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Geology of the Gazelle Peninsula, T.P.N.G.

by

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RECORDS 1970/63

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SUMMARY

The Gazelle Peninsula 1:250,000 sheet ($4^{\circ} - 5^{\circ}S$, $151^{\circ} - 152^{\circ}30'E$) covers the northeastern part of the island of New Britain and includes the peninsula itself, a strip of coast southwest of the peninsula, and a number of islands including the Duke of York group, Watom and Lolobau. The peninsula is roughly rectangular, has an area of about 6,000 sq km, and is made up of a main range (Baining Mountains, highest peak 2410 m), a northeastern lowland, and an isthmus in the southwest. Population is concentrated in the northeast lowland within 30 km of the major port, Rabaul.

The area is entirely made up of volcanic rocks, associated sediments and limestone. The oldest rocks are the Eocene Baining Volcanics which form the backbone of the Baining Mountains. These have been intruded by contemporary and Oligocene hypabyssal and plutonic rocks, and are partially overlain by Upper Oligocene to Lower Miocene Merai Volcanics in the southeast, Middle Miocene Yalam Limestone in the centre west, and Upper Miocene to Pliocene volcanics in the centre and east (Nengmukta Volcanics, Sinewit and Sigule Volcanics). Pliocene limestone and limey sediments are exposed on and near the isthmus (Lakit Limestone, Sai Beds), Pleistocene river gravels northeast off the Baining Mountains (Riet Beds) and Pleistocene raised coral along the east coast. Quaternary volcanics make up the northeast lowland. The main structural features are northwest-trending faults with vertical and possibly lateral displacement (Baining Fault and faults across the isthmus) and northeast-trending faults with vertical displacement. The Baining Fault defines the northeastern front of the Baining Mountains.

The development of the Gazelle Peninsula began in the Eocene with the deposition of the Baining Volcanics by submarine pyroclasis and associated gravity slumping. These rocks were moderately deformed in the late Eocene or early Oligocene. Vulcanism resumed in the Upper Oligocene (Merai Volcanics) but ceased before the Middle Miocene when the Yalam Limestone was deposited. Volcanic activity resumed in the Upper Miocene and continued into the Pliocene (Nengmukta, Sinewit and Sigule Volcanics) and Quaternary with possibly a pause in the Upper Pliocene. The present tectonic regime was established in the late Pliocene: vertical fault movements have elevated the Baining Mountains and have generally depressed the Wide Bay - Open Bay area, and the area continues to be seismically active.

The Baining Volcanics (Eocene) are indurated andesitic marine volcaniclastic rocks with minor splitic lava flows and related hypabyssal intrusions. The most common rock types are massive or thick-bedded fine-grained volcanic conglomerate and greywacke with minor siltstone. Limestone is found only as scattered clasts and nodules in the volcaniclastic rocks and as rare thin interbeds. Dips where observed are steep and shearing and close jointing are common. Rocks in several areas of the North Baining Mountains show incipient regional metamorphism, and biotite and hornblende schist has developed in a narrow zone in the Central Baining Mountains. Epidote alteration is

common. The Merai Volcanics (Upper Oligocene - Lower Miocene) resemble the Baining Volcanics but are not as indurated or deformed, contain a higher proportion of limestone, and dips where observed are not as steep. Thickness exceeds 700 m. The Yalam limestone (Middle Miocene) consists of 1000 m of medium to fine-grained bioclastic limestone with thick interbeds of more easily weathered clayey biomicrite and some more resistant chalky limestone. Terrigenous material is confined to basal beds of mudstone, sandstone and conglomerate. The Nengmukta Volcanics (Upper Miocene) consist of about 300 m of andesitic marine pyroclastics. The Sinewit and Sigule Volcanics (Upper Miocene to Pliocene) consist of 500 m or more of marine and fluviatile tuffaceous sediments with minor limestone and lignite (Sinewit) and some lava flows (Sigule). Plutonic rocks which intrude the Baining Volcanics are both basic and calc-alkaline. The calc-alkaline rocks form two distinct petro-chemical series in two provinces: (1) normal calc-alkaline rocks (leucogabbro to granodiorite) in the North Baining Mountains and (2) high-K calc-alkaline plutonic rocks (leucogabbro to adamellite or granite) in the Central and South Baining Mountains.

Quaternary volcanics of the northeast lowland have mostly emanated from the Rabaul eruptive centre. The eruptive centre is now marked by a caldera open to the sea (Blanche Bay) and a number of cones and vents, some of which are active. The caldera probably formed by collapse of a large central volcano less than 1500 years ago; collapse was accompanied by ejection of large volumes of pumice. Watom Island, northwest of Rabaul, is an inactive volcano. Lolobau Island is an active volcanic centre but the nearby Mount Likuruanga (the North Son) is extinct. Lolobau and Likuruanga form the eastern end of the Bismarck volcanic arc and are not related to the Rabaul eruptive centre.

Except for small amounts of alluvial gold won mostly in the 1930's there has been no mineral production on the Gazelle Peninsula. Iron, copper, lead, zinc and molybdenum mineralization is known, and systematic exploration is continuing.

INTRODUCTION

This report presents the results of reconnaissance geological mapping of the Gazelle Peninsula 1:250,000 sheet which covers the northeastern end of the island of New Britain in the Territory of Papua and New Guinea. The survey was carried out by the writer intermittently from 1966-9 as part of a programme of regional mapping by the Geological and Volcanological Branch of the Department of Lands, Surveys and Mines, Territory of Papua and New Guinea Administration, Port Moresby.

Topography

The Gazelle Peninsula 1:250,000 sheet covers the area 4°-5°S, and 151°-$152^{\circ}30'$E. It includes the Gazelle Peninsula itself, nearby small islands, and a strip of the northern coast of New Britain west of the peninsula. The peninsula is almost square in outline and occupies an area of about 6000 km^2; it lies between $4^{\circ}10'$ - $5^{\circ}00'$S, and $151^{\circ}30'$ - $152^{\circ}25'$E. It is connected to the main part of New Britain by a short isthmus, 35 km wide, between Wide Bay and Open Bay.

To west and north the peninsula is bounded by the Bismarck Sea, to the east by St Georges Channel, and to the south by the Solomon Sea. The northeastern part of the peninsula is low-lying, intensively cultivated, and densely populated; it includes the town of Rabaul. The remainder of the peninsula is mountainous, forested, and sparsely populated.

The peninsula may be divided into four physiographic units (fig. 1):-

(1) North Baining Mountains

(2) Central and South Baining Mountains (shown as 2A and 2B on Fig. 1)

(3) Northeast lowland

(4) Wide Bay - Open Bay isthmus

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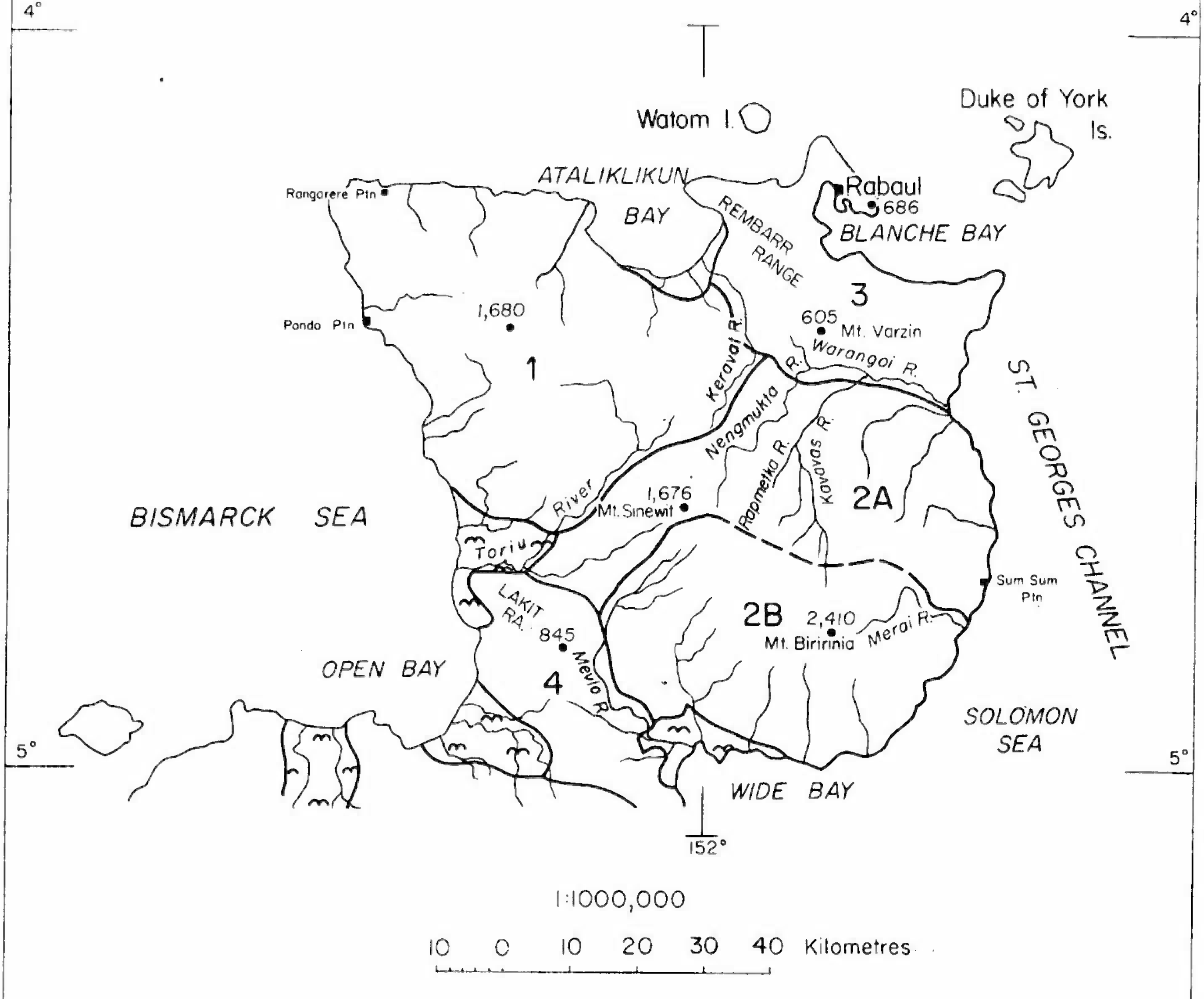
Fig 1

