaque minerals consist essentially of titaniferous magnetite; some contain exsolved irregular patches of ilmenite.

Several grains of magnetite contain anrrow lamellae of hematite; hematite also occurs along fine cracks and in irregular patches in some magnetite which suggests that at least some of the hematite is derived by the alteration of magnetite.

The hematite in specimens 0171, 1022A, 1212B, and 1195, in addition to forming lamellae in magnetite, is relatively concentrated around grain boundaries and as irregular intergrowths with magnetite. This hematite having the latter two modes of occurrence is almost certainly secondary, formed at the expense of magnetite by oxidation. This alteration may have occurred during the crystallisation of the rock or during subsequent weathering.

In some sections magnetite grades imperceptibly into mag-hemite with which it forms a mottled intergrowth. The mag-hemite shows a maximum concentration around grain boundaries and along fractures in the magnetite. It has formed by the oxidation of the magnetite.

Ilmenite occurs in accessory abundance as exsolution lamellae oriented along the octahedral planes of magnetite. Less commonly ilmenite forms discrete grains. In rock no.1214, extremely small blebs of ilmenite occur as exsolution inclusions in lamellae of rutile. These lamellae are oriented along the crystallographic planes of titaniferous magnetite.

Most grains of magnetite in rock no. 1214 contain abundant, extremely fine rods of spinel, oriented along the 100 crystallographic planes.

The occurrence of rutile is rare, however accessory amounts are associated with hematite and ilmenite exsolution inclusions in titaniferous magnetite in 1195 and 1214.

Sulphide minerals are rare in these rocks and where present they generally form grains smaller than 0.003 mm. in diameter. In rock no. 1195 several grains of chalcopyrite which measure up to 0.008 mm. occur as inclusions in magnetite and silicate minerals.

Several grains of pyrite were observed in some of the rocks. Some of these grains occur as inclusions in magnetite but most of them as discrete grains within the rock matrix.

Patchy aggregates of fine-grained hematite and hydrated iron oxides extensively replace the ferro-magnesian silicate minerals in rock no. 0171 and to a lesser extent in rock no.0162D.

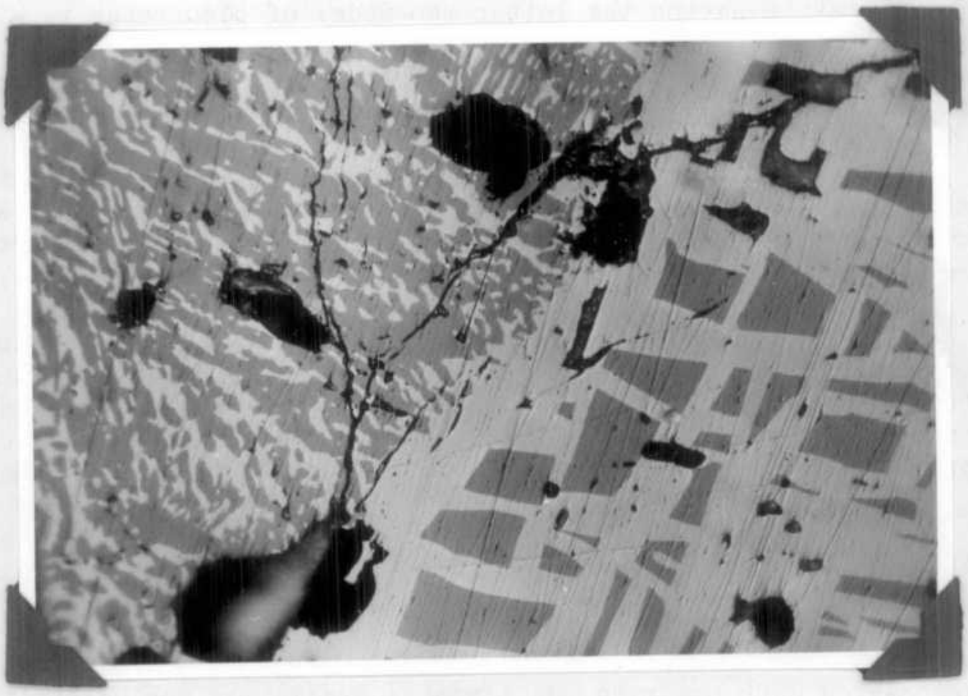


Figure 1. In the right hand side of the photo, lamellae of hematite (light) form a lattice structure in titaniferous magnetite (dark grey). The hematite is continuous into an adjacent part of the grain (left-hand side) where it forms a myrmekitic intergrowth with an unidentified ?iron oxide (dark).
Rk. No. 65-49-1022A. Neg. No. M/424. Mag. X560.

