COMMONWEALTH OF AUSTRALIA

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Geology of Bougainville and Buka Islands, New Guinea

BY

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GEOLOGICAL BULLETIN NO. 3—Geological Reports on New Britain, *by N. H. Fisher and L. C. Noakes,* 1942.

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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 Solomon Islands 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 Bagana volcano (5730 feet), the dormant Balbi (8502 feet) and Loloru volcanoes, and a number of extinct volcanoes, including Billy Mitchell, Takuan (7385 feet), and Taroka (7240 feet); crater lakes occur in the centres of Loloru 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 Formation, which forms the Parkinson Range on Buka. They consist of subaerial andesitic and basaltic lavas, agglomerates, tuffs, a basic pillow lava, and waterlaid 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 Balbi volcano. The Keriaka Limestone is overlain by unnamed 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 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. The volcanic rocks belong to the calcalkaline suite characteristic of orogenic regions.

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, unnamed 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 Recent 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 mineralization on Bougainville is associated with two porphyritic microdiorite bodies intruding agglomerate belonging to the Kieta Volcanics. The gold occurs in quartz stockworks within 'porphyry copper' deposits. Small quantities of alluvial and eluvial gold have also been found. Many of the beach sands around the coast of Bougainville contain concentrations of titaniferous magnetite.

Fig. 1: Locality Map.

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 mineralization 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 come within the circum-Pacific volcanic belt. 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), but have not been found on either Bougainville or Buka.

Quaternary volcanic rocks are dominant on Bougainville, where there are one active, two dormant, and several extinct volcanoes, and outcrops of undoubted 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 a Pleistocene organic limestone crop out 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. Patrol posts are maintained by the Administration 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

The four airfields in the area are served regularly from Rabaul by Trans-Australia Airlines: the Buka passage airport (suitable for DC3 and Fokker Friendship aircraft) on Buka, and the Wakunai, Kieta (Aropa), and Buin airfields (suitable for DC3 aircraft) on Bougainville. A weekly air service operates between Rabaul, Buka Passage, and Honiara (British Solomon Islands Protectorate).

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 settlements; however, few tracks exist in uninhabited mountainous areas in the interior of the island, which are therefore relatively inaccessible (Fig. 3).

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 villages, on sandbanks in rivers, and on most beaches, but landing spots are almost nonexistent in uninhabited mountainous areas.

Survey parties consisted of one or two geologists, up to ten locally hired 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 walking tracks, as river traverses were normally not practicable: the rivers flow swiftly and are subject to frequent and sudden flooding. Most of the coastal exposures were examined using a dinghy with an outboard motor.

Fresh rock exposures are mostly confined to areas of rapid down-cutting such as wave-cut platforms, cliff faces, river beds, and gorges. Elsewhere the rocks are generally deeply weathered, especially 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 were plotted directly on these. Later vertical air-photographs, taken in 1963, cover some of the gaps and cloud-obscured areas of the 1962 photographs. Both sets were taken by the Royal Air Force and are available from the Secretary, Department of Air, Canberra. A list of available air-photographs is given in Table 1, and flight diagrams are shown in Figure 2. Field observations were also plotted on military one-mile maps. The geological map was compiled from both the one-mile maps and the air-photographs.

Photogeological 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 Australians and Chinese and 62,000 indigenes live on Bougainville and Buka (Commonwealth of Australia, 1965), the main centres of population being at Sohano and Kieta. Villages are scattered throughout most of the area lying less than 3000 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.

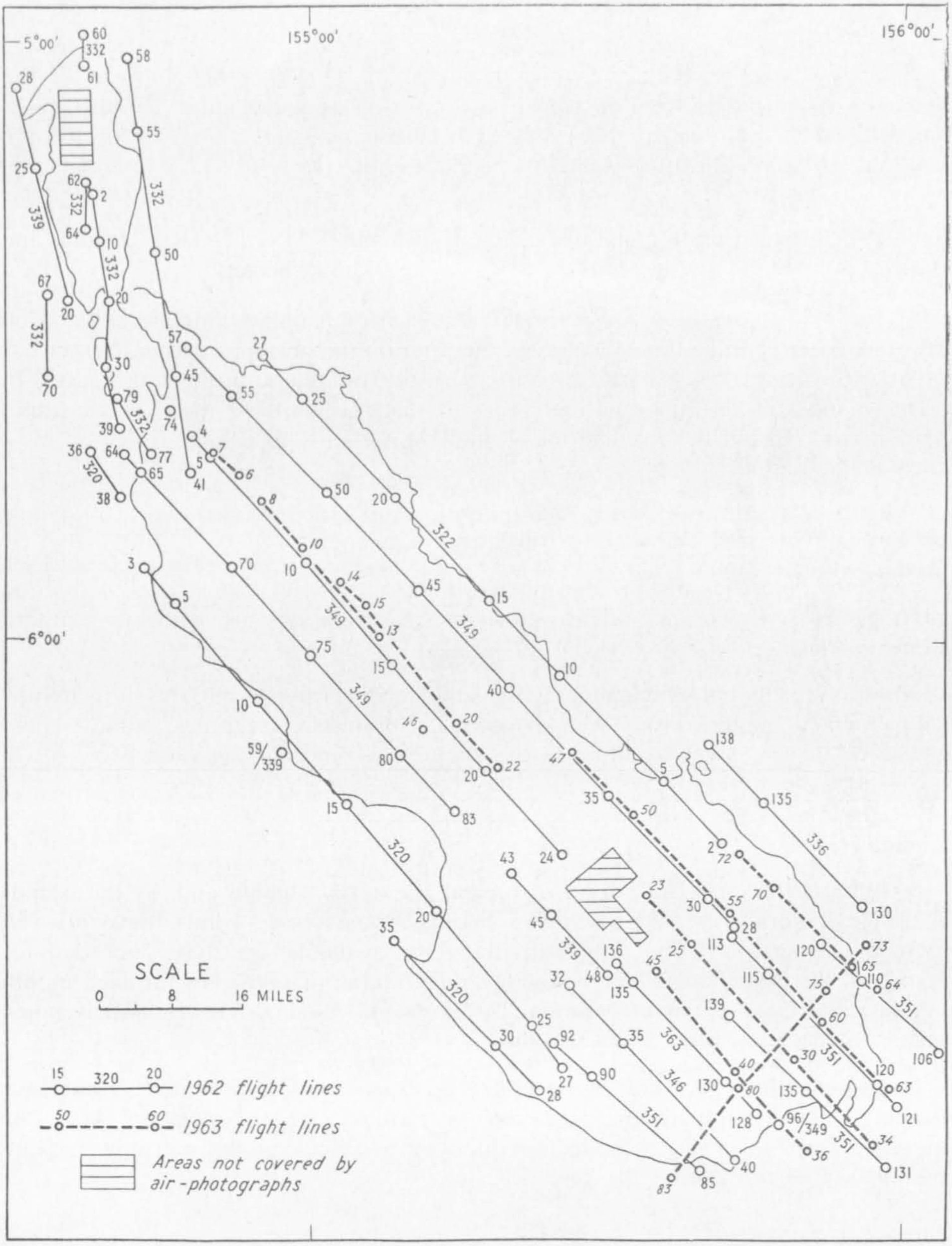

Fig. 2: Flight diagram for Bougainville air-photos.

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

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

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

The main industry is copra production. 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 villages have their own coconut plantations. Cocoa is becoming increasingly important and is now grown on most coconut plantations.

Conzinc Riotinto of Australia Exploration Pty Ltd employed over 100 people on Bougainville in 1965 while prospecting for copper.

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 population still practise subsistence farming, but this is generally supplemented by cash crops such as coconuts, oranges, pineapples, potatoes, and tomatoes. These are sold either at the markets at Buka Passage and Kieta, or to the local 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 shrouded in cloud by 9 o'clock in the morning and are relatively cool throughout the year.

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 was seen. Mosquitoes and scrub ticks are common locally and malaria is still a hazard. Saltwater 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 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 & 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 Balbi and 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 Bagana was described by Baker (1949). The dormant Loloru volcano 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 CSIRO visited Buka and Bougainville and carried out a regional survey of soils, vegetation, geomorphology, and geology (CSIRO, 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 Riotinto 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 north-west. 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 Takuan and Taroka lines of volcanoes, and the Deuro Range (Fig. 3).

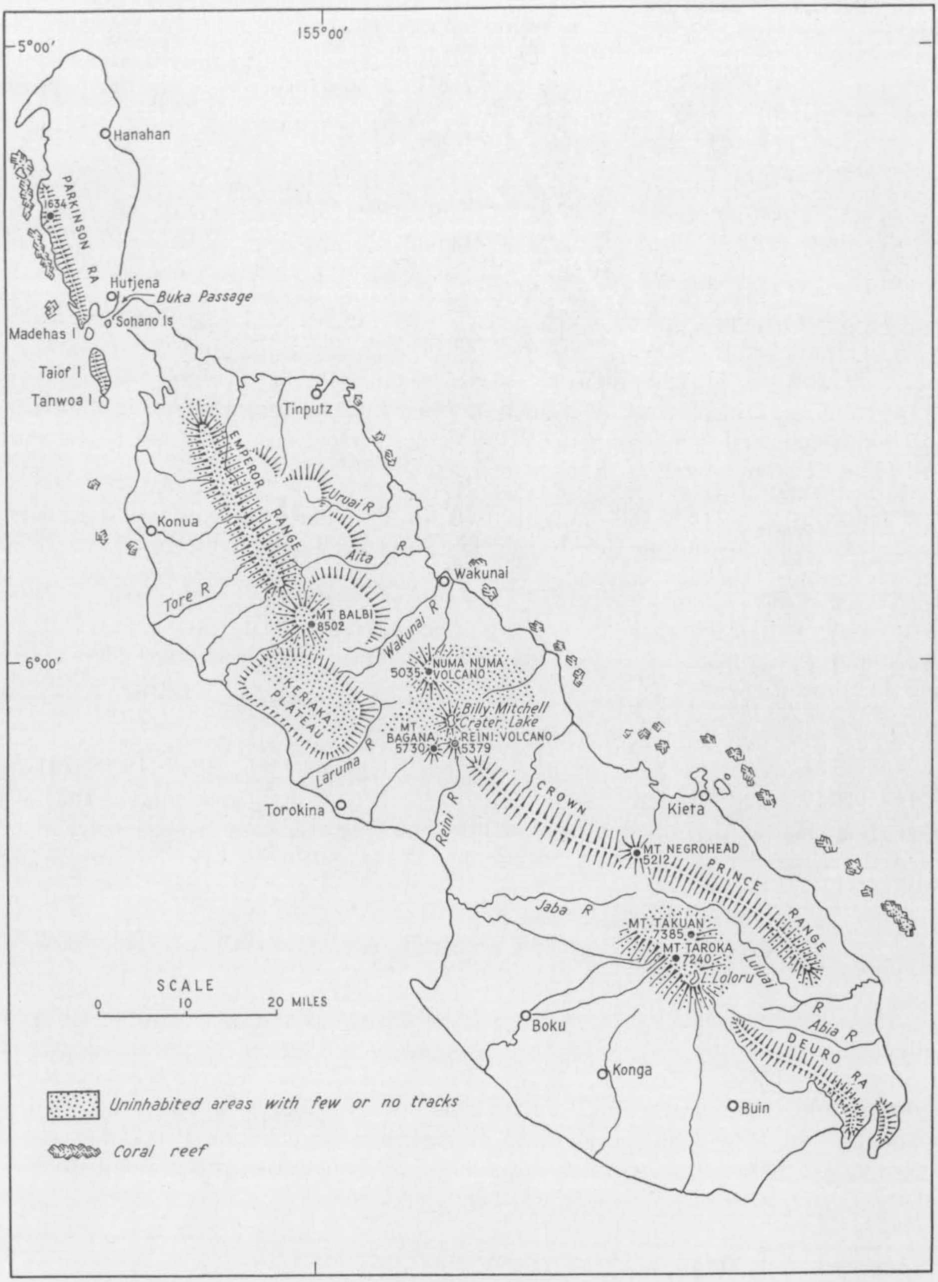

Fig. 3: Sketch map showing main topographical features of Bougainville and Buka Islands.

PLATE 1.