GAZELLE PENINSULA PHYSIOGRAPHIC REGIONS



1 NORTH BAINING MOUNTAINS

2A CENTRAL BAINING MOUNTAINS

2B SOUTH BAINING MOUNTAINS

3 NORTH-EAST LOWLAND

4 WIDE BAY - OPEN BAY DIVIDE

Alluvium

•605 Spot height (metres)

To accompany Record 1970/63 B56/A2/66

(1) The North Baining Mountains are bounded to the west and north by the Bismarck Sea, and to the south and east by the Toriu and Keravat Rivers. In the southern part karst topography characterises an extensive limestone surface. The surface dips gently southwestward from prominant north and east-facing cliffs which rise 1,700 m above sea level. North of the limestone surface steep-sided ranges rise to more than 1,000 m above sea level in the hinterland of the North Baining coast. To the northeast, the mountains fall away into undulating foothills south of Ataliklikun Bay and west of the Keravat River.

(2) The Central and South Baining Mountains form a single broad physiographic unit. The Central Baining Mountains are bounded in the northwest by the middle Toriu and upper Keravat Rivers, in the north by the lower Warangoi River, in the east by St. Georges Channel, in the southeast by the lower Merai River, in the southwest by the upper Mevlo River and a low saddle between the lower Toriu and middle Mevlo Rivers, and in the south by an arbitary line along the north flank of the axial range of the South Baining Mountains. In the western part, deeply dissected tuffaceous strata dip westward at a shallow angle from Mt. Sinewit (about 1,700 m above sea level), towards the Toriu River; a low pass to the southeast, between the Mevlo and Nengmukta River headwaters, separates Mt. Sinewit from the main range of the South Baining Mountains. Northeast of Mt. Sinewit a fairly deeply dissected, undulating land surface rises to about 350 m above sea level in the lower headwaters of the Warangoi River; in the upper headwaters, immediately southwest of the line of the Baining Fault (Fig. 33), the land surface rises steeply towards the main range of the South Baining Mountains. Further east a system of north-trending ridges separates the Warangoi River headwaters from the east coast; elevation of the ridges increases southward from near sea-level south of the lower Warangoi River, to more then 1,000 m.

The South Baining Mountains comprise an axial range trending northwest from the highest peak, Mt. Biririnia, 2,410 m, with steep flanks sloping east and south into the Solomon Sea and Wide Bay, and west into the Mevlo River; an arbitary line defines the boundary of the Central Baining Mountains on the north flank.

Drainage from both the North Baining and Central and South Baining Mountain blocks is roughly radial.

(3) The Northeast Lowland is a complex physiographic unit of relatively low relief, developed largely on Pleistocene and Recent ash from the Rabaul eruptive centre; it is bounded in the west and south by the lower Keravat and Warangoi Rivers, and in the east and north by St. Georges Channel. In the north the township and port of Rabaul is situated inside the caldera of the former Rabaul volcano, breached and open to the sea on the east side; two pre-caldera parasite cones rise 540 and 686 m above sea level on the north and northeast outer slopes of the caldera, and four post-caldera cones have grown to 226 and 229 m inside the caldera rim, and 494 and 375 m overlapping the rim. Fifteen kilometres west of Rabaul, Rembarr Range forms the east promontory of Ataliklikun Bay, with peaks up to 404 m above sea level; the range is composed of limestone draped with a thin veneer of volcanic ash. A dissected southwest-facing escarpment trends southeast from Rembarr Range toward the Warangoi River mouth and forms a watershed between north and south drainage; the height of the escarpment decreases eastward, and the watershed is poorly defined north of the lower Warangoi River. Southwest of the escarpment is a broad depression containing the lower Keravat and Warangoi Rivers. Vunakanau airstrip has been constructed on flat land northeast of the escarpment and 12 km south of Rabaul; hills on the escarpment edge prevent upgrading of the airstrip to provide a major air terminal for Rabaul. The Northeast Lowland has least elevation and is relatively flat near its eastern end, southeast of Kokopo; several wartime airstrips were constructed in this area. Mt. Varzin is an eroded volcanic peak, 605 m elevation, in the middle of the Lowland area; 6 km to the southeast is a smaller, less prominent volcanic peak.

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Coral limestone cliffs up to 150 m high form the eastern coastal margin of the Lowland. Watom Island, a volcanic island 12 km northwest of Rabaul, and the Duke of York Islands, predominantly coral islands 35 km east of Rabaul, also form part of the Northeast Lowland physiographic unit.

(4) The Wide Bay - Open Bay Isthmus is an area of coastal swamp and low mountain ranges, south of the lower Toriu River and west of the middle and lower Mevlo River; maximum elevation is 845 m in the Lakit Range. The highest peaks are near the east edge of a thin unit of Pliocene limestone which blankets the range and dips northwest at a shallow angle. South of the Gazelle Peninsula the land surface rises steeply into the mountains of the Kol-Mengen mountain block.

Climate

The climate of the Gazelle Peninsula is warm and humid in the coastal regions and cooler in the mountains. Rainfall distribution is controlled by topography and relation to the prevailing wind; except in the northeast corner average annual rainfall exceeds 2,500 mm. During the northwest monsoon season most rain falls on the north and west coasts. In the southeast trade-wind season most rain falls on the east and south coasts. In many inland areas rainfall is distributed evenly throughout the year, and the annual total is considerably higher than in the coastal regions.

At Rabaul the monthly rainfall averages 100-250 mm with an average annual total of 2000 mm falling mainly between November and April; temperatures are in the range 20° - 30°C and humidity is constantly high. 20 km to the southwest at Keravat the average annual rainfall is 3000 mm (with a monthly average of 180-300 mm) falling mainly between September and May. On the west coast Pondo Plantation records an average annual rainfall of 4600 mm, and the monthly averages vary from 180 to 850 mm with most rain falling between December and March. On the east coast at Sum Sum Plantation, the annual rainfall averages 3900 mm and monthly averages vary from 150 to 600 mm, with highest rainfall from July to September.

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Because of high rainfall and tropic climate, rain forest cover in the Gazelle Peninsula is dense, and areas of recent regrowth are virtually impenetrable.

Population, Industry, Access and Communications

Population and industry in the Gazelle Peninsula are concentrated in the Northeast Lowland. The indigenous population is predominantly Tolai and numbers more than 65,000; most of these people live in villages scattered throughout the area. The non-indigenous population is made up of Chinese and Europeans and numbers about 5,000, mostly in the townships of Rabaul and Kokopo. A network of roads provides access to Rabaul from villages and plantations throughout the area; only two roads extend beyond the edge of the lowland, to provide access to a resettlement area in the lower headwaters of the Warangoi River, and to timber leases west of the Vudal River.

Outside the Northeast Lowland an indigenous population of less than 5,000 Baining people lives in widely scattered villages (Figs. 2 and 3), mostly on the northeast fall of the North Baining Mountains, and in the Central Baining Mountains in the lower headwaters of the Warangoi River and eastward to the east coast; related people occupy several villages along the southeast and south coast, and several almost deserted villages between Wide Bay and Open Bay. Several hundred Kolou people live at Matanakunei village in Open Bay, along with the remnants of the small Mokolkol clan. A small population in several coastal villages along the south side of Open Bay, and on Lolobau Island, is related to the coastal population further west, along the north coast of New Britain.

Copra and cocoa plantations (Fig. 4), have been established in an almost continuous strip along 35 km of the North Baining coast, west of Ataliklikun Bay; fewer isolated plantations are located on the west coast, and several on the east coast. Timber is logged west of the Vudal River and on Lolobau Island, and in the near future extensive logging and milling operations will commence in Open Bay; a road is planned to link Open Bay with Rabaul.

Figure 2. Preparing for a ceremonial fire dance in the Central Baining Mountains.

Figure 3. Rest-house at Yalam village in the North Baining Mountains. Yalam Limestone scarp in background.

Figure 4. Coconut palms and cocoa trees in the northeast lowland.

Figure 5. Carriers crossing a river near Wide Bay.

Small boats supply coastal plantations and villages; shipping along the north and west coast is frequent, but along the southeast and south coast it is infrequent and difficulty is experienced in gaining access to this area. Walking tracks link villages in the inland area, but the greater part of the Gazelle Peninsula is unpopulated and trackless.

Rabaul is administrative headquarters of the East New Britain District, and commercial centre for much of the New Guinea Islands region; it contains a large shopping centre and a wide variety of light industries. Two or more daily passenger air services link Rabaul with mainland New Guinea, using Fokker Friendship and DC 3 aircraft operated by Trans Australia Airlines and Ansett Airlines of New Guinea. Lakunai airstrip inside the Rabaul caldera is presently in use, but investigations are in progress to locate an alternative site, suitable for the operation of larger aircraft. Less frequent air services link Rabaul with other centres in the New Guinea Islands and the British Solomon Islands Protectorate. Frequent overseas shipping services supply Rabaul, and carry produce to world markets; coastal shipping operates to all parts of the New Guinea Islands.

Radio links are maintained by the Administration Department of Posts and Telegraphs between Rabaul and mainland New Guinea, and by Overseas Telecommunications between Rabaul and Australia. An Outstations network operated by Posts and Telegraphs provides radio contact with Rabaul from outlying plantations, or from portable transceivers; a similar network operates for small boats.