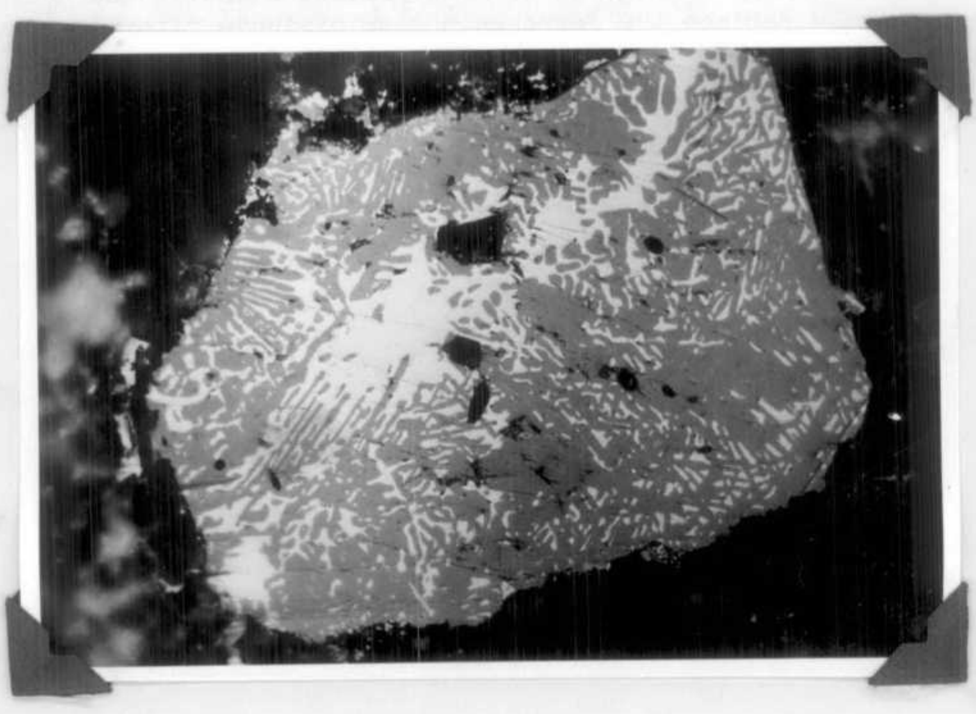


Figure 2. Myrmekitic intergrowth of an unidentified ?iron-oxide (dark) and hematite (light).
Rk. 65-49-1022A. Neg. No. M/424. Mag. X560.