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

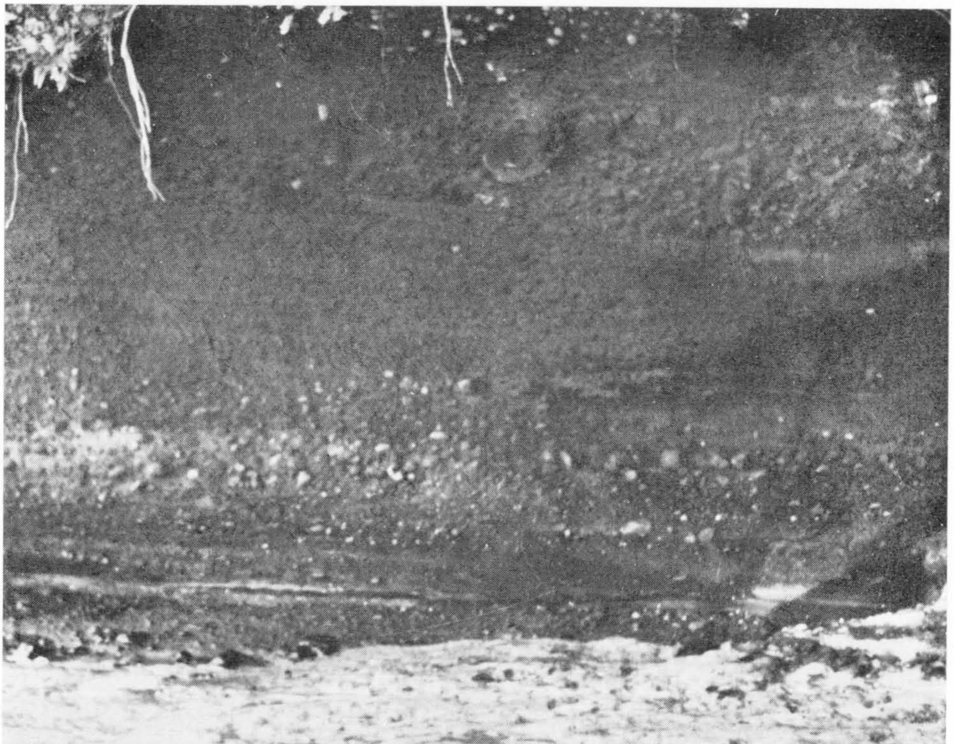

Fig. 2. Bedded fanglomerates of the Kieta Volcanics on the east coast of Tautsina Island, north-east of Kieta. (Photo F. S. Chong).

PLATE 2.

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

Fig. 2. Pyroxene crystals in the tuffaceous matrix of an agglomerate, Kieta Volcanics. A coastal exposure on the east side of Cape Pui Pui. (Photo F. S. Chong).

PLATE 3.

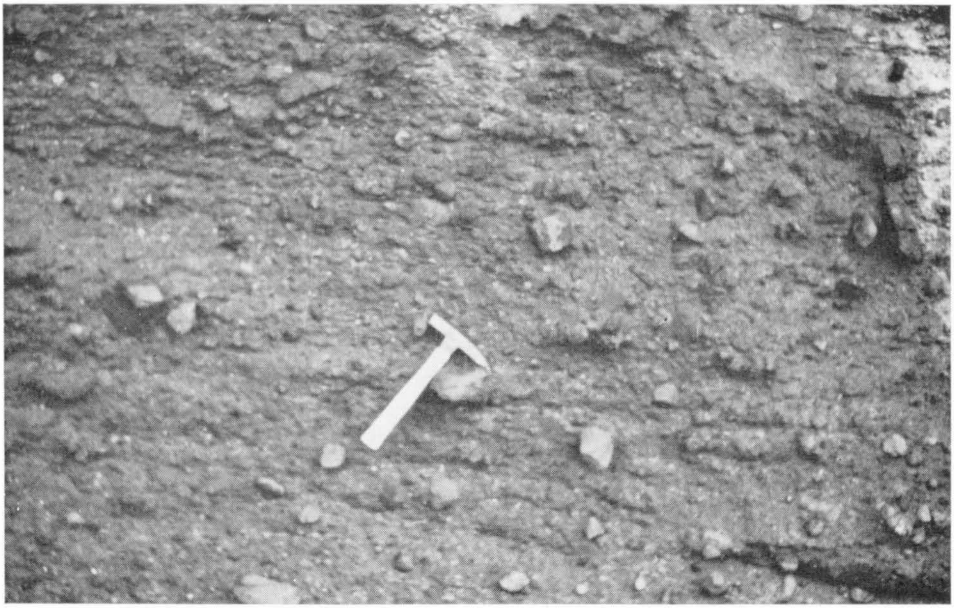

Fig. 1. Massive agglomeratic tuff on the east side of Cape Pui Pui, Kieta Volcanics. (Photo F. S. Chong).

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

PLATE 4.

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

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

The Emperor Range consists mainly of rugged mountains between 4000 feet and 7000 feet high, but it also includes Mount Balbi, 8502 feet, which is the summit of the dormant Balbi volcano and the highest point on the island. South of Balbi volcano an elevated limestone platform, the Keriaka Plateau, dips gently westwards from over 4000 feet near the centre of the island to less than 100 feet on the west coast.

A group of four volcanoes in central Bougainville separates the Emperor Range from the Crown Prince Range. These are 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 Bagana the rugged Crown Prince Range extends south-eastwards for 50 miles; Mount Negrohead, 5212 feet, is the highest point on this range.

The Takuan and Taroka lines 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, 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, is formed 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 are present 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, about 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 1634 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 and coral islands occur.

Topographical Names and Heights

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

No. 3059, Bougainville Island North 4-mile series, and

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.

ROCK NOMENCLATURE

In this report the following nomenclature for igneous, pyroclastic, and sedimentary rocks is used. This nomenclature is based on macroscopic and microscopic features.

Igneous rocks (modified after Morgan, 1964)

Andesite: This is a porphyritic rock with an average groundmass grainsize of less than 0.05 mm. 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.

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: generally coarser-grained than andesite and with 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 1 mm long, and interstitial augite, opaque minerals, and altered glass.

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

Diorite: a rock with an average grainsize greater than 1 mm 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 0.05-1 mm; 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 (modified after Morgan, 1964)

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

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

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

Ash: unconsolidated volcanic ejecta less than 4 mm 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 summarized 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 on Bougainville and the Buka Formation on Buka, consist of andesitic and basaltic 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 unnamed volcanics and also by some of the Pliocene(?) to Recent volcanic formations which make up the Bougainville Group. The Sohano Limestone, of Pleistocene age, crops out on the north coast at Bougainville and on Buka.

The volcanic rocks of Bougainville and Buka belong to the calcalkaline suite of rocks characteristic of orogenic regions. They are mostly of andesitic composition but also include small amounts of basalt and dacite. All the volcanic rocks are porphyritic, containing phenocrysts of plagioclase and one or more of the following minerals: augite, hypersthene, olivine, hornblende, biotite, magnetite, quartz and apatite.

Table 2: STRATIGRAPHY OF BOUGAINVILLE AND BUKA ISLANDS

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

Oligocene (?) to lower Miocene (?)

Kieta Volcanics (new name)

The Kieta Volcanics, which are 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 trachyandesite lava. Most of the lavas and pyroclastic rocks were probably erupted subaerially, and pillow lavas have only been found at one locality.

The type area of the Kieta Volcanics is Rankama Point, 3 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 more 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 displayed 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 (Pl. 1, Fig. 2; and Pl. 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 subangular to rounded fragments, mostly less than 1 foot in diameter, enclosed in a matrix of buff-coloured sandstone identical with that of the interbeds. 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 subangular volcanic debris: they very commonly contain scattered pebbles and boulders. These conglomerates and sandstones are interpreted as fanglomerate deposits (cf. 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 (Pl. 1, Fig. 1).

Elsewhere within the Kieta Volcanics outcrop the sedimentary rocks mostly consist of thick and thin-bedded sandstone and siltstone, with some interbedded conglomerate. Some limestone pebbles containing *'Linderina'* sp., a lower Miocene foraminiferan (Terpstra, 1966), have been found in a conglomerate cropping out between Iwi and Toimonapu plantations on the south-east coast of Bougainville. The conglomerate cannot therefore 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.

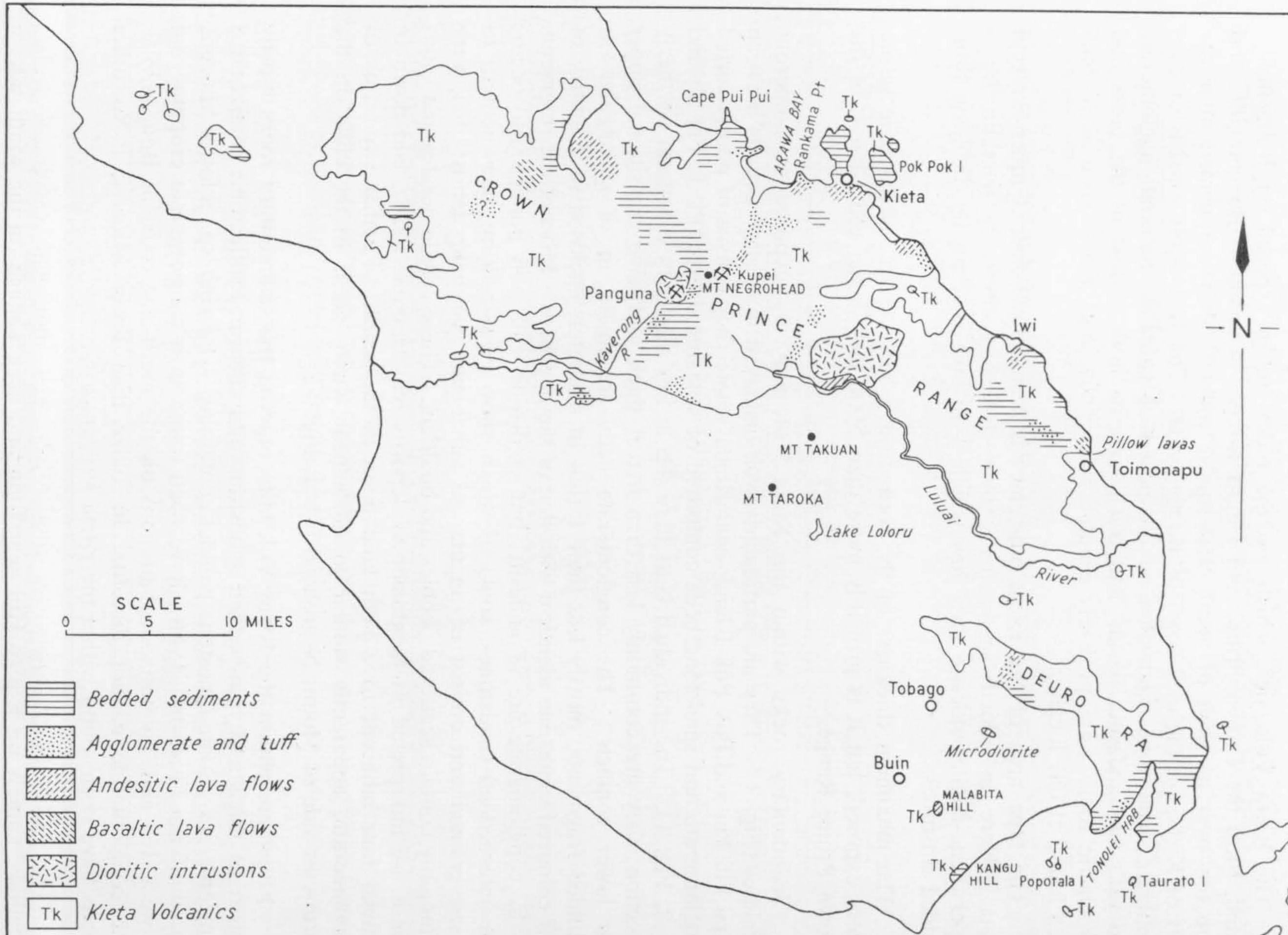

Fig. 4: Sketch map of southern Bougainville, showing outcrops of Kieta Volcanics.

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 (Pl. 2, Fig. 2; Pl. 3, Fig. 1). The majority of the boulders are of porphyritic pyroxene andesite. Less common are boulders of sandstone, tuff, pumice, and microdiorite: the microdiorite boulders occur in an agglomerate exposed in the Kaverong 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 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 subaerial tuff and aqueous sandstone formed of reworked tuff. One undoubted subaerial tuff occurs as a bed 3 feet thick on Popotala Island, south-west of Tonolei Harbour. This tuff is made up of 'pisoliths' up to 6 mm 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 rock, but basalt, commonly partly propylitized, also occurs. A basaltic pillow lava crops out at Toimonapu (Pl. 3, Fig. 2). A trachyandesite flow and dyke are exposed at Iwi, south-east of Kieta.

Three types of andesite occur within the Kieta Volcanics. These are, in order of abundance, hypersthene-augite andesite, augite andesite, and hornblende andesite. Modal analyses of some typical andesites are given in Table 3 (p. 22). Plagioclase phenocrysts are always present and occur as euhedral to subhedral zoned laths ranging in length from less than 0.5 mm to an average maximum of 5 mm: 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. Hypersthene phenocrysts are generally smaller than those of augite and have an elongate euhedral habit. Phenocrysts of green or brownish green hornblende range up to 1 cm or more in length; they may be surrounded by reaction rims. Olivine (which is invariably pseudomorphed by chloritic material) and hornblende occur as sparse phenocrysts in some pyroxene andesites, and sporadic phenocrysts of augite and brown biotite occur in some hornblende andesites. The phenocrysts lie in a very fine-grained groundmass consisting of feldspar microlites, pyroxene (clinopyroxene and/or hypersthene), magnetite, and interstitial felsitic material or, rarely, clear glass.