Following the eruption of Vulcan in 1937, a volcanological observatory was established at Rabaul by the Administration of the Mandated Territory of New Guinea. This has been expanded, and at the present day surveillance in the Rabaul area includes temperatures and tide measurements, tiltmeter measurements, and the interpretation of records from a partly telementered network of seismographs distributed around the caldera and linked with the Central Observatory. The Observatory is maintained by the Geological and Volcanological Branch of the Department of Lands, Surveys and Mines, with professional staff seconded from the Bureau of Mineral Resources.

History

The Northeast Lowland of the Gazelle Peninsula was occupied by Baining people until the early part of the nineteenth century, when migration of the Tolai people from New Ireland displaced them into the surrounding mountain ranges. In the latter part of the nineteenth century German traders and missionaries established some contact with the Tolais, and in 1884 Germany formally proclaimed its possession of German New Guinea, including New Britain. Administration was placed in the hands of the German New Guinea Company until 1899, when the Imperial Government assumed control. Administrative headquarters of the Territory were moved to Rabaul in 1909.

In 1914, Australian forces occupied Rabaul and the former German territories, which remained under military administration until mandated to Australia by the League of Nations in 1921. In 1937 Rabaul was severely damaged by the eruption of volcanic ash from Vulcan and Tavurvur volcanic centres inside the caldera.

Civil administration of the Mandated Territory was suspended in 1941; Rabaul was occupied by Japanese forces from 1941 to 1945, and suffered heavy Allied bombing until the end of the war. Civil administration was gradually restored in the former Mandated Territory of New Guinea, and Australia was granted Trusteeship by the General Assembly of the United Nations late in 1946. War damage was slowly repaired in Rabaul, which remained administrative headquarters of the New Britain District, although alternative sites, less prone to damage by volcanic activity, earthquakes and tidal waves, were investigated for several years. In 1966 the New Britain District was divided into the East and West New Britain Districts: Rabaul has remained headquarters of the East New Britain District. The Gazelle Peninsula is administrated through Sub-District Offices at Rabaul and Kokopo, and a Patrol Post at Lassul Bay, on the North Baining coast.

Agricultural development in the Northeast Lowland has continued since the days of German settlement. A Tolai population of less than 10,000 people at that time, has grown to more than 65,000 at the present day. Problems of land ownership and usage in the Lowland area are of increasing concern.

Previous Geological Investigations

Previous geological information from the Gazelle Peninsula consists of scattered observations and descriptions of small areas of specific interest; very little regional reconnaissance had been carried out before 1966.

The earliest recorded geological observations are those of E.R. Stanley, then Government Geologist of Papua, while attached to the Commonwealth Scientific Expedition to New Guinea in 1920-1921 (Stanley, 1922a). Stanley briefly examined the lower Toriu River area and the vicinity of Put Put Harbour. In the latter part of 1922 Stanley returned to New Britain, and spent several months investigating the economic mineral prospects of the hinterland of the North Baining coast. This followed the earlier identification of specimens of iron ore, minor base metal sulphides and gold in the vicinity of Rangarere Plantation (Stanley, 1922b).

The Talele Provisional Goldfield was proclaimed in 1933. This together with continued interest in the iron ore deposits led to the re-examination of the Rangarere area by geologists of the Administration of the Mandated Territory of New Guinea (Fisher, 1942) and the Bureau of Mineral Resources (Rahdon, 1956), and subsequent drilling of the iron ore deposits (Gardner, 1957).

Following the eruptions of Vulcan and Tavurvur in 1937, N.H. Fisher was transferred from Wau to Rabaul to establish a volcanological surveillance observatory. While stationed at Rabaul he conducted a number of geological investigations in the Northeast Lowland, and in the foothills of the North Baining Mountains (e.g. Fisher, 1939). In 1939 L.C. Noakes traversed from Wide Bay northwards across the South and Central Baining Mountains, passing east of Mount Sinewit (Noakes, 1942).

Small alluvial gold workings inland from Put Put Harbour were investigated in 1951 by the Government Geologist from Port Moresby (Edwards, 1951).

Preliminary site investigations for hydro-electric schemes have been conducted by geologists of the Bureau of Mineral Resources on the Batonga River (Fisher, 1959), the Towanokoko-Pondo Rivers (Fisher, 1959; Carter, 1962; Best, 1966) and the Toriu River (Carter, 1962; Best, 1966). A dam site on the lower Warangoi River has been investigated and the abutment area drilled (Read, 1968).

An investigation by the writer of copper mineralization in the Warangoi River headwaters (Macnab, 1967) highlighted the need for a better knowledge of the regional geology of the Gazelle Peninsula, and led to the initiation of this reconnaissance survey.

Method of Work

In February-May 1967 the writer spent 10 weeks in the field. Closely spaced traverses were carried out in the northwest part of the North Baining Mountains, and widely spaced traverses in the Central and South Baining Mountains. A brief period of field supervision was afforded by D.B. Dow (Bureau of Mineral Resources) in mid-April, 1967, in the Central Baining Mountains.

Mapping continued in the latter part of March and early April, 1968, with one week spent in fieldwork in the Northeast Lowland, and 2 weeks in the Wide Bay-Open Bay area in co-operation with a Department of Forests helicopter survey party. In August to September, 1968, 3 weeks were spent in fieldwork in the east and northeast parts of the North Baining Mountains.

A Bell Jetranger helicopter, under contract to the Bureau of Mineral Resources New Britain Field Party, was used for 2 days in early March, 1969, to examine exposures along the middle Toriu River, on the southeast coast of the Peninsula, and in the Wide Bay area. In September, 1969, boat landings were made on Makada Island (Duke of York Islands) and south of Pondo Plantation: several days traversing were carried out south of the Sai River and coastal exposures were examined along the south side of Open Bay. The North Son and Lolobau Island were examined, in company with R.J. Ryburn and R.W. Johnson of the Bureau of Mineral Resources New Britain Field Party.

Because of the general absence of walking tracks, and poor exposures along those few tracks presently in use, most traversing was carried out along streams (Fig. 5). Tracks following spurs and ridges were cut where necessary. Field work is hampered by dense rain forest, rugged topography, and heavy afternoon rains with consequent flooding of watercourses.

Throughout much of the survey the writer was accompanied by field assistant Paul Leo. Baining carriers were recruited for all field work in the mountain areas, and proved to be energetic and cheerful workers.

Details of the Gazelle Peninsula aerial photograph coverage are contained on the New Britain flight diagram of the Division of National Mapping, Department of National Development, Canberra. Photography by Adastra Airways in 1962 covers the northern part of the Peninsula, while the southern part is covered by military photography flown in 1947-1948. At the time of the initial fieldwork in 1967, the military photography was not available to the writer; traverses were carried out in the southern part of the Peninsula using 1 inch to 1 mile maps of the wartime Provisional Map Series (U.S. Army, 1943). Traverse information from the northern part of the Peninsula was plotted directly onto the Adastra photographs; traverse information from the southern part was plotted onto the wartime maps, and transferred to the military photography when it was obtained later in 1967. Subsequently, all traverse information was recorded directly on aerial photographs.

Because the Provisional Map Series proved inadequate for use as base maps, aerial photograph assemblages were used to prepare photo-scale compilation sheets for most of the Gazelle Peninsula. Uncontrolled 1:50,000 drainage maps of a large part of the Gazelle Peninsula, prepared for U.S. Metals Ref. Co. by Geophoto Services, Brisbane, became available to the writer late in 1967. Early in 1969 controlled 1:50,000 topographic maps of the Wide Bay-Open Bay area were prepared by Qasco, Boroko, for the Department of Forests, Port Moresby.

In 1969 the writer prepared 1:50,000 scale geological maps covering the Gazelle Peninsula, using base maps adapted from all available sources, and modified where necessary by reference to the aerial photographs. These maps were reduced to a scale of 1:250,000, and fitted to the Gazelle Peninsula coastline and grid prepared by the Department of the Interior, Canberra, for the 1969 Bureau of Mineral Resources crustal study programme. The geological map so produced is included with this report.