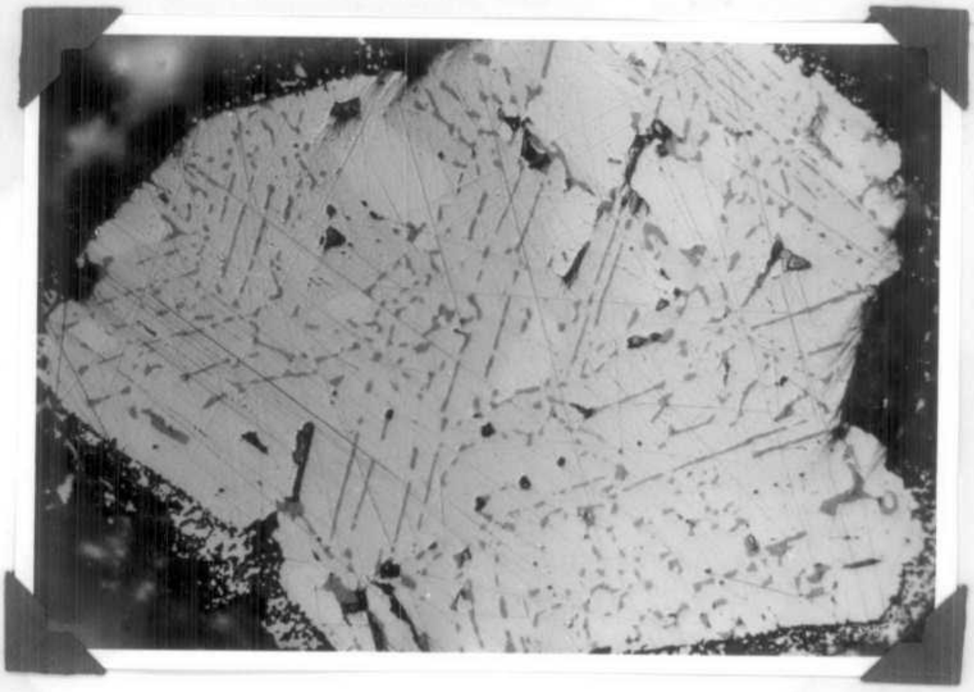


Figure 3. Oriented inclusions of an unidentified ?iron-oxide (dark) in hematite (light). The hematite is altered around its margin to hydrated iron oxides.
Rk. No. 65-49-0162D. Neg. No. M/424. Mag. X560.

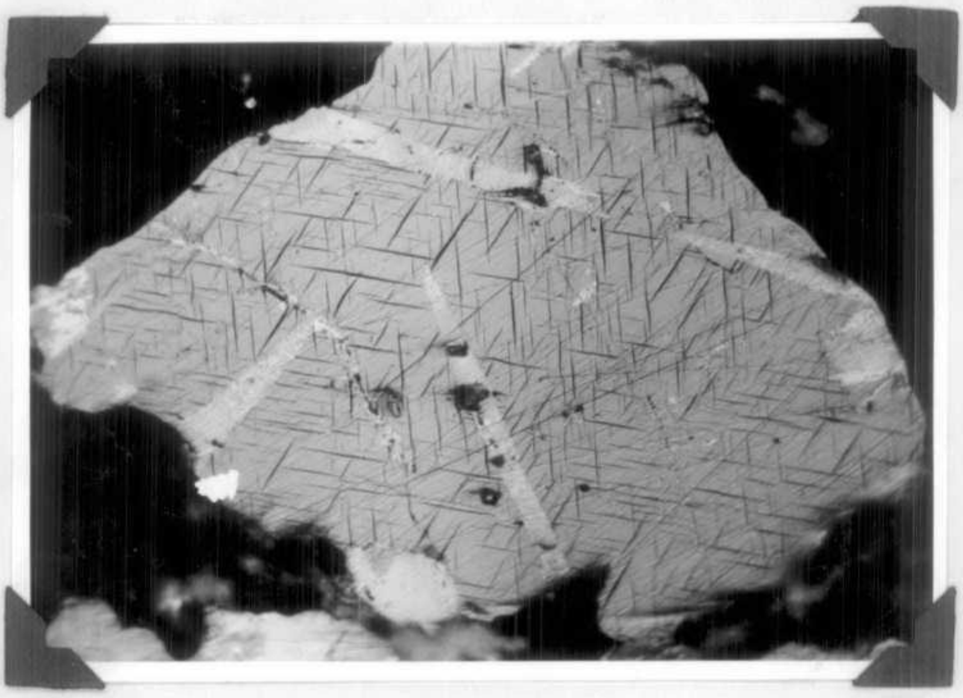
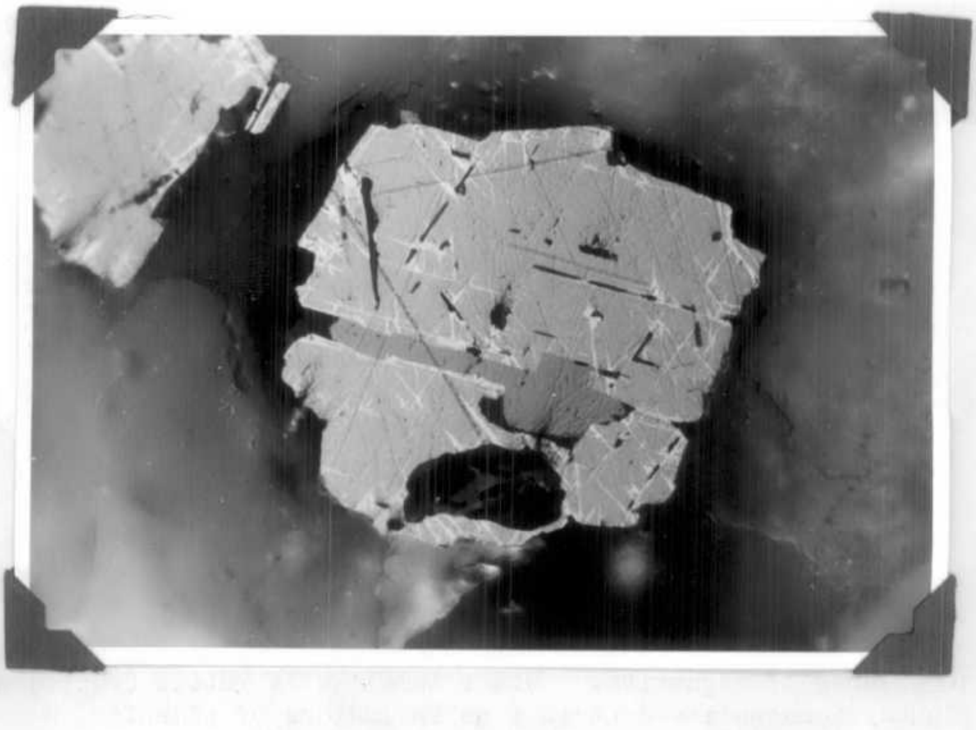