The trachyandesite at Iwi contains sparse phenocrysts of plagioclase (andesine), augite, and green hornblende, enclosed in a subtrachytic groundmass consisting of elongate plagioclase laths, pyroxene and magnetite granules, and altered glass.

The basalt lavas contain phenocrysts of calcic plagioclase (bytownite-labradorite), pale brownish augite, and, in some specimens, olivine pseudomorphed by calcite and serpentine. The groundmass is made up of plagioclase laths up to 1 mm long and interstitial augite, opaque minerals, and altered glass.

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.

Away from the metamorphic aureoles calcite and zeolites commonly occur as amygdale and vein minerals. 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 may be represented by some of the agglomerates and dioritic intrusions that occur within the outcrop area of the formation (Fig. 4). The volcanoes were probably initially submarine and became subaerial later, when they formed volcanic islands. The Crown Prince and Deuro Ranges may be the eroded remnants of these islands. After repeated eruptions the volcanoes were built up by lavas and pyroclastic material, while derived terrestrial and marine sedimentary rocks, including fanglomerates, were deposited on the flanks.

The age of the Kieta Volcanics is uncertain, as the only identified fossils from the formation are the lower Miocene foraminifera found in some limestone pebbles within a conglomerate bed near 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.).

Buka Formation (new name)

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

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 underlies 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; the fragments are enclosed in a tuffaceous matrix.

Lava flows of amygdaloidal basalt crop out 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 occur as alteration products of the plagioclase and augite. The amygdales are infilled with zeolites, chlorite, calcite, and actinolite.

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

The Buka Formation is apparently unfossiliferous, and its age is uncertain. It 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, which appears to be in a much more advanced stage of erosion than the post-Miocene Emperor Range of northern Bougainville. The Buka Formation is therefore considered to be upper Oligocene to lower Miocene, comparable with the Kieta Volcanics on Bougainville Island.

LOWER MIOCENE (Tertiary 'e' stage)

Keriaka Limestone (new name)

'Keriaka' is the name both 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.

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 can rarely be determined. It ranges from pale buff to pale grey, and is locally partly recrystallized and veined by calcite.

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 4000 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.

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 integrated 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 are 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 2500 feet near Sisivi. The largest of these outcrops, just west of Mantai Mission, has a well developed karst topography similar to that of the Keriaka Plateau, and unlike the smaller limestone outcrops, where karst topography is not readily apparent on the air-photographs.

Fossils preserved in the Keriaka Limestone (Mawson & 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 is marine and that it formed at depths generally not exceeding 75 to 100 feet. The foraminiferal fauna is closely related to that found and described by Adams (1965) in the upper Te beds of the Melinau Limestone, Sarawak, and indicates that the age of the Keriaka Limestone is lower Miocene, Tertiary 'e' stage. The Keriaka Limestone is older than the biostromal Mount Vasu Limestone on Choiseul, B.S.I.P., which is Tertiary f_{1-2} stage and is of similar age to the Kamanga Grit of Choiseul (Coleman, 1963).

The Keriaka Limestone is overlain by Bakanovi Volcanics near Mantai Mission, by unnamed 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.

MIOCENE(?) TO PLIOCENE(?)

Unnamed Volcanics

In the northern part of central Bougainville outcrops of volcanic rocks of uncertain age 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 and consist of andesitic, basaltic, and dacitic lava, agglomerate, and tuff.

These 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. The few lava specimens examined under the microscope could not be distinguished petrographically from the lavas of either the Kieta Volcanics or the Bougainville Group.

South of Sisivi the unnamed volcanics have been intruded and locally hornfelsed by small microdiorite bodies.

From both their location and their erosional state the unnamed 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.

PLIOCENE(?) TO RECENT

Bougainville Group (new name)

The Bougainville Group comprises the younger volcanic rocks of Bougainville and covers more than half the island. The 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 (Pl. 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 the Bougainville Group includes other volcanic rocks which are the products of unspecified volcanic centres; these volcanic rocks 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 (Pl. 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,

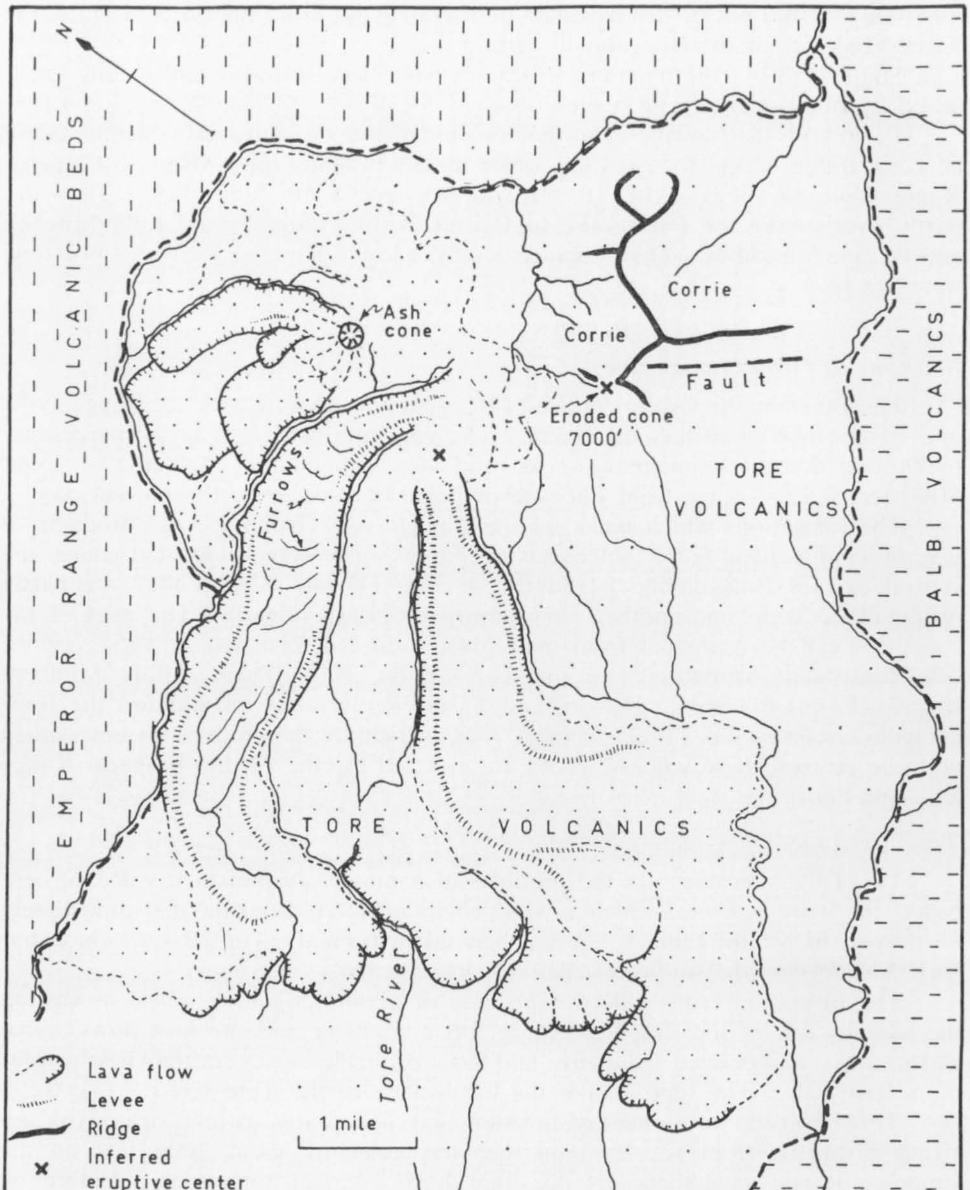

Fig. 5: Sketch map of Tore Volcano showing recent lava field.

and 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.

The upper part of the Tore volcano between the little eroded lava flows and Balbi volcano, and including the pyramidal peak, has been much more extensively eroded, and little, if any, of the constructional surface 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.

Three pebbles of biotite-augite andesite collected by J. G. Speight in 1964 from near the front of one of the Tore lava flows have been examined in thin section. The andesite contains phenocrysts less than 5 mm long of plagioclase, pale green augite, reddish brown biotite, magnetite, hypersthene, greenish brown hornblende, and apatite (Table 3). The phenocrysts are enclosed in a fine-grained matrix composed of plagioclase microlites, clinopyroxene and magnetite granules, subordinate hypersthene rods, and interstitial cryptocrystalline material. Cristobalite occurs in some vesicles.

The plagioclase phenocrysts show normal, oscillatory, and reverse zoning generally within the labradorite range. Hypersthene occurs in the cores of some augite crystals and also as separate phenocrysts. The phenocrysts of biotite and hornblende have opaque reaction rims.

Balbi Volcanics (new name)

The Balbi Volcanics occupy an area of over 200 square miles and consist of agglomerate, tuff, ash, andesite lava, and derived fan deposits. The volcanic rocks were erupted from the dormant Balbi volcano, a complex stratovolcano rising to a height of 8502 feet at the south-eastern end of the Emperor Range, north-west Bougainville (Pl. 4, Fig. 1). The type area of the formation is the eastern flank of the volcano, 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 late Pleistocene to Recent. They unconformably overlie Keriaka Limestone, unnamed volcanics, and Emperor Range Volcanic Beds, 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 aligned roughly north-west. 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 (Pl. 5, Figs 1 & 2; Pl. 6). 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 the volcano just over 1 mile south-west of crater C. The solfatara field lies between craters B and F. Here, and also inside crater B, there are solfataras with temperatures of over 110°C. Two prominent domes, which were not examined on the ground, occur south and south-east of crater A.

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 Volcanics	28	<1	—	—	—	13	—	1	—	<1	58	Pl, Ma, Fst
12		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		25	6	—	—	4	—	—	2	—	<1	62	Pl, Cp, Ma, Fst
28		30	4	—	—	9	—	—	2	—	<1	55	Pl, Cp, Ma, Fst
29	Emperor Range Volcanic Beds	20	2	<1	—	<1	—	<1	1	<1	<1	77	Pl, Cp, Hy, Ma, Fst
30		34	6	—	1	—	—	—	2	—	<1	57	Pl, Ma, Fst
31		23	8	1	5	—	—	<1	1	—	<1	62	Pl, Cp, Ma, Gl
32	Unnamed 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 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 (Tables 3 and 6)

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 Balbi volcano.
8. Hypersthene-augite andesite (65490599); lava bomb, summit area of Balbi volcano.
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, Bagana volcano.
14. Augite andesite (65490122); 1952 lava flow, south-west side Bagana volcano.
15. Augite andesite (65490148); pre-1946 lava flow, south-east flank, Bagana volcano.
16. Augite andesite (65490151); 1946-47 lava flow, east flank, Bagana volcano.
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, Takuan volcano.
21. Augite andesite (65491212B); boulder on valley side, Poenga River.
22. Hornblende-augite andesite (65491213); boulder on top of lava flow, 4 miles east of Mount Takuan.
23. Hornblende dacite (65490160); dome on north side of Luluai River, 14 miles east-south-east of Mount Takuan.
24. Hornblende dacite (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. Hornblende-augite andesite (65491022B); boulder in creek near Konga.
28. Augite-hornblende andesite (65491022C); boulder in creek near Konga.
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).

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*Specimen number.

Three large amphitheatre-headed valleys have been formed on the flanks of Balbi volcano. 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 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 & Wadsworth (1965) consider that the valleys on Reunion are also due to rapid erosion, but the circular amphitheatres of the two valleys on Balbi volcano are thought more likely to be old explosion craters: it is probably significant that solfataras occur in the amphitheatre on the north-east side of 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 form slightly elevated sinuous flows which may be of nuée ardente or lahar origin (Pl. 6).

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 Balbi volcano is reputed to have occurred some time between 1800 and 1850 (Branch, 1965a) and is said to have killed a number of people. During the eruption nuées 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 (Pl. 6). The present activity of the volcano is confined to solfataras 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 nuées ardentes are likely to be emitted during its next eruption (Branch, 1965a).

Petrography. The lava flows and the rock fragments in the agglomerates on Balbi are of andesitic composition. 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. Sparse phenocrysts of brown hornblende and brown biotite also occur. The phenocrysts lie in a very fine-grained and partly glassy groundmass made up of plagioclase microlites, hypersthene rods, magnetite granules, and interstitial pale brownish isotropic glass ($n < 1.54$) or altered glass. Modal analyses of two andesites from Balbi are presented in Table 3.