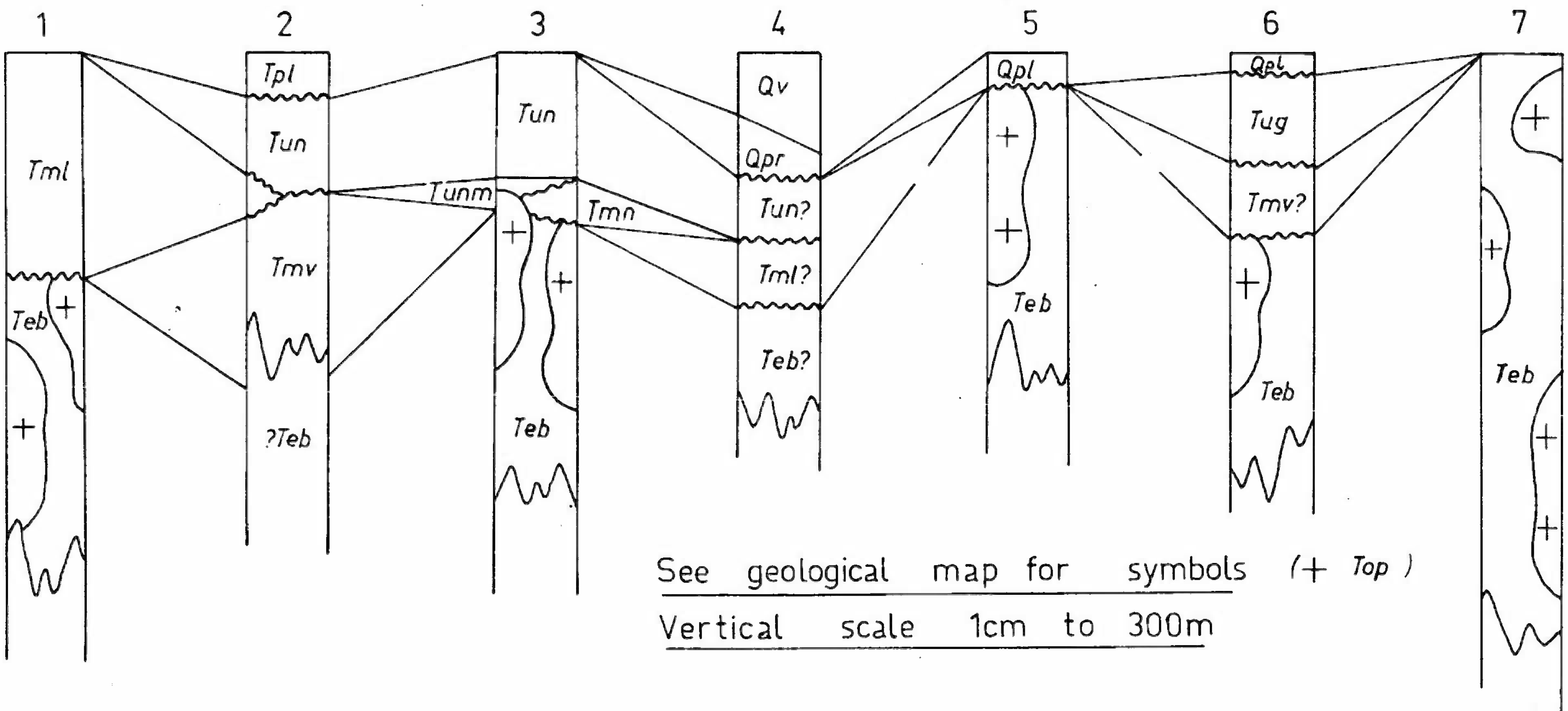
Several hundred micropalaeontological samples, collected by the writer in the course of fieldwork, were examined in the Bureau of Mineral Resources by D.J. Belford and J.G. Binnekamp (Belford, 1968; Binnekamp, 1970); ages determined from these samples proved invaluable in defining relations between geological units. More than 400 thin sections of selected rock specimens have been examined by the writer, and petrographic descriptions are incorporated in this report. Wet chemical analysis of 33 plutonic rock samples was carried out by Australian Mineral Development Laboratories, Adelaide (Appendix 1). A more detailed account of the plutonic rocks of the Gazelle Peninsula will be submitted by the writer to the Australian National University, as part requirement for the degree of Master of Science.

STRATIGRAPHY

The Gazelle Peninsula is made up of Cainozoic volcanogenic rocks, associated intrusives, and subordinate limestone. The oldest rocks are Eocene. The stratigraphic succession is summarized in the following table, and the succession at different localities is diagrammatically prasented in Fig. 6.

GAZELLE PENINSULA - STRATIGRAPHIC CORRELATION CHART

Fig 6



1 Central part of North Baining Mountains

2 Inland from Matanakunei village

3 Mt Sinewit

4 West part of Northeast Lowland

5 Duke of York Islands

6 Inland from Put Put Hbr

7 Inland from Wide Bay

To accompany Record 1970/63

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Quaternary	Superficial deposits (Qa, Qab, Qav, Qv, Qpl)	
	Riet Beds (Qpr)	
Tertiary		
Pliocene	Sai Beds (Tps)	
	Lakit Limestone (Tpl)	
Upper Miocene to Pliocene	Sigule Volcanics (Tug)	Sinewit Volcanics (Tun)
		Mevlo Member (Tunm)
Upper Miocene	Nengmukta Volcanics (Tmn)	
Middle Miocene	Yalam Limestone (Tml)	
Upper Oligocene to Lower Miocene	Merai Volcanics (Tmv)	
Eocene	Baining Volcanics (Teb)	

Intrusive plutonic rocks (Top) were probably emplaced in Oligocene time.

BAINING VOLCANICS (new name)

The oldest rocks in the Gazelle Peninsula are the Eocene Baining Volcanics which form the core of the Baining Mountains. These rocks have previously been called the Baining Series (Fisher, 1942a); they are here renamed and redefined. The Baining Volcanics are exposed in the northern part of the North Baining Mountains, in the Central and South Baining Mountains, and along the main body of the island of New Britain, southwest of the Gazelle Peninsula.

The Baining Volcanics is a thick pile of undifferentiated volcaniclastic marine sedimentary rocks, with sporadically interbedded lava flows, intruded by genetically related dykes and sills; massive or thick-bedded, fine to medium-grained volcanic conglomerate and volcanic greywacke dominate the succession, with massive to thin-bedded volcanically derived siltstone developed locally. The volcanic debris and rare flows are largely of fine-grained holocrystalline and vitrophyric porphyritic andesite with minor spilite. These rocks are in places hornfelsed and, at one locality, dynsmically metamorphosed to hornblende and biotite schist. Thin beds of autochthonous limestone are exposed at several localities and some of these contain much volcanic debris. Limestone clasts are present in volcaniclastic rocks at a number of widespread localities.

Foraminifera in the scattered limestone exposures indicate an Eocene age (Tertiary a and b stages).

In outcrop the volcanics are dark-coloured,hard, massive and strongly jointed rocks with fracture fillings of zeolite, calcite and some quartz. Epidotization is localized about joints and pyrite is developed in places. Shearing is common and in many places joints have been offset by later movements.

The thickness of the Baining Volcanics is probably greater then 2 km, but lack of bedding makes any accurate estimate impossible. Dips where observed are steep and, in one instance, overturned.

Thermal metamorphism associated with plutonic intrusions is restricted to very narrow contact zones, except in two small areas on the north coast and in the Central Baining Mountains where there is wider development of hornfelses and hydrothermal alteration. An incipient cleavage induced in the Volcanics by shearing was noted in several areas in the North Baining Mountains, and hornblende and biotite schists crop out in a narrow linear zone in the Central Baining Mountains. Induration, alteration, shearing and jointing of the Baining Volcanics is weakest in the Wide Bay area.

Massive or thick-bedded, fine-grained <u>volcanic conglomerate</u> forms the major part of the Baining Volcanics. It is made up of angular to subrounded, black, red-brown, brown and grey aphanitic and porphyritic lava fragments, some of which are vesicular. These are set in hard, mostly light-coloured recrystallized matrix, which

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generally contains a small amount of fine fragmental material; a white cement is present in some outcrops (Figs 7 and 8). Fragment size is generally small, up to several centimetres, but varies up to 10cm and rarely to 50 cm. The finer grained rocks are moderately or poorly sorted and fragment size varies considerably especially in the coarser conglomerates.

Large-scale grading is apparent in thick conglomerate beds at several localities. In outcrop the conglomerates generally appear to be unbedded, but in places are coarsely bedded or contain beds of finer grainsize; where seen, the base of beds is mostly sharply defined. Narrow bands and lenses of volcanic conglomerate occur in many thin-bedded greywacke-siltstone successions; in some, bands of pebble conglomerate contain erratic larger cobbles. Most fragments in the volcanic conglomerate are subangular to poorly rounded; with marked increase in angularity of fragments the rock becomes a volcanogenic sedimentary breccia. Breccias so defined are of widespread but generally minor occurrence, differing little from conglomerates in habit; they are most abundant along the north coast of Wide Bay.

With decrease in grainsize, volcanic conglomerate and sedimentary breccia grade into greywacke and arenite. (The distinction between greywacke and arenite is here based on the abundance of matrix.) Volcanic greywacke (Fig. 9) is very widespread, forming massive outcrop in many areas. It is a highly indurated dark grey-green to black rock, made up of angular to subrounded volcanic fragments in an abundant microcrystalline matrix (85% to 15%); in some sections it is pebbly, in others it is interbedded with and grades into indurated siltstone. Volcanic arenite contains less than 15% matrix, and is widely distributed but considerably less abundant than the greywacke; it is best developed in some areas of siltstone development.

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Hard volcanically-derived siltstone is light to dark-coloured, and is made up of angular siltsized volcanic fragments in a very abundant microcrystalline argillaceous matrix. In some areas predominantly light-coloured siltstones are thickly or thinly interbedded with fine to coarse-grained, light-coloured arenites and greywackes. Generally these rocks look like turbidites. Coarser-grained beds may be graded, and small-scale soft sediment deformation is evident in some thin-bedded successions(Fig. 10). One outcrop of fine-grained arenite displays minor current bedding. Massive black siltstone crops out in a number of areas; in the Central Baining Mountains hard black siltstone with a splintery fracture and minor greywacke and fine-grained conglomerate are interbedded with thick, uniform lava flows. It is difficult in the field to distinguish between strongly indurated black siltstone and very fine-grained black lava or intrusive rock. Massive, dark siltstones were probably deposited slowly from suspension in deep basins.