Figure 4. Fine spindle-like inclu ions of spinel (black) oriented along the 100 planes of magnetite. Wider lamellae of rutile (white) along the 111 planes of magnetite contain f ne inclusions of ilmenite.
Rk. No. 65-49-1214. Neg. No. M/424. Mag. X560.

<u>Figure 5.</u> Fine spindle-like inclusions of spinel (black) oriented along the 100 planes of magnetite. Wider lamellae of hematite along the 111 p anes of magnetite.
Rk. No. 65-49-1214. Neg. No. M/424. Mag. X560.



<u>Figure 6.</u> Inclusions of ilmenite (dark grey) and hematite (white) in magnetite.
RK. No. 65-49-1212A. Neg. No. M/424. Mag. X560.

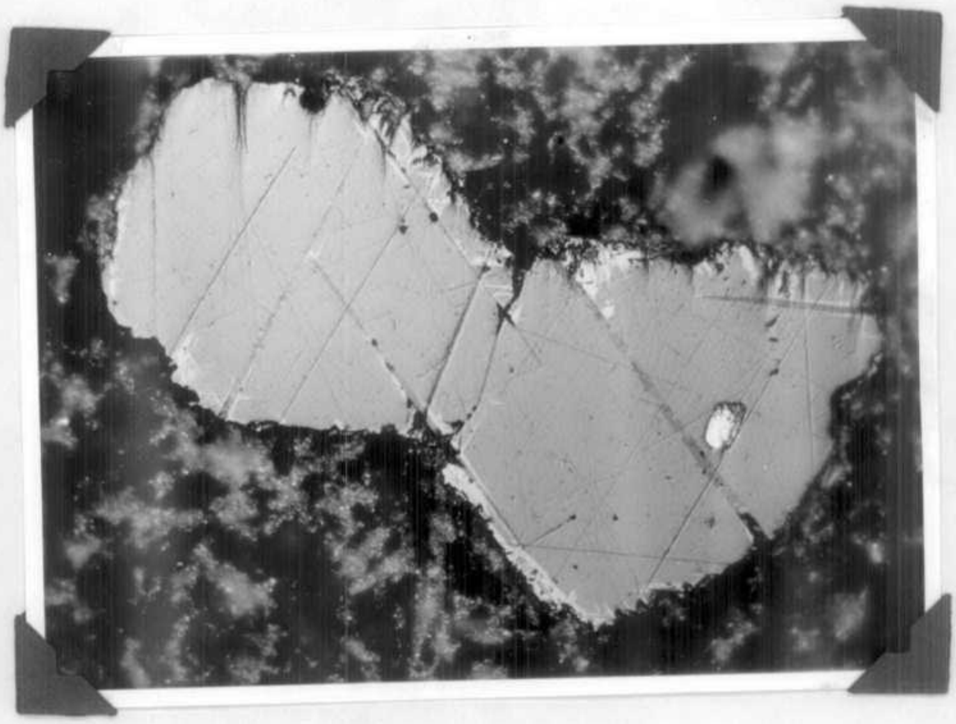


Figure 7. One bleb-like inclusion of chalcopyrite (bright white) and lamellae of ilmenite (dark grey) in magnetite. The magnetite is altered around its margins to hematite (white).
Rk. No. 65-49-1195. Neg. No. M/424. Mag. X560.

File No. 65-6865
7/3/66.

APPENDIX B.