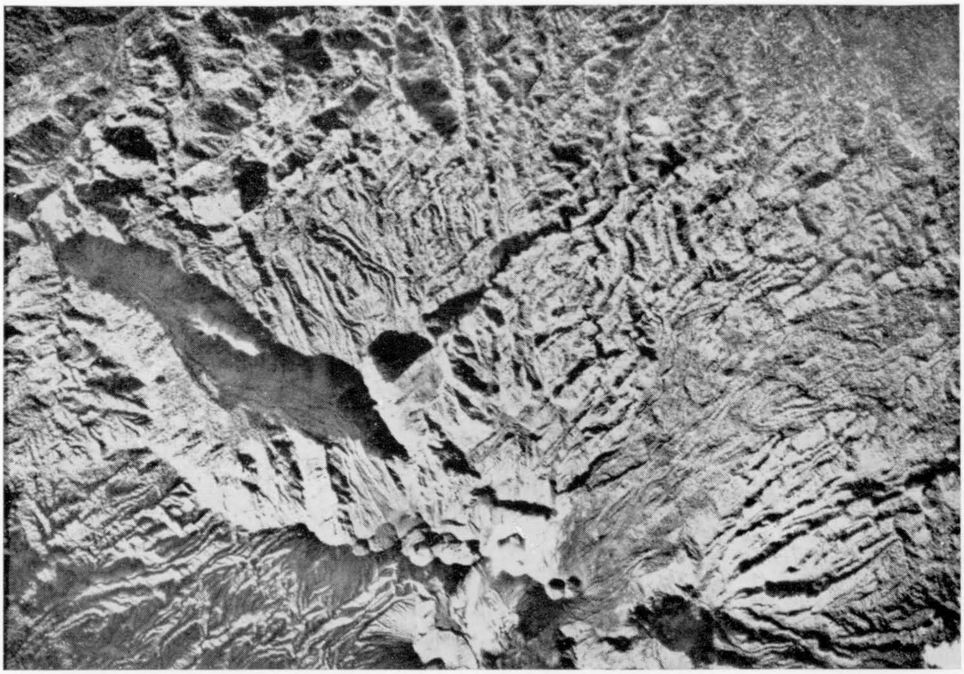
The plagioclase phenocrysts are mostly less than 3 mm long, and show

PLATE 5.

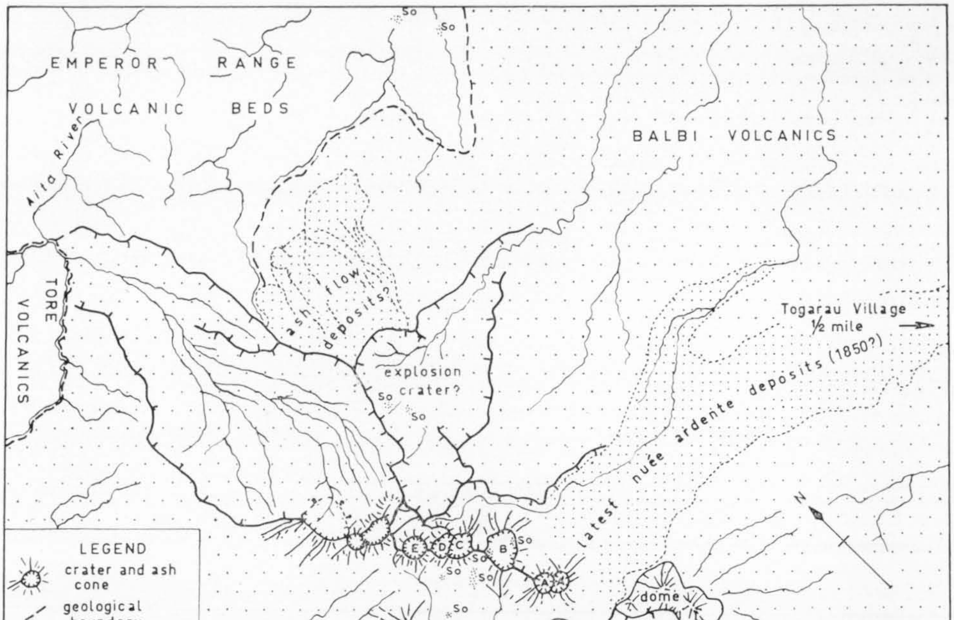
Fig. 1. Summit area of Balbi volcano, from the south-east. Craters A and A′ are in the foreground, in front of crater B; craters C, D, and E are behind crater B; crater F is just off the photograph, to the left. The main solfatara field can be seen in the left middle distance. The Emperor Range is in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

Fig. 2. Balbi volcano, crater B, from the south-east. Craters C and D are shown in the left background. (Photo F. S. Chong).

PLATE 6.



(a) Vertical air-photograph mosaic of Balbi volcano. R.A.F. photograph; sortie 543A/418. Nos. 11 & 12. 24 June 1963.



(b) Interpretation of mosaic.

PLATE 7.

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

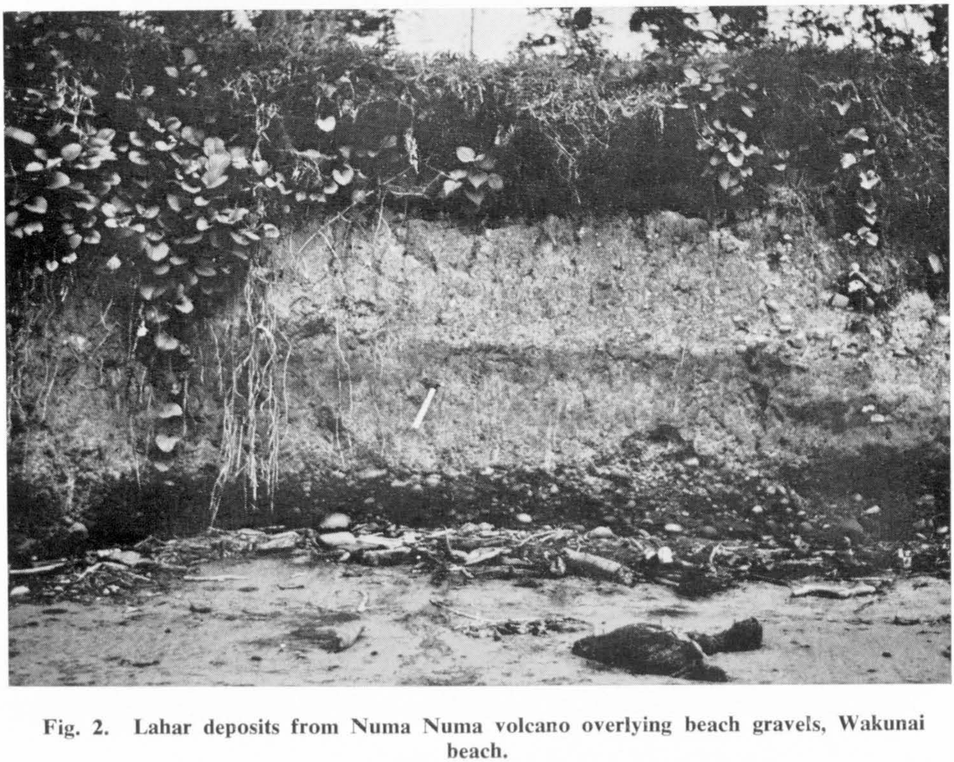
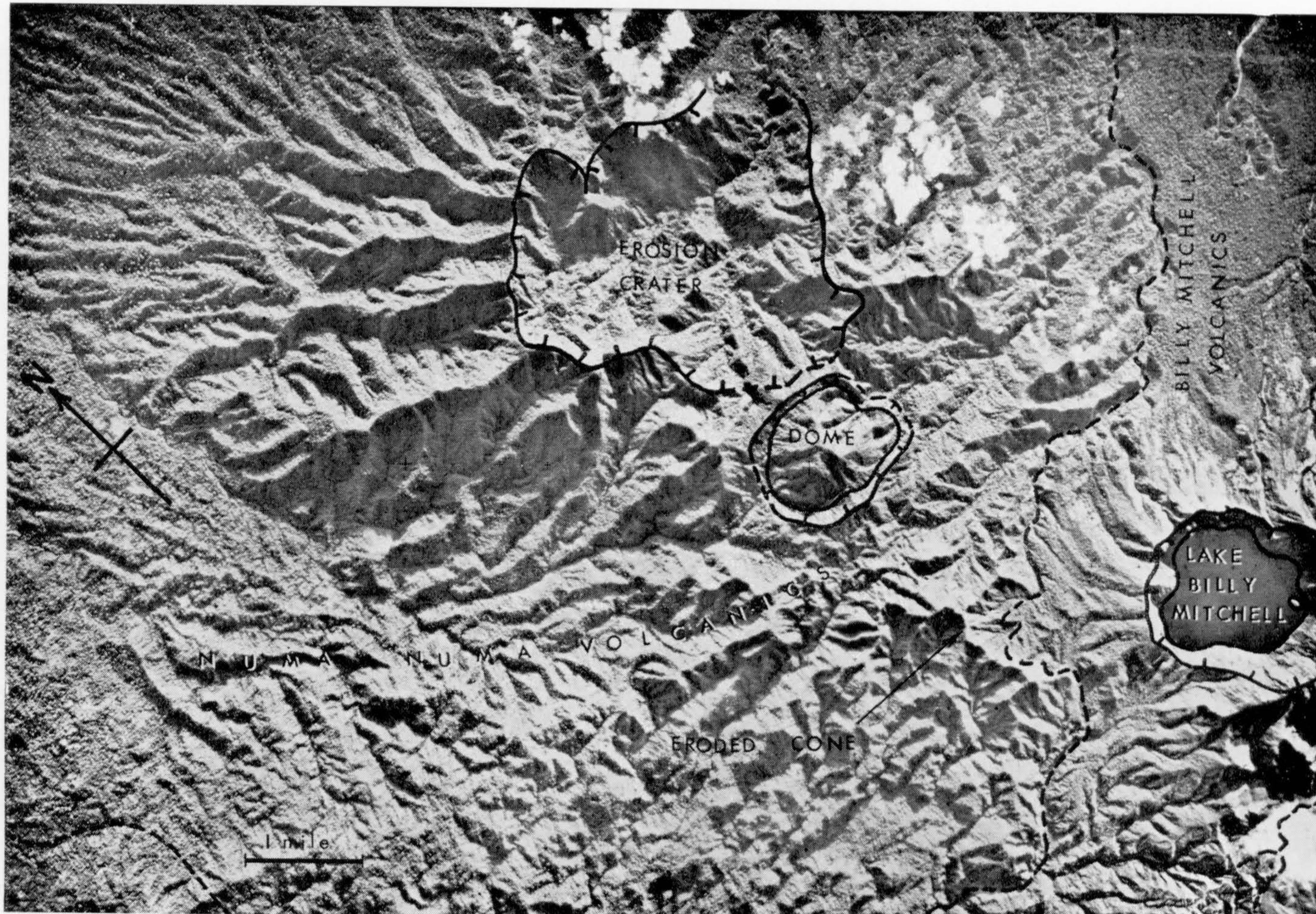


Fig. 2. Lahar deposits from Numa Numa volcano overlying beach gravels, Wakunai beach.

PLATE 8.



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 534A/418, Nos. 17 & 18, 24 June 1963.

PLATE 9.

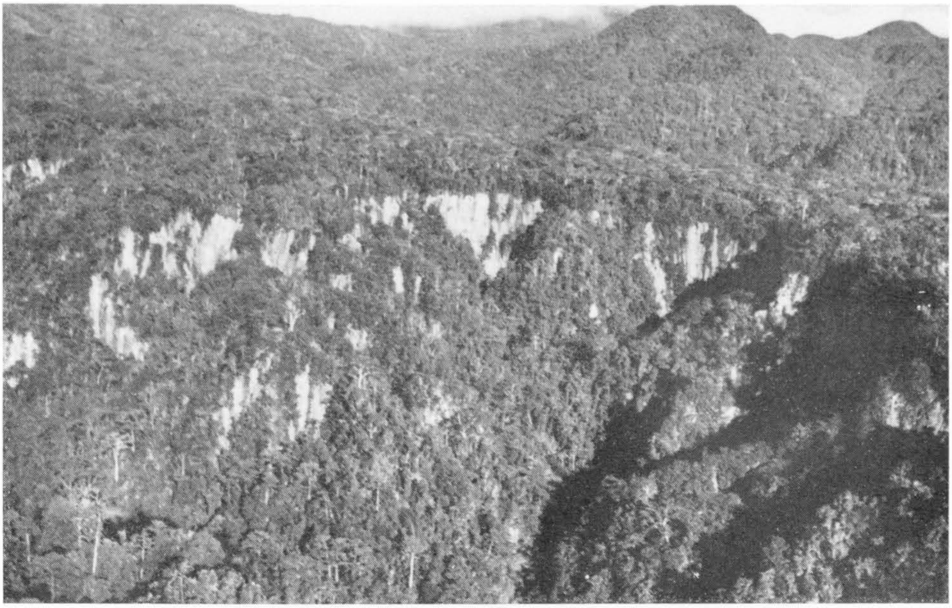
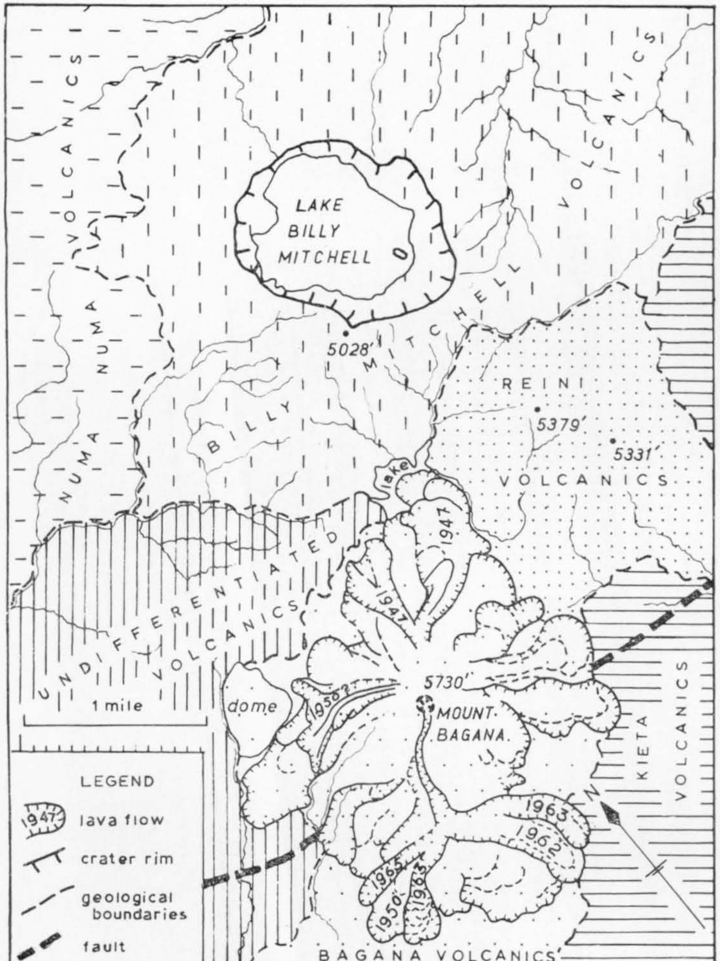