Conditions during deposition of the Baining Volcanics were generally unfavourable to limestone development, and calcareous rocks are of limited extent in the thick sedimentary pile. The most common evidence of carbonate deposition is the presence at a number of widely separated localities of small, fine-grained, fossiliferous limestone fragments in volcanic conglomerate (Fig. 11). These conglomerates rarely contain minor calcite matrix and cement, and grade with increasing proportion of cement, into pebbly limestones made up of oxidised lava fragments, fine-grained limestone fragments and microfossil remains, set in calcite cement. The cement is in some cases recrystallized and generally contains deformed lenses of chloritic mud. Small limestone lenses occur in situ in fine-grained conglomerate and greywacke at several localities, and in one outcrop limestone pods are caught up in a submarine lava flow. Thicker limestone units were noted at three localities: (i) on the north coast at Rangarere Plantation, (ii) in the Central Baining Mountains where thermally metamorphosed limestone is interbedded in the Volcanics, and (iii) near the east coast where a faulted inlier in

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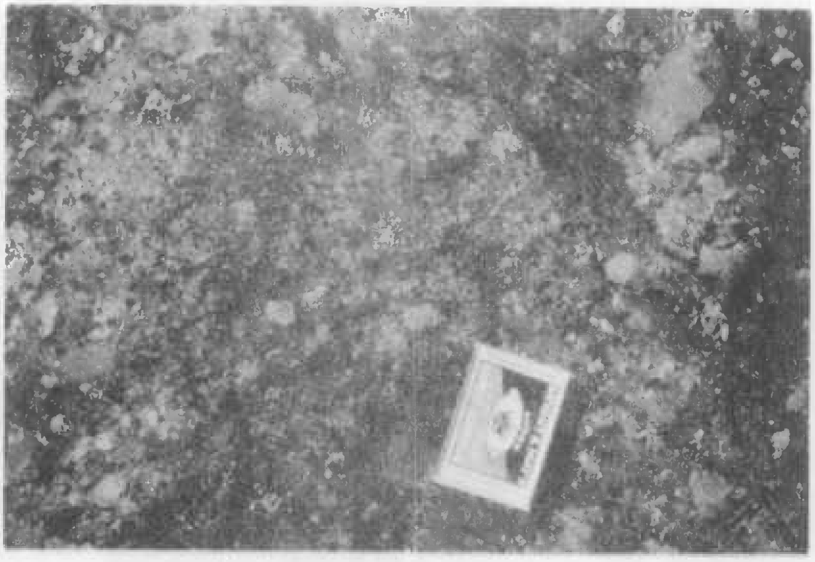

Figure 7. Baining Volcanics. Fine-grained volcanic conglomerate.

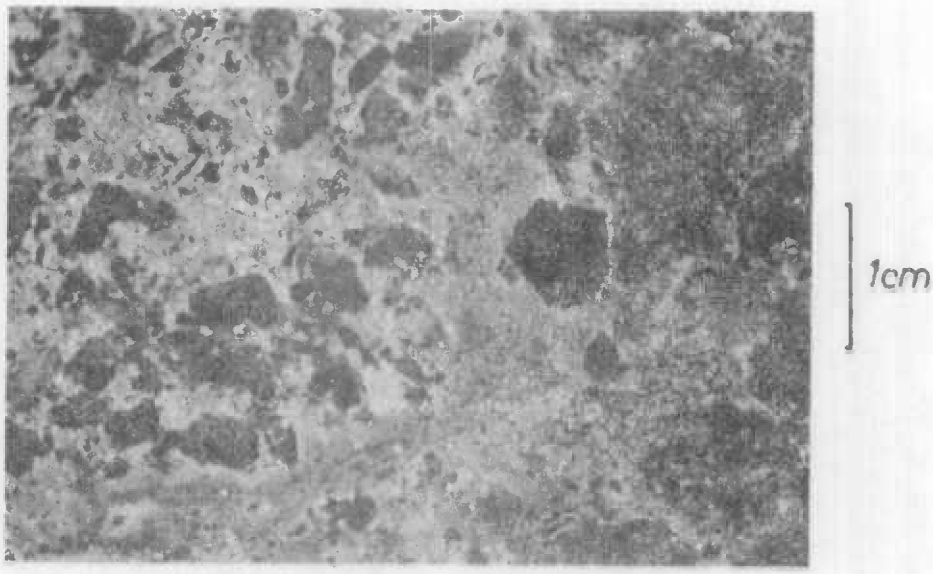

Figure 8. Baining Volcanics. Fine-grained volcanic conglomerate, with abundant recrystallized matrix.

Figure 9. Baining Volcanics. Thin-bedded, unsorted volcanic greywacke and fine-grained conglomerate and breccia. Wide Bay.

Figure 10. Baining Volcanics. Soft-sediment deformation in thin-bedded volcanolithic siltstones in the North Baining Mountains.

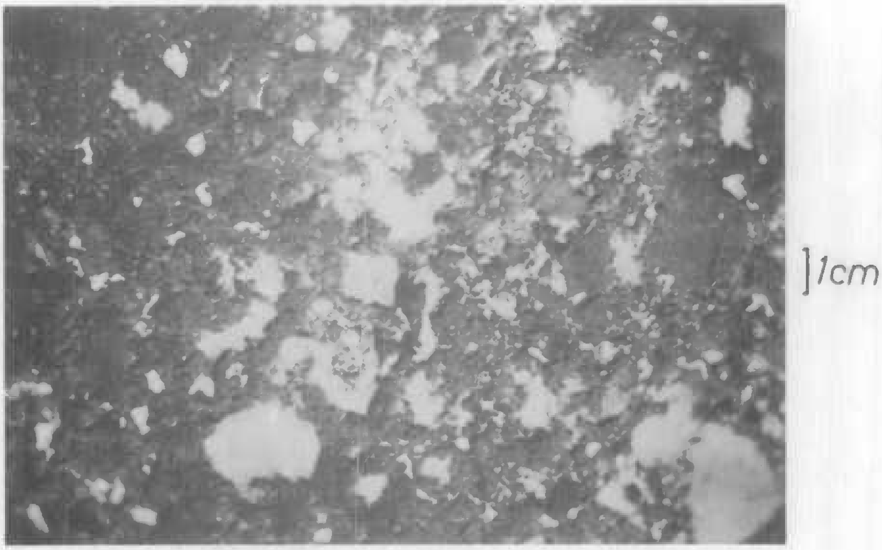

Figure 11. Baining Volcanics. Limestone clasts in a fine-grained volcanic conglomerate.

Figure 12. Biotite-albite-quartz schist with cordierite poikiloblasts, developed from Baining Volcanics in the Central Baining Mountains. Plane polarized light. Specimen 53NG0421B.

the Sigule Volcanics contains partly recrystallized white limestone interbedded with indurated greywacke of the Baining Volcanics. In areas showing some evidence of carbonate development, rare microfossils occur in the matrix of non-calcareous rocks (e.g. volcanic conglomerates in which there are no limestone clasts or calcite matrix or cement). The microfossils can only be detected in thin section.

In outcrop the lavas of the Baining Volcanics are typically strongly jointed, fine-grained, dark-coloured rocks, many with small plagioclase phenocrysts and zeolite-filled vesicles and amygdales. Probable pillow structures have been identified at a number of localities, and intense disturbance of unconsolidated sediments by outpouring lava flows has been noted. Such features include the incorporation of limestone pods into the lava flows. Many rocks identified petrographically as lavas appear to belong to relatively thick, undisturbed flows; field evidence for an extrusive origin of these rocks is generally lacking, and some may be intrusive. Some of the agglomerate or breccia may be deposits of fragmented submarine lava flows preserved close to their source.

Fine-grained dark hornfelses developed from Baining Volcanics crop out in narrow zones along the margin of some high-level plutonic intrusions; thermal alteration and hydrothermal activity probably related to the plutonic activity is more widespread in the vicinity of Rangarere Plantation on the north coast, and between the middle Rapmetka and Kavavas Rivers in the Central Baining Mountains. Well foliated biotite and hornblende schists (Fig. 12) occupy the centre of a narrow linear zone trending north along the middle Rapmetka River. These were probably produced by dynamic metamorphism. Hornfelses occupy the margins of the zone, which is up to 0.5 km wide and is intersected at the northern end by plutonic rocks. Limited stoping of the schists and retrogressive metamorphism in the contact aureole of the pluton indicate that the dynamic metamorphism took place earlier than the intrusion of the plutonic rocks.

Discussion

The Baining Volcanics are thought to be the product of submarine vulcanism, and to record the first stages in the development of a volcanic island or island arc. The dominant process is explosive andesitic vulcanism on the sea floor. This is accompanied by some redistribution of the volcanic debris into adjacent deeper basins, by some extrusion of lava, and by peculiarly little development of limestone.

Recent literature on submarine pyroclasis is reviewed below, and this is followed by a discussion of features of the Baining Volcanics which might be diagnostic of submarine eruption.

Submarine pyroclastic processes

Andesitic volcanoes on land are characterized by explosive eruption and emission of volcanic debris. Andesitic vulcanism below sea-level should be even more explosive because the effects of water penetrating to the hot eruptive centre, and of the rapid quenching of extruded lava. Carlisle (1963) has shown that if shattering of lava takes place on initial eruption and quenching, further shattering can take place when fragments are chilled almost to the temperature of the surrounding water, because of stresses imposed by the removal of the temperature gradient in the fragments. Explosive vesiculation of outpouring lava in some instances causes intense fragmentation. Carlisle showed that vesiculation of submarine lavas at shallow water depths is closely dependant on the viscosity and temperature of emission of the lava; explosive vesiculation can only take place at moderately high temperatures in lavas with low viscosities, and consequently is not an important factor in the formation of much andesitic submarine pyroclastic debris. Large phreatic eruptions, triggered by penetration of sea water to depth and not necessarily accompanied by the extrusion of fresh magma cause the upheaval and further shattering and comminuting of earlier formed lava and debris distributed about eruptive centers.

Rittmann (1962) stated that below about 2000 m hydrostatic pressure due to the water column is sufficient to inhibit the formation of steam, and consequently most deep submarine eruptions involve the quiet outpouring of lava. Cotton (1969) has shown that large basaltic volcanoes building from the ocean floor have a core of submarine lava flows, overlain and enveloped by about 2000 m of fragmental basaltic debris (in his estimation largely scoriaceous) which is intruded by a network of dykes and is capped, above sea-level, by subaerial lava flows.

It may be concluded that andesitic eruptive activity in a shallow-water submarine environment, results in the production of large volumes of fairly finely fragmented pyroclastic debris; unfragmented lava flows are uncommon in this environment, being restricted to subaerial eruptions, and submarine eruptions at depths greater than 2,000 m. Because of rapid cooling, the pyroclastic fragments mostly have vitric or very fine-grained holocrystalline groundmass.