Ore Mineralogy Report No. 5:

THE EXAMINATION OF MINERALISED DIORITES FROM THE PANGUNA (PUMKUNA) AND KUPEI MINES, BOUGAINVILLE ISLAND. N.G.

by

I.R. Pontifex

The specimens were submitted by D.H. Blake. They consist essentially of porphyritic microdiorites from zones of porphyry copper type mineralisation.

Field No. 93a

Locality: Eastern adit, Panguna Mine, Panguna Creek.

Description: This is a microdiorite which is cut at random by fine quartz veins carrying small amounts of opaque minerals.

Titaniferous magnetite is the most abundant of these and it forms about 5% of the rock. Discrete grains and small aggregates of magnetite are scattered through the rock and these show relative concentration in veins.

Chalcopyrite, which forms about 1% of one section and considerably less than 1% of another, generally occurs as elongate and skeletal grains, associated with magnetite, and is almost entirely confined to the veins. Their maximum grain size is 1.2 mm. X 0.5 mm. Rare discrete grains of chalcopyrite occur in the matrix.

Accessory bornite is restricted to the veins in the rock. It is intergrown with some chalcopyrite and some grains of bornite act as host to chalcopyrite inclusions. Commonly it is altered to chalcocite around grain margins.

Field No. 93c

Regst. No. 65-49-0093c.

Locality: Drill core from hole no. B.V.P.12, Panguna Mine. Depth 175 ft.

Description: Small grains of magnetite are scattered through this rock; they make up about 3% of it. Several discrete grains of chalcopyrite were also observed in the rock matrix; these have an average size of 0.005 mm.

Field No. 93w

Locality: On mine grid line 650N, Panguna Mine.

Description: Small grains and aggregates of titaniferous magnetite make up about 5% of the rock. Most of these are scattered through the rock matrix but some are localised in patches within fine quartz veins.

Magnetite commonly contains alteration lamellae of hematite.

Several grains of chalcopyrite (0.055 mm. across), which are surrounded by an alteration rim of chalcocite, are enclosed within quartz in the quartz veins.

F'eld No. 88a

Locality: Kupei Mine, drill hole no. B.V.K.2, depth 56 ft.

Description: Several quartz veins up to 8 mm. wide cut through this diorite; these carry opaque minerals.

The veins contain abundant small cavities which indicates that they are fissure fill veins.

The most abundant ore mineral is titaniferous magnetite. Most of this is localised in small granular aggregates within the quartz veins, but discrete grains of magnetite are also scattered through the adjacent wall rock.

In the polished section examined only one grain of chalcopyrite was observed; this measures 0.1 mm. across. It is surrounded by hydrated iron oxides which most likely formed at the expense of pre-existing chalcopyrite.

The veins also contain patches and stains of malachite and limonite.

Field No. 88/2

Locality: Open cut, Kupei Mine.

Description: The rock is a microdiorite. Small subhedral grains and aggregates of magnetite are scattered through the rock matrix, coarser grains and aggregates of magnetite and copper sulphides are confined to quartz veins.

In the veins, magnetite tends to form the margins and grains of intergrown bornite and chalcopyrite occupy the centre. The bornite and chalcopyrite are partly altered to hydrated iron oxides which form a roughly quadrangular boxwork texture. Magnetite is partly altered to hematite.

Field No. 88c

Locality: Kupei Mine, drill hole no. B.V.K.2, depth 218 ft.

Description: The only opaque minerals in this specimen are skeletal masses of pyrite up to 4 mm. in maximum dimension and accessory grains of magnetite disseminated through the rock matrix.

Summary and Conclusions

The rocks in the vicinity of the Panguna (Pumkuna) and Kupei mines are porphyritic diorites and microdiorites. The ore minerals contained in the rocks from the two mines are essentially the same. In order of decreasing abundance they are: titaniferous magnetite, chalcopyrite, bornite and the supergene alteration products of these: hematite, chalcocite, hydrated iron oxides, and malachite. Pyrite was found only in drill core specimen from 218 ft. at the Kupe Mine.

Fine grains of magnetite are generally disseminated throughout the rocks but they show relative concentration, commonly in aggregates, within quartz veins. The chalcopyrite and bornite frequently form composite grains and these are almost exclusively restricted to fissure fill veins within the rocks. Rarely small grains of chalcopyrite are disseminated through the adjacent country rock.