Fig. 1. The main amphitheatre-headed gorge of the Pukarobi River, on the eastern flank of Billy Mitchell volcano. About 300 feet of a massive ash deposit (white) are exposed here in cliff faces.

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). (Photo G. A. Taylor).



(b) Interpretation.

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

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

Fig. 2. Bagana volcano, 7 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 Plate 10). (Photo C. D. Branch).

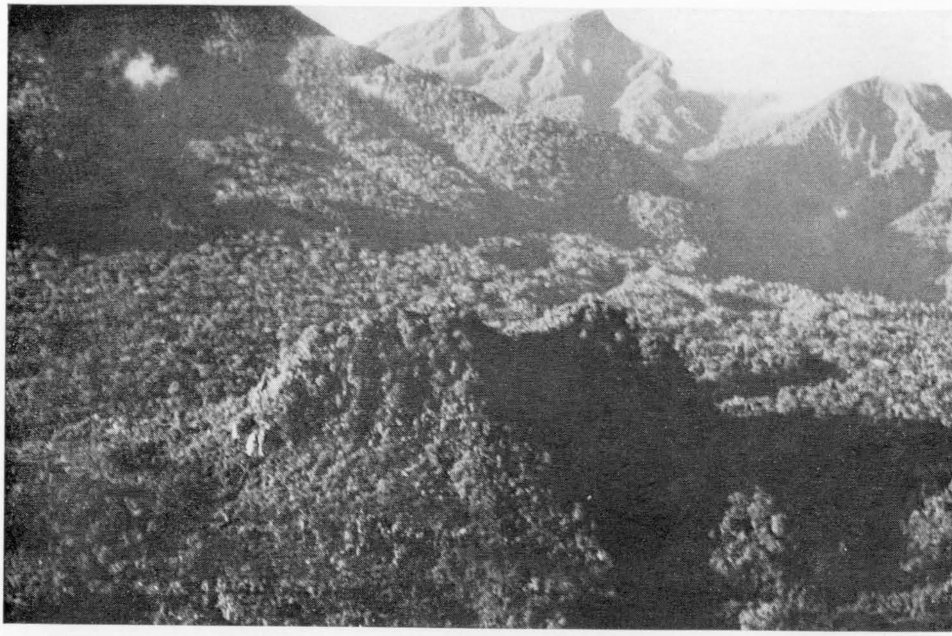


Fig. 1. Dacite dome near Damu, looking south. The north-western flank of Takuan volcano is behind the dome. The Taroka line of volcanoes is shown in the right background.

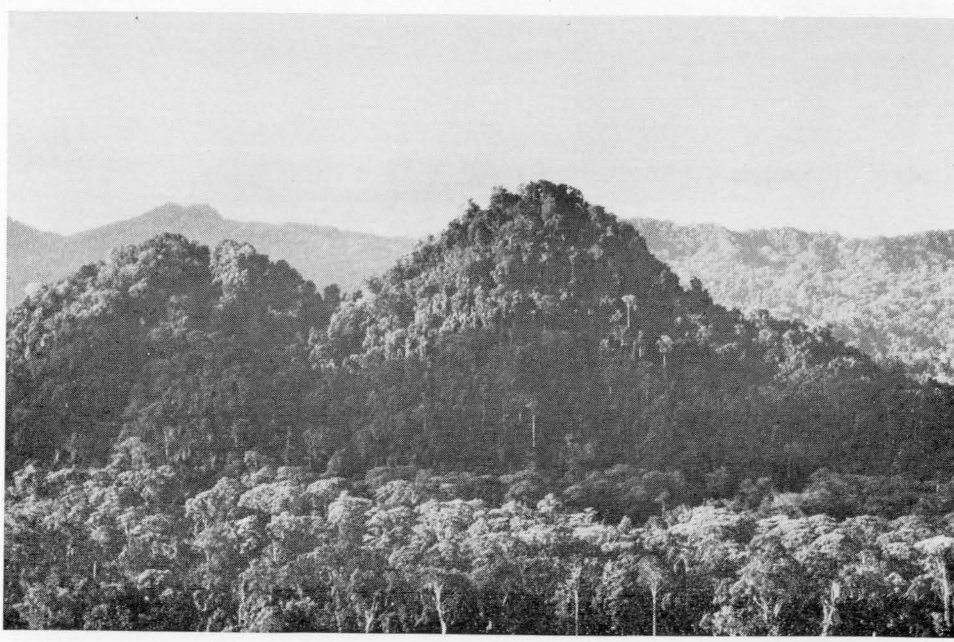
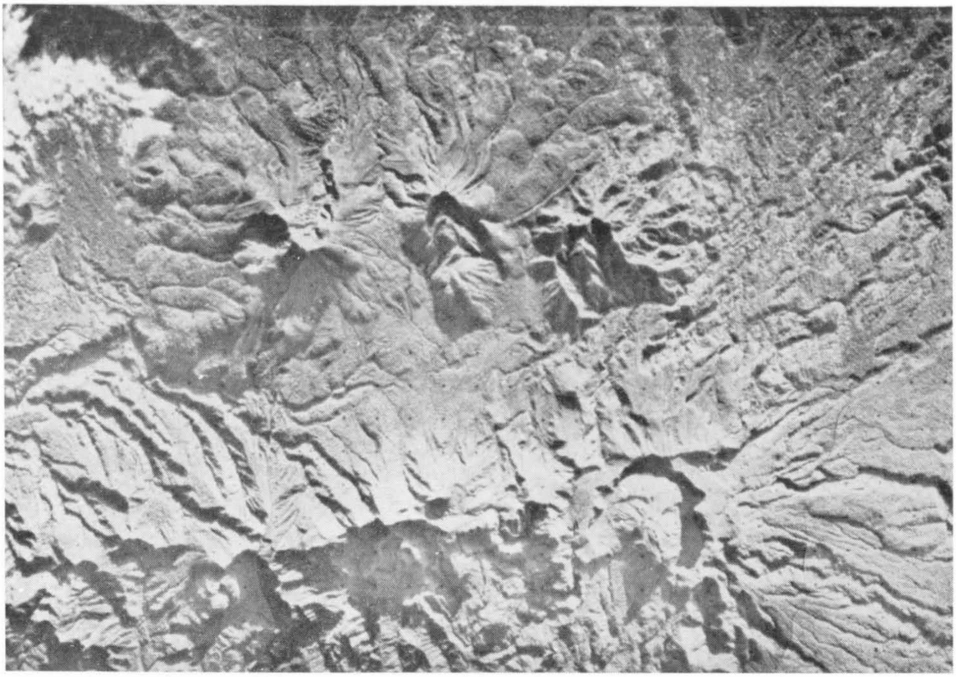
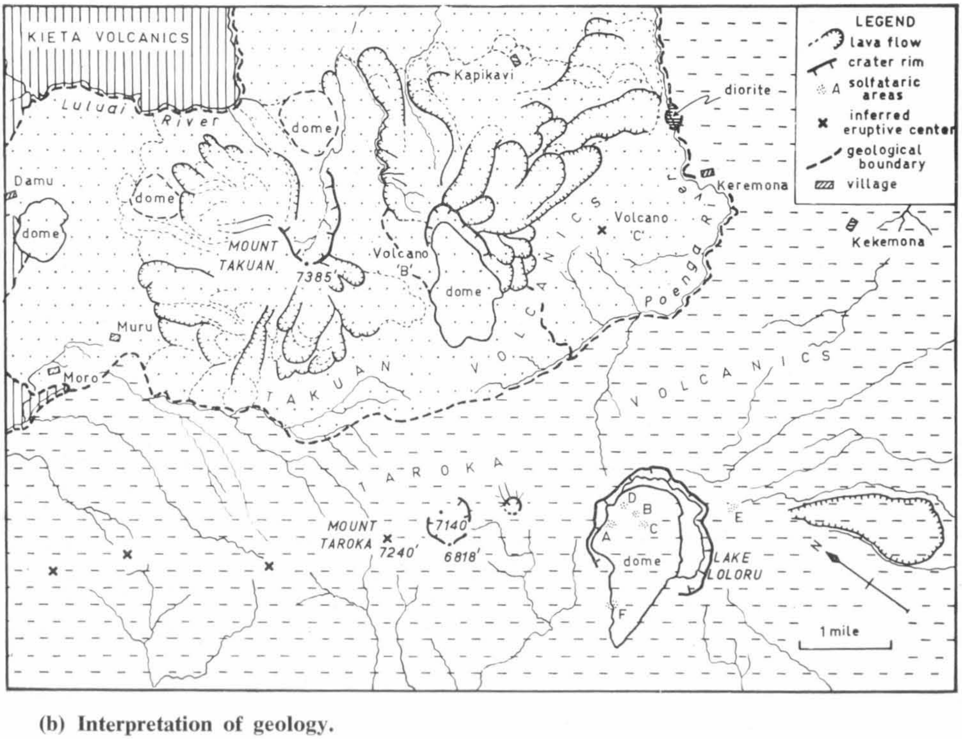


Fig. 2. Dacite dome on the north bank of the Luluai River, 14 miles south-east of Mount Takuan. The Crown Prince Range is in the background.



(a) Vertical air-photograph mosaic of the Takuan and Taroka lines of volcanoes. R.A.F. photographs; sortie 543A/418, Nos. 23-25. 24 June 1963.



(b) Interpretation of geology.

PLATE 14.

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

Fig. 2. Cliffs of Sohano Limestone 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 100 feet in the right foreground.

normal, reverse, and oscillatory zoning: the zones range in composition from andesine (An45) to bytownite (An74). The augite phenocrysts are generally less than 2 mm long, and commonly have cores of hypersthene. Hypersthene also forms separate euhedral phenocrysts, which are smaller and more elongate than those of augite. Olivine phenocrysts are less than 1 mm in diameter; some show marginal alteration to iddingsite. The apatite phenocrysts are euhedral, less than 0.5 mm 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)

The Numa Numa Volcanics are the products of a previously unnamed extinct volcano, here called the Numa Numa volcano, which is situated south-east of Mount Balbi (Pl. 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 (Pl. 7, Fig. 2). The type area is the north flank of the volcano. The formation is probably about 5000 feet thick beneath the summit area of the volcano.

Most of the Numa Numa Volcanics are probably Pleistocene. The formation overlies Keriaka Limestone to the west and unnamed 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 stratovolcano which has a shield-like topographical form (Pl. 7, Fig. 1). The summit area consists of an erosion caldera, a dome, and a deeply eroded volcanic cone (Pl. 8). The erosion caldera is more than 1000 feet deep and 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, reddish or greenish brown 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 plagioclase microlites, hypersthene needles, magnetite granules, and interstitial felsitic material. Most of the specimens have vesicles containing tridymite and cristobalite.

Plagioclase forms zoned phenocrysts ranging in length from less than 0.1 mm to more than 2 mm: 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 hornblende phenocrysts are between 0.5 and 2 mm long. Those of basaltic hornblende are commonly 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, which occupies the crater 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 (Pl. 9, 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 waterlaid 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 innumerable rounded andesite lava fragments.