During eruptions submarine pyroclastic debris settles on to the flanks of parent volcanoes. Inherent instability, or disturbance by earthquakes during or after eruption, causes repeated gravity slumping of rapidly accumulating debris into deeper water, where it comes to rest as thick beds of marine volcaniclastic sediments. The mode of transport, distance of travel, and degree of grading and sorting of the final deposit depend on grainsize and sorting of the debris before slumping, the degree of water-saturation of the slumped mass, steepness of slopes down which it flows, and the topography of the depositional area. Coarse debris and debris which is fairly well settled before slumping mostly form avalanches which strip the surface and may tear up and incorporate angular blocks of surface strata as they move down the slope, before coming to rest as an unsorted, ungraded deposit near the foot of the volcano. With increasing water-saturation the moving body of debris has less effect on surface strata, and travels a greater distance before coming to rest; graded bedding becomes apparent and the avalanches grade, at the upper limit of water-saturation, into turbidity currents. Fiske (1963) called such avalanches of pyroclastic debris subaqueous pyroclastic flows; these flows are mostly fairly highly water-saturated, and travel considerable distances before coming gently to rest as thick, tabular bodies with planar bottoms and tops, in many instances displaying moderate vertical grading in fragment sizes and density. Fragments are mostly small (up to 3 cm across), and glassy matrix (in some instances finely tuffaceous) makes up as much as 70% of the rock. Beds range in thickness from about 3 m to more than 60 m; beds less than 3 m thick are mostly fine-grained rocks deposited by turbidity currents (Fiske, ibid.).

A prominent feature of subaqueous pyroclastic flow deposits formed under ideal conditions is "doubly graded" bedding (Fiske and Matsuda, 1964). If the water is sufficiently deep that the eruption column does not break the surface, sorting of the pyroclastic debris takes place during an eruption. The larger and heavier fragments (mostly lapilli), which make up the greater part of the pyroclastic material formed by the eruption, fall in a continuous rain on to the flanks of the volcano, causing rapid accumulation of debris which is carried away by repeated pyroclastic flows. Deposits from individual flows are probably mostly indistinguishable, producing a thick cumulative unit in the depositional area. Finer ash begins to settle with the lapilli, and the debris deposited in the later stages of eruption is not as well sorted as that of the initial phase; when the eruptive activity ceases progressively finer material settles on the flanks of the volcano, and the debris deposited by the final pyroclastic flows decreases in grainsize and density. As fine sand and silt-sized fragments settle more slowly, water-saturation of the accumulating material increases and it is carried away in surges by turbidity currents, to be deposited in thin, well-graded beds, with successive beds displaying finer fragments at the base. Fine-grained ash and dust from the eruption are carried away in suspension and are probably deposited slowly in deeper basins. If pumice is produced it mostly floats to the surface and is carried away by winds and surface currents; if it sinks it is concentrated in the upper part of the pyroclastic flow unit. Vertical grading of individual beds, combined with the overall vertical grading displayed by the succession of pyroclastic debris deposited from a single volcanic eruption, was termed "double grading" by Fiske and Matsuda (ibid.). It is best displayed when the eruption is of fairly short duration. The doubly graded succession of submarine pyroclastic eruptions is easily complicated by a number of factors, including the fragment size and the nature of the debris produced, duration and frequency of eruptions and proximity to other erupting centers, the height of the eruption column, the action of strong marine currents, the slope of the flanks of the eruption center and the depositional environment.

When a submarine volcano builds to sea-level it is subjected to wave action and surface currents; if the products of subsequent eruptions are mostly pyroclastic the volcano may be constantly and rapidly reduced to a level below wave action. If lava flows cap the volcano and are not fragmented and removed by phreatic eruptions, the volcano continues to build and may reach a substantial height above sea-level, continually pouring subaerial lava and pyroclastic debris into the sea at its periphery. In the New Hebrides a thick succession of marine clastic rocks composed of predominantly coarse volcanic debris and lesser carbonate reef debris was deposited in the Lower Miocene (Jones, 1967; Robinson, 1969). Andesitic material was derived from both emergent and submarine volcanoes by epiclastic and subaerial and submarine pyroclastic mechanisms. Carbonate was derived by wave action on coral reefs fringing volcanic islands, and by shallow areas of reef-shoal development; the environment was a volcanic archipelago in a region of warm oceanic currents. Conglomerate and sedimentary breccia are the predominant lithologies, with some associated arenite and siltstone; many rocks consist entirely of volcanic debris, while some include carbonate debris which may predominante, and some are composed entirely of unsorted reef talus. The coarse-grained rocks are typically unsorted to poorly sorted deposits composed of angular to fairly well rounded fragments varying in diameter from 2 m to silt size; according to

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Jones, debris accumulated in shallow water before being transported into deeper water as rubble avalanches or "rubble flows". Some finer-grained deposits were formed in the same way, but many were derived directly from submarine eruptions, by pyroclastic flows and partly by turbidity currents.

Application to Baining Volcanics

The following features of the Baining Volcanics are thought to indicate submarine vulcanism.

(i) Fine-grained volcanic conglomerate and less common volcanic greywacke make up the bulk of the Baining Volcanics and form very thick beds.

(ii) Fragments are mostly of vitrophyric or very fine-grained holocrystalline lava with small phenocrysts; some are vesicular, rarely scoriaceous. They are accompanied by a variable proportion of crystal grains and fragments.

(iii) Fragments are mostly subangular, and range generally in size from several millimetres to several centimetres, less commonly up to 10 cm. They are mostly fairly poorly sorted and there is almost always a marked gap in grainsize between fragments and the very fine-grained recrystallized matrix which makes up as much as 80% of some rocks.

(iv) No evidence of shallow water deposition by traction currents was found; the lower boundary of beds is even and there is little evidence of scouring or disturbance of underlying sediments during deposition.

(v) Normal grading from medium-grained conglomerate to pebble greywacke was noted in several very thick beds.

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(vi) Thin-bedded turbidite deposits are interbedded in the succession, comprising well-graded, volcanically derived siltstone and fine-grained greywacke and arenite.

(vii) Thick units of dark, massive, volcanically derived siltstone crop out in several areas. These include minor interbedded greywacke and fine-grained conglomerate in one area, along with a number of thick lava flows. Such rocks were probably deposited from suspension in deeper basins.

(viii) Limestone is rarely present. It is found mostly as fairly small fragments mixed with volcaniclastic debris; at several localities it occurs as small autochthonous deposits which may contain volcanic debris. There is no evidence that large reef-shoal complexes were formed.

(ix) Petrographic examination shows that lava and vitric clasts in many volcanic greywackes and fine-grained volcanic conglomerates vary considerably in such things as size and proportion of phenocrysts, grainsize and the amount of glass in the groundmass, devitrification, alteration and oxidation of glass, and vesicularity. In many instances the variation is no more than is normally encountered in debris from a large eruption, while in some instances the similarity between clasts is so marked that they must have been derived from a single source.

(x) Lava flows are sporadically interbedded in the volcanics. Some are identified by probable pillow structures, and others by deformation of the sediments onto which they flowed; brecciation of some flows is apparent, and coarse angular conglomerates agglomerates and breccias which crop out in several areas may have resulted from minor transportation of similar debris. Lava interbedded with massive dark siltstones may have been erupted quietly in deep water, although many rocks identified petrographically as thick unfragmented lava flows may be intrusive into the conglomerates and greywackes in which they occur. Little evidence was obtained indicating the location of central vents; such vents may have been largely obliterated by phreatic eruptions.

(xi) Bedded volcanic conglomerates and greywackes in part of the Wide Bay area are made up of completely unsorted debris; lava flows in the vicinity may be subaerial, pointing to the emergence of a volcanic island.

MERAI VOLCANICS (new name)

The Merai Volcanics are an undifferentiated succession of moderately indurated volcaniclastic marine sedimentary rocks and subordinate lava flows of uppermost Oligocene to Lower Miocene (Tertiary "e" stage) age. The rock unit is exposed along the Merai River and in the Wide Bay - Open Bay Area, and is named from the Merai River (4°46'S, 152°15'E).

The Merai Volcanics resemble the Baining Volcanics, but are less strongly indurated, jointed and sheared. Fine-grained, massive or thick-bedded volcanic conglomerate is the predominant rock type, accompanied in most areas by volcanic greywacke, arenite or tuff, and, less commonly, siltstone. Lava flows are sporadically interbedded in the succession in some areas, and intermediate to basic hypabyssal intrusive rocks are widespread. Carbonate reef debris and microfossil remains are common in fine-grained detrital rocks in the Open Bay area, and rarely form thin beds of nearly pure bioclastic limestone. Thickness of the unit is not known but exceeds 700 m; dips are shallow.

In the middle Merai River the Volcanics crop out in two small areas, partly fault-bounded and partly unconformably overlain by subaerial tuffs, agglomerates and lavas flows of the Upper Miocene to Pliocene Sigule Volcanics. In the lowermost area the rock types are massive volcanic pebble, cobble and boulder conglomerates which consist of poorly sorted and unsorted, angular to subrounded clasts of fine-grained black, brown and grey-coloured porphyritic and aphanitic lava, with varying proportions of dark recrystallized matrix and, rarely, minor white zeolite cement. Subordinate greywacke and arenite are interbedded, and, at one locality, contain small lenses

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of partly recrystallized, impure red limestone with Tertiary e stage foraminifera. Further upstream finer-grained lithologies are more prominent, and the rocks are more strongly jointed and sheared; thin lava flows are sporadically interbedded, and dark intermediate to basic porphyries intrude the section. These are both penecontemporaneous intrusives related to the Merai Volcanics and younger intrusives related to the Sigule Volcanics.