These relationships indicate that the copper sulphides are derived from the diorite and were emplaced either in its last stages of crystallisation, or introduced into fine fissures which formed in the diorite after its crystallisation. In the latter case the diorites may have been reconstituted and mobile quartz may have acted as a selective collector of sulphides and some magnetite before becoming localised in veins. The implication here, is that areas in the diorite body which contain the greatest concentration of fissures will also contain the greatest concentration of primary copper sulphides.

Several ore specimens from the Pumkuna lode and the Kupei mine have previously been described.* The mineral assemblage in these is essentially the same as found in the specimens described above; the proportion of the minerals present however, is variable.

The specimens described in this report represent what is generally understood to be "porphyry copper" deposits. Most of them are unlikely to be ore grade material but adjacent areas within the diorites which contain greater concentrations of inherent copper, or which have been secondarily enriched, may prove to be ore grade.

* J.E. Thompson. B.M.R. Records 1962/39. "The Pumkuna Copper-Gold Prospect, Bougainville Is., Territory of Papua and New Guinea".

APPENDIX C.

Ore Mineralogy Report No. 6 File No. 65-6865

3/3/66

THE EXAMINATION OF MINERALISED ROCKS FROM REBOINE BAY AND NEAR ATAMO, BOUGAINVILLE IS. T.P.N.G.

by

I.R. Pontifex

The specimens were submitted by D.H. Blake.

Field No. 1117b

Regst. No. 65.49.1 17.

Locality: Arakawan River, near Atamo. Lat. 6°14'S. Long. 155°22'55"E.

Description: This specimen consists of a microdiorite in contact with hornfels. The contact is marked by a prominent vein of pyrite, up to 1 cm. wide, which has been slightly displaced by small fractures. Stringers of pyrite which are generally parallel to the contact are abundant in the diorite. Less abundant stringers of pyrite in the horn e , occur both parallel o the contact and roughly parallel to the fractures displacing it.

The pyrite in the main vein along the contact is granular and brecciated; it is associated with a quartz gangue which has been introduced into fractures within this pyrite. This quartz carries accessory chalcopyrite which is altered around the margins to chalcocite.

The pyri.e fractured after the introduction of the quartz-chalc pyrite.

The hornfels contains abundant disseminated inclusions of titaniferous magnetite, these have an average size of 0.008 mm.

Some pyrite contains small inclusions of pyrrhotite.

No gold was found in the two sections examined. The textural relationships in the sections examined indicate the following paragenesis.

1. Introduction of diorite into the hornfels.
2. Introduction of pyrite along the contact and in fissures within the diorite.
3. Deformation of the rock and the production of small fissure veins in the hornfels parallel to, and at oblique angles to the contact. These veins were filled by pyrite, and subsequently quartz and minor chalcopyrite.

   Events No. 2 and 3 conceivably occured during the final stages of the emplacement of the diorite. It is most likely that the pyrite, quartz and chalcopyrite are derived from the diorite.
4. Late stage fracturing of all the minerals in the vein.

Field No. 224-1

Locality: Doreina, Reboine Bay south of Kieta.

Description: This rock consists of coarsely granular and subhedral pyrite scattered through a quartz matrix. The pyrite grains vary in size from 0.01 mm. to 3 cms. across; many of them are elongated and have a generalised common orientation. Cavities within the aggregate are mostly lined with crystalline drusy quartz. The pyrite grains are strongly brecciated.

The composition and relationships of the minerals in this rock and their overall cataclastic texture indicates that it is probably part of a large mineralised vein which has localised a fault fissure. It is apparent that movement has occured along the fissure subsequent to the emplacement of the vein.

Field No. 224-2

Locality: Doreina, Reboine Bay, south of Kieta.

Description: This is a quartz vein which carries small amounts of euhedral pyrite, lesser amounts of anhedral chalcopyrite, and accessory sphalerite.

The quartz is cellular in parts and some of the cells are lined with hydrated iron oxides. Most of these are probably pseudomorph cavities formed by the alteration of pre-existing sulphides, followed by the removal of most of the alteration products.

The maximum grain size of the pyrite is 2.5 mm., of chalcopyrite 2 mm., and of sphalerite, 1 mm..

The sphalerite contains extremely fine exsolution blebs of chalcopyrite.

The weathered surface of chalcopyrite consists of a steel-blue veneer of chalcocite and lesser amounts of bornite.

PLATE 1

BOUGAINVILLE and BUKA ISLANDS 1:250,000

SHEETS SB 56-8, SB 56-12