The only other exposures of Billy Mitchell Volcanics examined were farther 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, unnamed volcanics, Numa Numa Volcanics, and Reini Volcanics, and they are unconformably overlain by 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 Lake Billy Mitchell (Pl. 10) 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 have rough 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 ardente 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 glassy or cryptocrystalline groundmass (Table 3). The plagioclase phenocrysts are up to 6 mm long, and are conspicuously zoned, varying in composition from An45 to An70 (average An60). Hornblende forms phenocrysts up to 3 mm long: these are various shades of green and brown and in some specimens are surrounded by opaque reaction rims; most of the sparse augite phenocrysts 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 Bagana, an active stratovolcano which rises 5730 feet above sea level, 12 miles north-east of Torokina. The formation consists of dark grey andesite lava flows, subordinate tuff and agglomerate, and derived alluvial fan deposits.

Lava flows are confined to the flanks of Bagana volcano, 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, unnamed volcanics, and Billy Mitchell Volcanics, and abut against Reini Volcanics.

Bagana Volcano and its activity have been described by Fisher (1939, 1954, 1957), Taylor (1956), Best (1956), and Branch (1965a). The volcano is a symmetrical cone about 4500 feet high which has been built up predominantly of andesite lava flows (Pls 10 and 11). 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, p. 20): the flows are less than 50 yards wide near the crater, but become much wider towards the base of the cone. Interspersed with the flows are 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 (Pl. 10).

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 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 to the Bureau of Mineral Resources for May 1950) descended the flanks of the volcano, and the emission of lava flows in 1946-47, 1952, and 1963-1965 (Pl. 10). 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 flow had split into four arms, two flowing west and two south. Their fronts had reached the base of the cone and were advancing at the rate of 1 foot or less a day. The post-1946 lava flows are the sites of innumerable active solfataras. Several hot springs issue from the base of the cone.

Petrography. Ten lava specimens, including some from 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 lava specimens also contain phenocrysts of olivine (Table 3). The groundmass of magnetite phenocrysts and sparse hornblende and hypersthene phenocrysts; some the andesite consists of plagioclase microlites, hypersthene rods, and magnetite granules enclosed in clear brown isotropic glass, or altered glass. Tridymite and crystobalite occur in some vesicles.

Plagioclase forms phenocrysts of all sizes up to 3 mm; these show intermittent and continuous normal zoning from cores of bytownite (An70-80) to margins of sodic labradorite (An46-57): oscillatory zoning is rarely apparent, and the oscillatory zoned plagioclase phenocrysts in hornblende andesite pebbles described by Baker (1949) as coming from Bagana probably came from an older, unidentified, volcanic centre. Pale greenish augite phenocrysts have a maximum length of 3 mm. Hypersthene occurs in the cores of some augite crystals and also forms separate phenocrysts. The phenocrysts of 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 1.5 mm long and are commonly rimmed by small hypersthene rods.

Reini Volcanics (new name)

The Reini Volcanics are the products of an unnamed extinct volcano, here called the Reini volcano, on the east side of 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 down the flanks of Reini volcano and 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, tuff and agglomerate. 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.

Reini volcano is a deeply serrated and eroded cone with twin peaks rising to 5379 feet and 5331 feet above sea level (Pl. 10). 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, Bagana, and Takuan. 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 specimen from Reini volcano has been studied in thin section. This is a hornblende-augite andesite containing phenocrysts of plagioclase, augite, reddish brown hornblende, and magnetite (Table 3) enclosed in a groundmass of plagioclase microlites, hypersthene rods, granules of magnetite and subordinate clinopyroxene, and very pale isotropic glass.

The plagioclase and augite phenocrysts are less than 1.5 mm long. Those of plagioclase show normal zoning from cores of bytownite to margins of labradorite (An85 to An58); some also show weak oscillatory zoning. The hornblende phenocrysts are up to 2.5 mm long, and have opaque reaction rims.

Bakanovi Volcanics (new name)

The Bakanovi Volcanics consist of andesite lava, tuff, and agglomerate. 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 centre, 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; it 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. Farther 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 remnant 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 of hornblende andesite. They contain phenocrysts of plagioclase and green hornblende up to 6 mm 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 An55).

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 point 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 Taroka line of volcanoes to the south-west. In addition to the three volcanoes, two small dome-like bodies, each about 500 feet high, occur along 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 (Pl. 2, Fig. 1), and the other is on the north-east side of the Luluai River, 14 miles east-south-east of Mount Takuan (Pl. 12, Fig. 2).

Andesite lava, alluvial fan deposits, tuff, agglomerate, and dacite lava make up the Takuan Volcanics. The type area is Takuan Volcano, which consists predominantly of andesite lava, and the maximum thickness of the formation 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. Only Takuan volcano has been named; the other two are referred to as volcano B and volcano C (Pl. 13).

Takuan Volcano is a cone about 5000 feet high built up mostly 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 Bagana volcano. 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 farther to the south-west. Well preserved lava flows which were extruded before the cone was breached occur on the other sides of the volcano.

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

Although all three volcanoes are now extinct, the good preservation of the lava flows on Takuan and volcano B indicate that both 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 was blown away and a large dome was extruded. From the air-photographs it appears that the pyroclastic material produced during this eruption probably 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 Takuan.

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

Petrography. Of the seven lava specimens from the Takuan group of volcanoes that have been examined in thin section, six are hornblende-augite andesite, and one is an augite andesite (Table 3). The specimens 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 7 mm long, but those of plagioclase and augite are generally less than 3 mm long. The plagioclase phenocrysts show distinct normal zoning from cores of labradorite-bytownite (average An70) to margins of oligoclase-andesine (average An30); they also show weak oscillatory zoning. The hornblende phenocrysts have prominent reaction rims; in one specimen the hornblende is greenish brown and in the others it is reddish brown.

The domes near Damu and on the north side of the Luluai River are made up of hornblende dacite containing abundant phenocrysts, up to 4 mm 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 dark brown, largely replaced by opaque material, and the other is pale greenish brown; the dark brown 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-westerly range which runs parallel to the 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), the summit of the extinct Taroka 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 waterlaid 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 ashflow 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 line of volcanoes comprises a number of closely spaced strato volcanoes, including Taroka and the dormant Loloru volcano, all situated along a north-west line (Pl. 13). These volcanoes, like most of the other volcanoes on Bougainville, are covered by dense jungle.

Loloru Volcano was first recognized as being potentially active by G. A. Taylor in May 1951. The summit area consists of a crater just under 1½ miles in diameter and partly filled by a dome which has overflowed through a breach in the south-west wall of the crater. On the opposite side of the crater a crescent-shaped lake, Lake Loloru, has been formed between the dome and the eastern crater wall (Pl. 9, Fig. 2; see also Fisher, 1954, fig. 9). The water level of the lake is about 4500 feet, and the top of the dome, the highest point of the volcano, is over 6000 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, 1 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 13. 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 (Pl. 13), and few craters are preserved. However, there appear to be at least six major eruptive centres here, including that of Taroka; their probable positions are shown in Plate 13. The constructional surfaces of the extinct volcanoes are 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, the valleys radiate outwards from the centres of the volcanoes.

The very young aspect of the dome in Loloru crater and the presence of active solfatara fields here indicate that it 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 they are extinct and are probably of Pleistocene age.

Petrography. The lava dome in Loloru crater and the lava fragments in the agglomerates and river gravels are of 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 hornblende phenocrysts are either dark brownish green or brown to reddish brown; in most specimens they are surrounded by opaque reaction rims.

The groundmass consists mostly of plagioclase microlites and glass or devitrified glass: in addition small crystals of hornblende, clinopyroxene, and magnetite are also commonly present, and minute hypersthene crystals have been recognized in some specimens. The groundmass is generally vesicular. Tridymite occurs in some of the vesicles.

The one cognate inclusion examined in thin section contains phenocrysts of brown 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)

Much of northern Bougainville is covered by volcanic rocks which have been erupted from a number of extinct and mostly deeply eroded volcanic centres situated along the Emperor Range north of 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 reach the coast near Konua, Soraken, and Baniu Bay. Tuff and agglomerate, interpreted as mostly 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 solfataras were discovered in two tributary valleys of the Aita River (Pl. 6). Farther north, 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, at Melilup and Puspa, have intruded and thermally metamorphosed the adjacent volcanic rocks.

The Emperor Range Volcanic 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. They 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 farther south, on the eastern side of the range, are probably pre-Pleistocene, and they appear to have been erupted from volcanic centres on the eastern side of the main watershed. The sites of some of these centres 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 lavas contain 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 augite andesites of probable Pleistocene age near Konua, Soraken, Baniu, and Teop.

Two basalt specimens collected 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 (Pl. 4, 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 subaerial erosion.

The reef limestone is a massive pale whitish rock made up of corals, algae, echinoids, molluscs, 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, 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 form, has been identified (Terpstra, 1966), in limestone samples taken from a ledge at the base of the cliffs at Iltopan. However, the larger foraminifera characteristic of the lower Miocene Keriaka Limestone are entirely absent.

From the fossil evidence at Iltopan it would appear the lowest exposed part of the Sohano Limestone may be lower Miocene. Yet the lack of erosion of the raised reef complex indicates 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 thickness of lower Miocene limestone is exposed below 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 a 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 Formation forming the Parkinson Range. On northern Bougainville the limestone overlaps intrusive dioritic masses near Umum and Raua harbour, and abuts against Emperor Range Volcanic Beds. Over most of its outcrop the limestone is overlain by a reddish brown tuffaceous soil.

QUATERNARY

Alluvium

Quaternary 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. Such deposits 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.

Sand composed mainly of comminuted coral occurs 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. The ash ranges in thickness from less than 1 inch to several feet, and occurs 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 best preserved on ridge tops, as it has generally been removed from steep slopes and redeposited as alluvium in the valleys. It is made up of volcanic glass and euhedral to subhedral crystals of plagioclase, hornblende, magnetite, and augite.

The ash probably ranges in age from late Pleistocene to Recent. Large quantities of ash were produced during recent eruptions at Loloru, Billy Mitchell, Bagana, and Balbi volcanoes, and also during earlier eruptions of Numa Numa volcano, and the Takuan and Taroka groups of volcanoes.

INTRUSIVE ROCKS

The Kieta Volcanics, unnamed volcanics, and Emperor Range Volcanic Beds have been intruded and locally hornfelsed by a number of high-level dioritic bodies. These intrusives 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. Sulphide minerals are associated with most of the intrusives.

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 intrusive, a small plug-like microdiorite body, is associated with the copper and gold mineralization 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 intrusives are older than the Sohano Limestone and Emperor Range Volcanic Beds immediately surrounding them. Both are of porphyritic microdiorite. The Melilup, Puspa, Panguna, and Isinai intrusives, on the other hand, are made up of a variety of rock types, including microdiorite, diorite, granodiorite, monzonite, syenite, and granophyre, and are surrounded by metamorphic aureoles up to several hundred feet wide. Their limits could not be determined accurately as no actual contacts were seen in the field, and the intrusives cannot be easily distinguished from the country rocks on the air-photographs. Copper and gold mineralization is associated with the Panguna intrusive.

The intrusions probably range from upper Oligocene to Pleistocene. The oldest are those of the Crown Prince Range, which are thought to be comparable in age to the Kieta Volcanics which they intrude; the youngest are probably those of the Emperor Range. One granodiorite specimen from the southern part of the Isinai intrusive has been dated by A. W. Webb (Bureau of Mineral Resources), using the K-Ar method, at 5 million years (upper Pliocene).

Petrography

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

Most of the small andesite and microdiorite intrusions are mineralogically similar to the andesite rocks they intrude. They contain phenocrysts of plagioclase (andesine-labradorite), hornblende, augite, and magnetite, enclosed in a fine or very fine-grained largely feldspathic 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 grainsize about

1 mm) of plagioclase, alkali feldspar, green hornblende, biotite, quartz, opaque minerals, and augite (analysis 1, Table 4).