Between Wide Bay and Open Bay, Merai Volcanics crop out extensively southwest of the Mumus Fault; their base is not exposed, and they are unconformably overlain by mostly calcareous shallow-water marine facies rocks of the Upper Miocene to Pliocene Sinewit Volcanics. Behind Matanakunei village in Open Bay, evidence from stream boulders indicates that a thin lens of Yalam limestone is interposed between the Merai and overlying Sinewit Volcanics. In the Wide Bay - Open Bay area fine-grained volcanic conglomerate and greywacke are the predominant lithologies, with some interbedded lava flows and fine-grained dark intrusives. The clastic rocks resemble those of the Merai River, but many contain reef and shoal debris and microfossil remains, some of which are poorly preserved, worn and broken; fine calcite is present in the matrix of most of these rocks, and calcite may also form a later cement. With increase in carbonate content, volcanic conglomerate grades into bioclastic limestone with volcanic fragments, and to thin beds of almost pure limestone in some instances. Foraminifera indicate a Tertiary stage age; in one sample derived Eocene foraminifera accompany the stage fauna.

Along the north side of Open Bay south of the Pondo River, Merai Volcanics underlie Yalam Limestone. Here the Volcanics consist of poorly to moderately indurated, thickly and some thinly bedded fine-grained black volcanic conglomerate, tuff and shaley siltstone, with subordinate interbedded lava flows and related dykes. The conglomerates mostly consist of angular red, brown and black lava fragments up to 5 cm across, in a soft brown or black lithic crystal tuff matrix. Rare limestone clasts and lenses and microfossil remains are present in some conglomerates, and a calcareous matrix

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or calcite cement with microfossil remains is common in many of the fine-grained clastic rocks. Foraminifera indicate a Tertiary 'e' stage age. Carbonaceous plant remains are preserved in some shaley siltstones. Several miles south of Pondo Plantation the Volcanics dip northwards at a shallow angle. At the base of a 30 m section, fine-grained volcanic conglomerate with erratic lava bombs up to 1 m across, grades upwards into a 6 m section of black crystal tuff. This is overlain by 12 m of shaley black calcareous siltstone, with a 15 to 30 cm band of crystal tuff near the base. This is overlain in turn by bedded, fine and coarse-grained tuff and fine-grained conglomerate. Joints are widely spaced and some mark displacements of up to 3 m; some are filled with zeolite or calcite veining.

South of Open Bay ~~behind~~ Baia village a thickness of more than 500 m of shallow dipping Merai Volcanics forms the coastal ranges. Southeast of Baia the Volcanics are moderately indurated and poorly jointed, and consist of massive or thick-bedded, fine-grained volcanic conglomerate, with minor arenite and siltstone, and rare interbedded lava flows, intruded by dolerite. The conglomerate is made up of fairly tightly packed subangular black, brown, red, grey and green lava fragments, mostly less than 6 cm across, set in minor green or grey matrix; some contain erratic subrounded lava boulders more than 1 m across. Rare limestone nodules and microfossil remains include some diagnostic Tertiary 'e' stage foraminifera. Boulders of brecciated and chalcedony - healed lava in the stream wash are probably derived from submarine lava flows interbedded in the conglomerate. Fine-grained grey volcanic conglomerate, with thick grey arenite and siltstone interbeds, and thin grey-brown mudstone bands, crop out along the coast west of Baia village. Calcite cement, calcareous matrix and microfossil remains are common in some arenites and siltstones. Rounded pebbles of reworked siltstone are present in some arenite and siltstone beds, and small boulders of arenite occur in fine-grained conglomerate.

Discussion

Micropalaeontological evidence indicates that deposition of the Merai Volcanics continued throughout the Tertiary e stage, and possibly into the lowermost part of the Tertiary f stage, in several areas (J.G. Binnekamp, pers. comm., 1970). Deposition was probably restricted to shallow seas marginal to islands of Baining Volcanics. Most volcanic debris was derived from contemporaneous vulcanism (possibly largely submarine), and some from erosion of the emergent land masses. Erosion of contemporaneous shoal and reef material is apparent in the Open Bay area, and carbonate debris is more common in the Merai Volcanics than in the Eocene Baining Volcanics. The Merai Volcanics resemble the marine volcaniclastic rocks of the New Hebrides (Jones, 1967) but are finer-grained and generally contain less reef and shoal debris.

Vulcanism was widespread in the Bismarck Archipelago in the Tertiary e-stage. Volcanics of this age are exposed elsewhere on New Britain (R.J. Ryburn, pers. comm., 1969) and on New Ireland (French, 1966; Hohnen, 1970). The e-stage Jaulu Volcanics on New Ireland are similar to the Merai Volcanics.

YALAM LIMESTONE (new name)

The Yalam Limestone is Middle and possibly Upper Miocene in age and consists of more than 1000 m of coarsely-bedded white biogenic limestone. This blankets the southern half of the North Baining Mountains in the western part of the Gazelle Peninsula. The name is taken from Yalam village (4°25'S, 151°45'E) where the limestone forms cliffs 750 m high which rise to a height of 1650 m above sea-level (Figs 13 and 14). The composite foraminiferal assemblage in the lowermost 300 m of the succession indicates a Tertiary lower f stage age (Middle Miocene); no age has been determined for the upper part of the succession in the Gazelle Peninsula, because of the absence of diagnostic foraminifera, but a similar limestone unit in western New Britain ranges through Middle Miocene to lowermost Upper Miocene (J.G. Binnekamp, pers. comm., 1970). The Yalam Limestone is equivalent to the Neogene Series of Noakes (1942) which was considered to range in age from Tertiary e stage to Upper Miocene. Reappraisal of faunal assemblages and resampling of some localities has shown that all of Noakes' Neogene Series is Middle Miocene (D.J. Belford, J.G. Binnekamp, pers. comm., 1969).

Yalam Limestone crops out over 600 sq km of the southern part of the North Baining Mountains. It forms a thick sheet which dips at a shallow angle to the west coast of the Peninsula from high cliffs on the north and east. Well developed karst topography characterises the elevated limestone surface (Fig. 15), except where deep erosion in the southern part of the outcrop area has exposed basal mudstones. North of this area, the limestone crops out along the North Baining coast from Lassul Bay eastward to Vunalama Plantation in Ataliklikun Bay. It is fault-bounded to the south, and dips northerly from the Baining Fault, from a maximum elevation of about 600 m on the ridge east of the Nambung River. It forms steep rugged hills with karst topography immediately east of Lassul Bay. South of Ataliklikun Bay, Yalam Limestone crops out in the undulating coastal hills west of the Vudal River, and forms small limestone knolls in the swamp country south of Vunapladig village. Basal sandstones and conglomerates are exposed a short distance to the east of Rangoulit village. Rembarr Range, the eastern promontory of Ataliklikun Bay, is an upfaulted northerly extension of the Limestone, with a thin veneer of Recent volcanic ash. Stream boulders behind Matanakunei village on Open Bay indicate a thin unit of Yalam Limestone in the Lakit Range, presumably interposed between Merai Volcanics and overlying Sinewit Volcanics. The limestone was not found *in situ* in the Lakit Range, and is not apparent on air-photographs. Southeast of Open Bay, a thick sheet of Yalam Limestone dips northwards on the northwest flank of the Kol-Mengen Mountain block, and is fault-bounded along the foothills south of the Sai River. Similar limestone crops out extensively elsewhere on the island of New Britain.

Figure 13. Cliff of Yalam Limestone west of Yalam village.

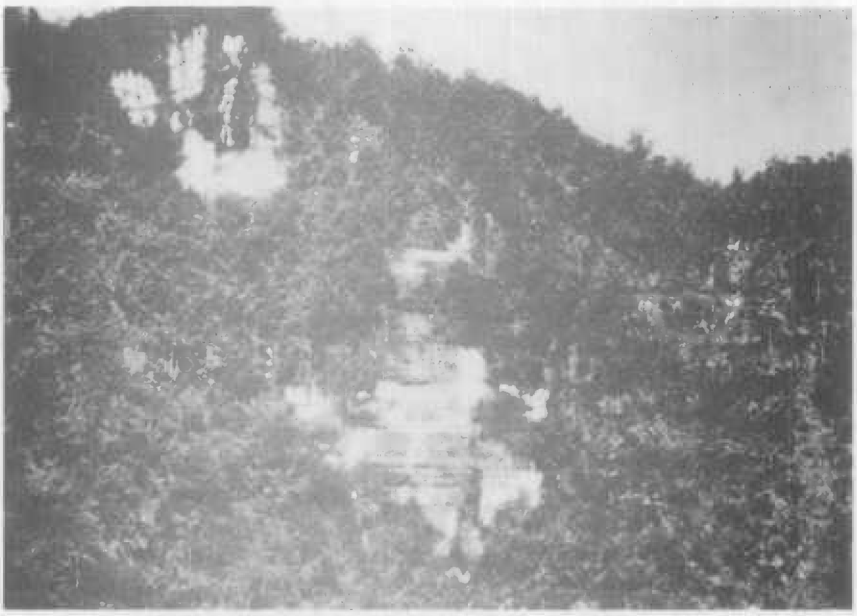

Figure 14. Detail of cliff of Yalam Limestone shows differential weathering of thick limestone beds.

Figure 15. Karst topography developed on the surface of the shallow-dipping Yalam Limestone in the North Baining Mountains.

Figure 16. Photomicrograph of calcareous sandstone from the base of the Yalam Limestone shows rounded plagioclase, quartz and lava fragments, and microfossil remains, in calcite cement. Crossed nicols.
53NG0601.

A vertical section of 970 m of Yalam Limestone was measured and sampled in the vicinity of Yalam village. The base of the section was in the gorge of the Batonga River below the village, and the top in the cliffs west of the village; a further 100 m thickness not sampled forms the highest peak in the North Baining Mountains, a short distance north of the measured section.