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 (labradorite-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), Kaverong 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 mineralization at Panguna mine is an altered porphyritic microdiorite similar to that at Kupei mine, with which it may be connected at depth. It contains plagioclase, augite, and pale green hornblende phenocrysts, 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 Formation, unnamed 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 a moderately fine-grained groundmass of plagioclase laths, (up to 1 mm long) augite, opaque minerals, and altered basaltic glass. All the basalts examined had undergone 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	Plagioclase	Hypersthene	Clinopyroxene	Magnetite	Interstitial material
Kieta Volcanics (23) — augite andesite	███		▬▬	- - -	·······	·······		——	- - -	███	- - -	- - -	——	███
Kieta Volcanics (23) — hornblende andesite	███		·······			▬▬	·······	——	- - -	███			——	███
Tore Volcanics (3)	███		▬▬	——		——	——	——	——	███	——	——	——	███
Balbi Volcanics (14)	███		▬▬	——	·······	- - -	- - -	——	- - -	███	——		——	███
Numa Numa Volcanics (8)	███		▬▬	- - -	·······	▬▬		——	- - -	███	——		——	███
Billy Mitchell Volcanics (9)	███		- - -			▬▬		——	- - -	███			——	███
Bagana Volcanics (10)	███		▬▬	——	- - -	——		——		███	——		——	███
Reini Volcanics (1)	███		▬▬			——		——		███	——	——	——	███
Bakanovi Volcanics (3)	███					▬▬		——	- - -	███			——	███
Takuan Volcanics (7)	███		▬▬	- - -		▬▬		——	- - -	███	——	·······	——	███
Taroka Volcanics (22)	███	·······	▬▬		·······	▬▬		——	- - -	███	·······	——	——	███
Emperor Range Volcanic Beds (13)	███	·······	▬▬	- - -	- - -	·······	- - -	——	- - -	███	- - -	- - -	——	███

███ > 15% of total rock

▬▬ 4% – 15% of total rock

—— 0 – 4% of total rock

······· = rarely present

- - - = commonly present

(7) = number of samples examined

Andesite

Andesite is easily the most abundant volcanic rock on Bougainville. It is a pale grey to black, less commonly brownish, rock containing phenocrysts of plagioclase, magnetite, and one or more of the following minerals: augite, hypersthene, hornblende, olivine, apatite, and quartz. The phenocrysts, which make up more than 20 percent of the total rock, lie in a very fine-grained and commonly vesicular matrix (average grainsize less than 0.05 mm) which generally contains some glass or altered glass. The petrography is summarized in Table 5 and some typical modal analyses are given in Table 3.

Mineralogy. Plagioclase phenocrysts have a euhedral, equant to elongate, tabular habit, and range up to 5 mm in length. They are twinned on Carlsbad, albite, and less commonly pericline laws, and show oscillatory, normal, and reverse zoning of both gradational and discontinuous types (Baker, 1949); and also patchy zoning (cf. Vance, 1965); the zones range from bytownite to oligoclase. Each zone generally has a euhedral outline, although corroded and partly resorbed zones are not uncommon. Many of the plagioclase phenocrysts contain inclusions which can be divided into 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 (cf. Kuno, 1950).

Augite phenocrysts are euhedral to subhedral, and commonly have a slightly elongate habit. They are pale to very pale green, and may show colour zoning. Some augite phenocrysts have cores of hypersthene or, more rarely, hornblende.

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.

Phenocrysts of hornblende are euhedral to subhedral, elongate prismatic. Two main varieties occur; a green hornblende, and a brown to reddish brown basaltic hornblende. In many specimens the hornblende phenocrysts are surrounded by reaction rims.

Magnetite, the main opaque mineral, forms euhedral to anhedral equant phenocrysts up to 0.5 mm in diameter. The magnetite is a titaniferous variety, and is associated with hematite, which occurs as lamellae within and as rims around the magnetite phenocrysts, and with minor amounts of maghemite, ilmenite, hydrated iron oxides, and an unidentified opaque mineral. Some andesite specimens also contain specks of pyrite and chalcopyrite.

Apatite occurs as stout prismatic phenocrysts less than 0.5 mm 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 forms 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.

In most cases the andesite from 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 unnamed volcanics were examined to determine whether they 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. Hypersthene phenocrysts are much less common in the Emperor Range Volcanic Beds than in either the Balbi Volcanics or the Bagana Volcanics.

The andesite of the Numa Numa Volcanics cannot readily be distinguished from that of the Takuan Volcanics. Both differ from andesite of the Taroka Volcanics in containing hypersthene as an important constituent in the groundmass.

The hornblende phenocrysts in the hornblende andesite of the Bakanovi Volcanics are bright green and characteristically show conspicuous oscillatory colour zoning, whereas the hornblende phenocrysts in the andesite of the Billy Mitchell Volcanics are mostly reddish or greenish brown and appear unzoned.

Dacite

Three dacite bodies on Bougainville were sampled, one within the unnamed volcanics and two within the Takuan Volcanics. The dacite contains 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, 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.

Chemistry

Chemical analyses of some volcanic rocks from Bougainville are given in Table 6, and a variation diagram of the principal oxides is given in Figure 6. The rocks analysed comprise 6 pyroxene andesites (including 4 from Bagana volcano), 2 hornblende-pyroxene andesites, 1 hornblende andesite, and 1 dacite. In comparison with similar volcanic rocks of the Tongariro region, New Zealand (Clark in Gregg, 1960), Hakone region, Japan (Kuno, 1950, 1959), and Cascade region of North America (Thayer, 1937), (Williams, 1942), the analysed rocks from Bougainville are richer in alkalis and poorer in lime.

Conclusions

The igneous rocks of Bougainville are fairly typical members of the calc-alkaline suite characteristic of orogenic belts (Kuno, 1959; MacDonald, 1960; Turner & Verhoogen, 1960, p. 272). Most of the andesites contain hypersthene in the groundmass and appear directly comparable to the andesites of the *hypersthenic series* described by Kuno (1950, 1959) from Japan. The rocks of the hypersthenic series are considered by Kuno to have been produced by fractional crystallization of olivine basalt magma accompanied by assimilation of granitic rocks. The andesites which do not contain groundmass hypersthene may be comparable to Kuno's *pigeonitic series:* the rocks of this series are considered to have been derived from a parental olivine basalt magma through simple fractional crystallization (Kuno, 1950, p. 994).

TABLE 6. Chemical analyses of volcanic rocks from Bougainville (for key to analyses see p. 23).

Specimen No.	16	13	14	17	15	2	8	12	28	23
General Location	Bagana Volcano	Bagana Volcano	Bagana Volcano	Reini Volcano	Bagana Volcano	Malabita Hill (near Buin)	Balbi Volcano	Billy Mitchell Volcano	Taroka Volcano	Luluai River
SiO_2	54.0	54.8	55.2	56.3	56.5	58.8	60.8	62.2	62.7	65.1
Al_2O_3	16.5	17.2	17.4	17.2	17.7	16.6	16.8	16.4	16.6	16.5
Fe_2O_3	4.35	4.05	4.55	6.45	2.95	3.95	2.20	5.20	3.95	3.20
FeO	4.60	4.50	3.85	1.36	4.60	2.95	3.15	0.53	0.64	0.98
MgO	4.55	3.75	3.80	2.95	3.30	3.25	2.15	2.35	2.20	1.48
CaO	8.40	8.05	7.70	8.45	7.85	6.35	5.60	5.90	6.30	4.75
Na_2O	5.20	4.10	4.30	3.90	4.10	3.60	4.10	4.10	4.10	4.60
K_2O	1.61	1.69	1.63	1.54	1.67	2.75	3.90	1.92	1.95	2.05
H_2O over 100°C	0.03	0.14	—	0.24	0.15	0.42	0.31	0.31	0.41	0.40
TiO_2	0.27	0.92	0.90	0.71	0.40	0.81	0.77	0.59	0.63	0.51
P_2O_5	0.37	0.39	0.34	0.31	0.37	0.32	0.22	0.23	0.24	0.20
MnO	0.18	0.18	0.18	0.17	0.17	0.13	0.12	0.13	0.12	0.07
CO_2	0.10	0.05	0.10	0.15	0.10	0.05	0.10	0.10	0.20	0.05
Total	100.11	99.82	99.95	99.73	99.86	99.98	100.22	99.96	100.04	99.89

Analyst — A. Jorgensen, A.M.D.L.

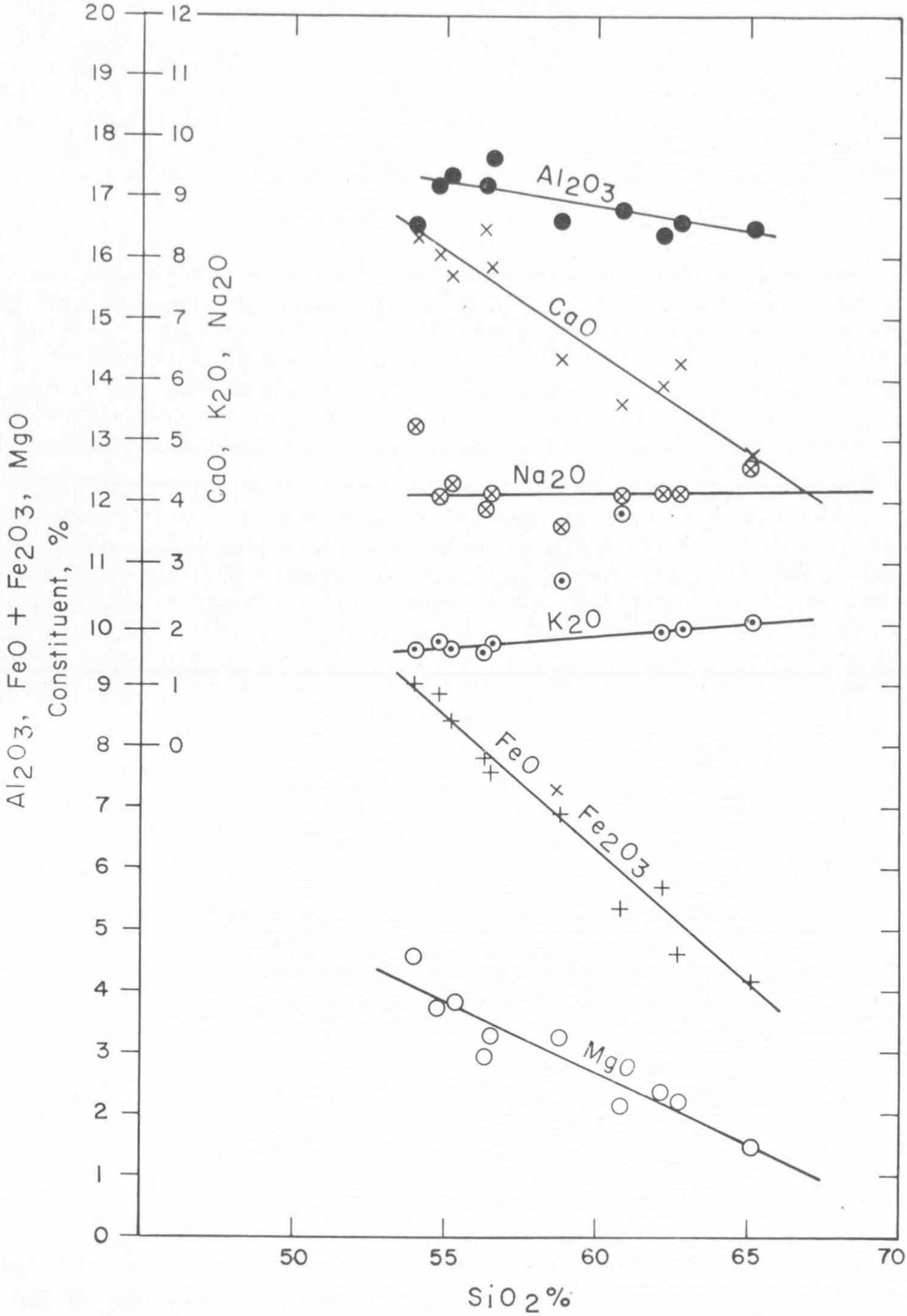


Fig. 6: Variation diagram of volcanic rocks from Bougainville, T.N.G.

METAMORPHISM

Both contact and low-grade regional metamorphic rocks occur on Bougainville. Contact metamorphic rocks consisting of hornfelsed volcanic and sedimentary rocks belonging to the Kieta Volcanics, unnamed volcanics, and Emperor Range Volcanic Beds 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 Formation and Kieta Volcanics.

Most of the rocks that have been affected by contact metamorphism come within the albite-epidote hornfels facies of Fyfe, Turner, & Verhoogen (1958), and are characterized by the mineral assemblage alkali feldspar/epidote/actinolite/chlorite/calcite/quartz. In addition rocks of the hornblende hornfels facies, 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 recrystallized.

The Buka Formation, 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. 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 probably several thousand feet of rock have been removed by erosion from the top of the zeolite bearing rocks.

STRUCTURE

Structural Setting

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

Bougainville and Buka Islands form part of the Solomon Islands, a north-westerly 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.

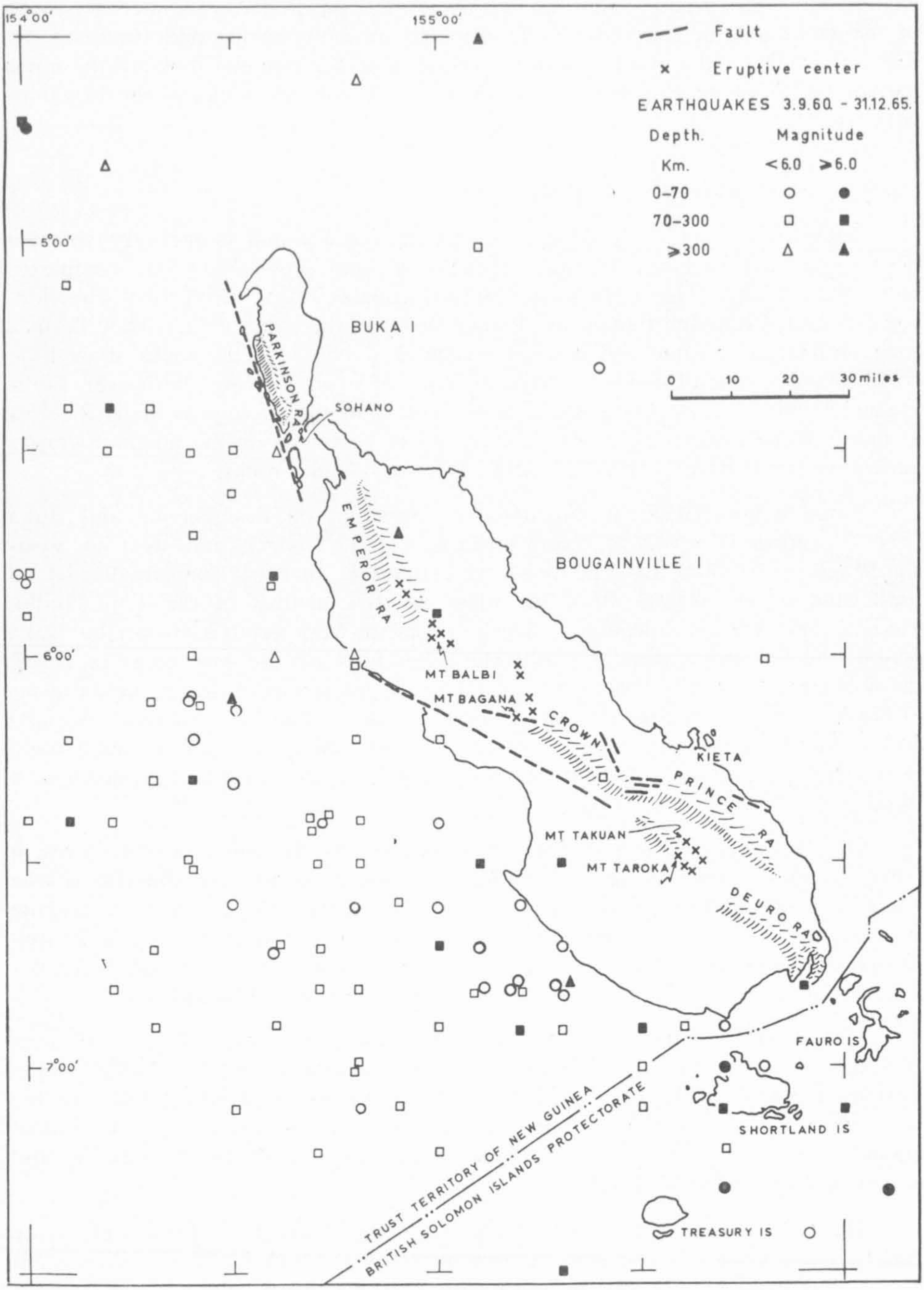


Fig. 7: Main structural elements of Bougainville and Buka, and epicentres of recent earthquakes.

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

Structure of Bougainville and Buka

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 none of strong folding. However, faults are much more prevalent than has been shown on the geological map (Pl. 15), 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. 7): north-west (320°), north-north-west (335°-340°), and west to west-south-west (270°-300°). The north-west trend is that of Bougainville Island itself, and of the alignment of the main eruptive centres of the Tore, 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 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 Bagana Volcano (Pl. 10). 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 Figure 7. One is off the west coast of Buka, trending 345°; it follows the straight coastline and is parallel to the Parkinson Range. The other 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 given 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 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 epicentres 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 with foci less than 200 kilometres deep, and deeper shocks are comparatively rare (Fig. 7). 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 kilometres.

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

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 also 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 Cair[illegible]ic vulcanism in the area probably started in the Oligocene. The first [illegible] thought to have produced a group of submarine volcanoes which [illegible] 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.

While 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, some with associated copper and gold mineralization, 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 Formation 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

The middle Miocene to Pliocene appears to have been a time of uplift and tilting, subdued volcanic activity, and subaerial erosion. Uplift and tilting are best shown by the Keriaka 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 Tore, Balbi, Numa Numa, Billy Mitchell, Bagana, and Reini volcanoes, the Takuan and Taroka lines of volcanoes, and volcanoes of the north-western part of the Emperor Range have been active; these are all subaerial strato volcanoes. The pre-Pleistocene volcanoes, where they were left uncovered by younger rocks, continued to be eroded, and reef complexes were built up offshore. In the Pleistocene the Sohano Limestone on Buka and on the north coast of Bougainville was uplifted and gently tilted to the south and west.

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 mineralization 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 & Fisher, 1965). Small amounts of copper sulphides are also associated with some of the other diorite intrusives 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 mineral 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. Gold mining was begun on a small scale in the Kupei-Panguna area in 1934, and 1789 fine ounces of gold and 89 ounces of silver had been produced by 1941, 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).

TABLE 7. GOLD PRODUCTION—BOUGAINVILLE ISLAND

(Thompson, 1962)

Year	*Gold* (Fine oz) approx.	*Value* $A
1935	45	
1936	113	
1937	598	
1938	487	
1939	297	38,994
1940	217	
1941	32	
1942-1948 No production		
1949	166	
1950	126	3760
1951	95	2938
1952	78	2428
1953	6	188
1954	15	480
1955	5	160
1956-1958 No production		
1959	2	72
	2282	48,020

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 7.

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 dwt gold 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 mineralization surrounds the lode and grades outwards into unmineralized porphyritic microdiorite. The lode is cut by several steeply dipping faults striking roughly east, most of which carry mineralized clayey or pyritous material.

The gold-bearing quartz veins in the lode are up to 3 inches wide. They contain abundant chalcopyrite, bornite, and titaniferous magnetite, 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 & 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 dwt to 1 oz 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, malachite, and titaniferous magnetite, and small amounts of pyrite, molybdenite, and gold. 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 abandoned 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 Riotinto of Australia Pty Ltd (CRA) 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, CRA began 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 occurs in shattered porphyritic microdiorite close to intrusive contacts with hornfelsed agglomerate; the agglomerate contains pyrite but little or no copper sulphide.

The mineralized microdiorite is considerably altered, being partly silicified and chloritized, 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 more than 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 local deposits of Recent or Pleistocene ash several feet thick, which closely resemble weathered microdiorite, and also, on steep slopes, by landslip 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; Pontifex in Blake & Miezitis, 1966). Green malachite is prominent on most weathered microdiorite surfaces. Other minerals associated with the copper sulphides are titaniferous magnetite, sphalerite, molybdenite, pyrite, and traces of gold.

Sulphide mineralization, consisting predominantly of pyrite, but including some copper sulphides, is associated with the other diorite intrusions on Bougainville. It appears 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.

Pyrite and subordinate chalcopyrite and sphalerite are associated with quartz in a fissure occupying a fault zone near Iwi plantation, 15 miles south-east of Kieta.

Age of the Mineralization at Kupei and Panguna

The copper and gold mineralization at Kupei and Panguna is considered to be upper Oligocene or lower Miocene. The mineralization probably took place during or shortly after the emplacement and shattering of the host microdiorite. The microdiorite intrusions may represent the eroded cores of some of the volcanic centres from which the Kieta Volcanics were derived.

Mineral Sands

Many of the present-day 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 percent of the total mineral content. Titaniferous magnetite containing about 4 percent TiO_2 (G. Greaves, in Thompson, 1961) is the predominant heavy mineral, with subordinate hematite, pyroxene, and hornblende. These minerals are derived from the lavas and pyroclastic rocks on Bougainville and have been concentrated first by streams and then, on reaching the coast, by current and wave action. The heavy mineral concentrations appear to be thin and patchy, and they are not likely to form economic iron ore deposits.

Limestone

The Sohano Limestone and Keriaka Limestone are potential sources of limestone for agricultural and industrial purposes. Sohano Limestone has been quarried on Buka for use as a road metal.

Road Metal

Andesite, basalt, and intrusive rocks provide an abundant source of road metal on Bougainville. Small andesite quarries have been opened up near the new overseas wharf at Kieta and on Malabite Hill near Buin.

Water

The high annual rainfall and the absence of a dry season ensure an abundance of surface water throughout the year on Bougainville and Buka, except on limestone outcrops, where drainage is mostly underground. Many of the rivers could be utilized for hydroelectric power.

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I. R. Pontifex of the Bureau of Mineral Resources examined and identified ore minerals in specimens from Bougainville.

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GEOLOGICAL MAP
BOUGAINVILLE AND BUKA ISLANDS
TERRITORY OF PAPUA AND NEW GUINEA
1967
Scale 1:250,000
CROWN COPYRIGHT RESERVED
Data in brown refer to 1:250,000 topographical sheets
TRUST TERRITORY OF NEW GUINEA
PAPUA (AUST)
BOUGAINVILLE ISLAND NORTH
BOUGAINVILLE ISLAND SOUTH
Average magnetic declination for Bougainville Island, 7°30'E
Geology, 1965, from general reconnaissance and air-photo interpretation, by: D. H. Blake, Y. Miezitis, D. D. Middleton, F. S. Chong
Compiled, 1966, by: Y. Miezitis
Cartography by: Geological Branch, B.M.R.
Drawn by: M. E. Nancarrow
Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Issued under the authority of the Hon. David Fairbairn, Minister for National Development. Base compilation prepared by the Division of National Mapping, Department of National Development, from Royal Australian Survey Corps 4 miles to 1 inch topographical series (1945), with minor amendments from field work by the Geological Branch of the Bureau of Mineral Resources.
Aerial photography by the Royal Air Force; incomplete vertical coverage at 1:60,000 scale
Universal Transverse Mercator Projection
CAINOZOIC
QUATERNARY — Q — Alluvium, coral
PLEISTOCENE — Sohano Limestone — Qs — Coralline and shelly limestone
PLIOCENE(?) TO RECENT — Bougainville Group
Tore Volcanics — Czo — Andesite; Undifferentiated andesite, pyroclastics, derived fan deposits
Balbi Volcanics — Czb — Andesite, tuff, agglomerate, derived fan deposits
Numa Numa Volcanics — Czn — Tuff, agglomerate, andesite (?)
Billy Mitchell Volcanics — Czm — Tuff, agglomerate, andesite (?), derived fan deposits
Bagana Volcanics — Czg — Andesite; Undifferentiated pyroclastics and derived fan deposits
Reini Volcanics — Czr — Andesite, pyroclastics, derived fan deposits
Bakanovi Volcanics — Czk — Andesite, tuff, agglomerate
Takuan Volcanics — Czt — Andesite and dacite; Undifferentiated tuff, agglomerate, andesite, derived fan deposits
Taroka Volcanics — Czl — Andesite; Undifferentiated agglomerate, tuff, andesite (?), derived fan deposits
Emperor Range Volcanic Beds — Cze — Andesite, basalt, agglomerate, tuff, derived fan deposits
OLIGOCENE(?) TO PLEISTOCENE(?) — Czd — Microdiorite, diorite, monzonite, granodiorite, syenite, granophyre
MIOCENE(?) TO PLIOCENE(?) — Czu — Andesite, basalt, dacite, agglomerate, tuff
LOWER MIOCENE ('e' STAGE) — Keriaka Limestone — Tl — Foraminiferal and coralline limestone
OLIGOCENE(?) TO LOWER MIOCENE(?)
Buka Formation — Tb — Sandstone and siltstone composed of volcanic material; agglomerate, tuff, basalt
Kieta Volcanics — Tk — Agglomerate, tuff; sandstone, siltstone and conglomerate composed of volcanic material; andesite, basalt, pillow lava
Geological boundary
Fault
Where location of boundaries and faults is approximate, line is broken; where inferred, queried; where concealed, faults are shown by short dashes
Strike and dip of strata
Mine
Alluvial workings
Mineral beach sand deposit
Minor mineral occurrence
Au Gold
Cu Copper
Mt Magnetite
Active volcanic vent
Dormant volcanic vent
Extinct volcanic vent
Intermediate composition
Solfatara field
Vehicle track
Native track
Settlement
Mountain peak or prominent hill; height in feet
Airport
Airstrip
Hot spring (not all hot spring localities shown)
Coral reef
BUKA ISLAND
BOUGAINVILLE ISLAND
SOUTH PACIFIC OCEAN
SOLOMON SEA
EMPRESS AUGUSTA BAY
EMPEROR RANGE
KERIAKA PLATEAU
CROWN PRINCE RANGE
DEURO RANGE
PARKINSON RANGE
BALBI VOLCANO
TORE VOLCANO
NUMA NUMA VOLCANO
BILLY MITCHELL VOLCANO
BAGANA VOLCANO
REINI VOLCANO
BAKANOVI VOLCANO
TAKUAN VOLCANO
TAROKA VOLCANO
LOLORU VOLCANO
Sections
Scale: V/H = 1
BUKA ISLAND
BOUGAINVILLE ISLAND
Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T.
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