The Yalam Limestone is a remarkably uniform unit which shows little lateral or vertical variation over its area of outcrop, except for the local inclusion of basal mudstone, sandstone and conglomerate (Fig. 16). It is massive to thick-bedded, and is white, yellow-white and partly yellow-brown in colour. It is made up of medium- to fine-grained, hard bioclastic limestone, with thick interbeds of soft, clayey, easily-weathered biomicrite, and slightly harder, friable, chalky limestone, which predominates in some parts of the section. Cavities are common in coarser-grained units containing abundant algal, coral, bryozoan and molluscan remains, and in places the succession is partly recrystallized. Current bedding and related sedimentary structures are absent, although much of the detritus is well worn and obviously transported. The limestone is made up almost entirely of bioclastic debris, with a fine carbonate matrix or calcite cement; terrigenous material is present in only the basal units. Chemical analyses of 3 representative samples from the measured section shows $MgCO_3$ to be the main impurity in the limestone, ranging from about 1 to 3%; analyses by Broken Hill Proprietary Limited of drill core from Kilinwata Planation in Ataliklikun Bay, revealed patchy dolomitization of Yalam Limestone (W. Howell, pers. comm., 1969).

Basal units of the Yalam Limestone were deposited on an uneven surface. Rock types at the base include mudstone and, less commonly, calcareous sandstone and minor pebble conglomerate. Along the lower Pondo River soft grey and blue-grey, sparsely to abundantly fossiliferous mudstone is interbedded with limestone near the base of the Yalam Limestone; in places the mudstone is calcareous, grading into marl. Mudstone interbeds are mostly less than 3 m

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thick, but units up to 12 m thick have been recorded (Carter, 1962). Similar dark grey, fossiliferous mudstone crops out in the base of the Limestone east of Yalam village. Along the Toriu River below Malaseit village, 100 m of thickly-bedded, highly fossiliferous calcarenite and calcareous sandstone contains thin bands rich in magnetite, and displays sedimentary structures characteristic of very shallow water deposition; these rocks are stratigraphically located near the base of the Yalam Limestone. Petrographic examination of a calcareous sandstone shows it to consist of well-rounded grains of quartz and plagioclase, minor fine-grained volcanics (lava and greywacke), rare green hornblende, and abundant microfossil remains, set in abundant calcite cement. Tuffaceous material identified in some hand specimens is probably reworked lithic crystal tuff of the Merai Volcanics. In the hills east and southeast of Rangoulit village, calcareous sandstones and pebble conglomerates, with interbedded calcarenites and detrital reef-shoal limestone, form the base of the Yalam Limestone; the rocks strongly resemble those of the Toriu River. The source of the clastic fraction is erosion of Baining and Merai Volcanics, and plutonic rocks.

The Yalam Limestone is mostly shallow dipping, forming prominent dip slopes on which karst topography is well developed; steep dips have been recorded near faults. Widely spaced horizontal and vertical jointing has been noted, and this contributes to the cliff-forming habit of the limestone.

Discussion

Deposition of the Yalam Limestone began in lowermost Middle Miocene, and probably continued in some areas into the Upper Miocene. Except in basal units, terrigenous material is completely lacking, and this indicates the absence of nearby eroding land masses and lack of contemporaneous volcanism. The environment of deposition was mostly fairly shallow water, although the microfauna indicates that deeper basins developed locally in the later stages of deposition (J.D. Binnekamp, pers. comm., 1969). Individual limestone beds are mostly thick and far ranging, and thus reflect remarkably stable conditions of gradual subsidence throughout the Middle Miocene.

Throughout the Bismarck Archipelago and Solomon Islands the Tertiary lower f stage was a time of extensive limestone deposition, e.g. Manus Island, New Ireland, and New Britain. This contrasts with the vigorous Tertiary lower f stage vulcanism of the New Guinea mainland.

NENGMUKTA VOLCANICS (new name)

The Nengmukta Volcanics are bedded, tuffaceous marine sedimentary rocks, of probably lower Upper Miocene age. They are named for the Nengmukta River in the Central Baining Mountains ($4^{\circ}36'$S, $152^{\circ}03'$E) where they are exposed along several kilometres of the water course. They are the product of rapid accumulation of fine andesitic and dacitic pyroclastic and epiclastic debris in a shallow marine basin.

The succession consists of moderately indurated, thinly bedded, grey tuffaceous sandstone and siltstone (Fig. 17), with thick interbeds of easily weathered, light-coloured, fine-grained volcanic conglomerate and minor breccia. Many of the thinly bedded rocks are carbonaceous, and they commonly display graded bedding and mesoscopic soft sediment deformation structures; they are calcareous in part, with small nodules and lenses of fine-grained, unfossiliferous black limestone in at least one part of the section. Genetically related dacite and andesite porphyries intrude the sedimentary pile, and the Baining Volcanics and plutonic rocks in the surrounding area; younger intermediate and ?basic hypabyssal rocks intrude the Nengmukta Volcanics.

Although largely fault-bounded, the Nengmukta Volcancis are regularly bedded and little deformed. They unconformably overlie the Baining Volcanics, strike generally about 040 degrees magnetic, and dip northwest at 15 to 30 degrees. They are unconformably overlain along part of their southern margin (at the foot of Mt. Sinewit) by soft, bedded, pumiceous fluviatile sedimentary rocks probably belonging to the Quaternary Riet Beds. Topography and regular bedding indicate a probable thickness in excess of 300 m. No fossiliferous strata have been found.

Petrographic examination of the Nengmukta Volcanics shows them to be fairly fine-grained volcaniclastic sedimentary rocks; the predominant lithologies are fine-grained conglomerate and some breccia (characterized by extreme angularity of fragments), and greywacke and arenite (the latter containing less than 15% matrix), interbedded with siltstone and some mudstone. Because much of the debris is pyroclastic rather than epiclastic in origin, and evidence of sorting and major transport is lacking, many of the rocks may be classified as dacitic and andesitic lithic and vitric crystal tuffs. Lithic fragments are angular to subrounded and are mostly glassy lavas, made up of a few small phenocrysts and microphenocrysts of plagioclase and, less commonly, quartz, in a green-brown glass. The glass may be chloritized or variably devitrified to a quartzo-feldspathic groundmass; vesicles may be present, and some fragments are scoriaceous. Vitric fragments are variably vesiculated, devitrified and altered; altered glass shards are present in the matrix of several sections. Pumice fragments were identified in several sections. Crystal grains and fragments are largely plagioclase (variably sericitized, kaolinized, zeolitized, chloritized or epidotized), and some quartz; they occur in all rocks but are most abundant in those of finer grainsize. The matrix is green-brown or colourless and is largely isotropic; it consists of chlorite, indeterminate clay minerals and zeolite, with fine calcite and opaque carbonaceous material in some sections.

In some sections compaction of the sediment while poorly consolidated has caused a "flow foliation" in the matrix, and this may be accentuated by the recrystallization of optically oriented birefringent illite or chlorite in flared out streaks and patches. Small dark spherulites of isotropic ?clay minerals have grown with recrystallization of one silty mudstone. Reaction between matrix and fragments is extreme in some sections. Bedding is defined in thin section by variation in grainsize and density of packing, and may be accentuated by matrix "flow", and by carbonaceous bands. In some rocks which apparently bedded in hand specimen, the only evidence of bedding seen in thin section is very faint carbonaceous banding.

Figure 17. Thin-bedded, fine-grained Nengmukta Volcanics exposed along the Nengmukta River.

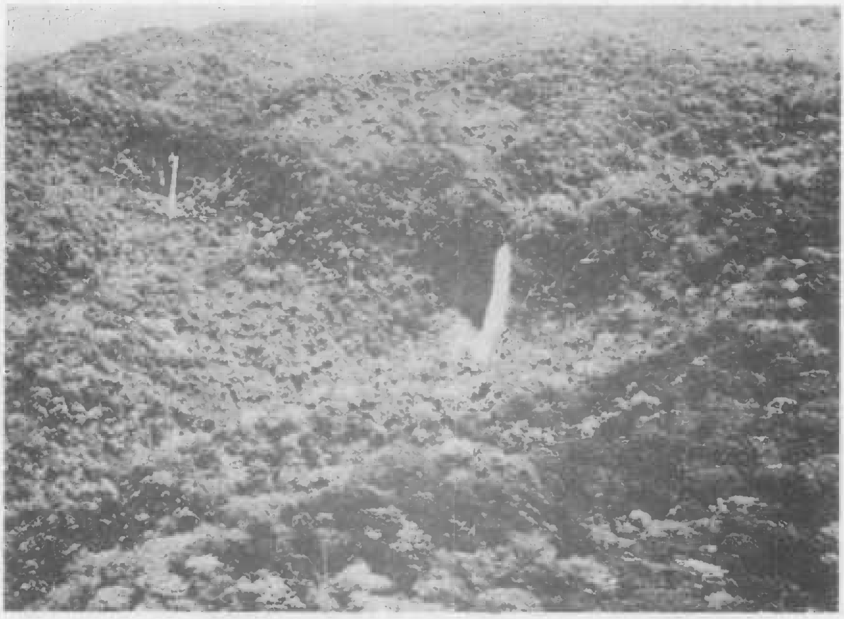

Figure 18. Dip-slopes of Sinewit Volcanics southwest of Mt. Sinewit.

The Nengmukta Volcanics accumulated rapidly from emergent and near-surface submarine eruptive centers. Pyroclastic and epiclastic debris was transported into a nearby basin by turbidity currents and submarine pyroclastic flows, triggered probably by both explosive eruptions and gravity collapse of material from the unstable submerged flanks of the volcanoes. Primary settling of ash showers may account for some graded bedding.

The Nengmukta Volcanics are younger than the Middle Miocene Yalam Limestone and older than the Upper Miocene to Pliocene Sinewit and Sigule Volcanics. Age is probably lowermost Upper Miocene. Sparse field evidence suggests a thin unit of Nengmukta Volcanics underlying subaerial ash-flow tuffs and lava flows in the base of the Sinewit Volcanics, in the headwaters of the Rapmetka and Mevlo Rivers. It is probable that the Nengmukta Volcanics represent the initial phase of renewed volcanism in the Upper Miocene following the period of quiescence marked by the Middle Miocene Yalam Limestone.

SINEWIT VOLCANICS (new name)

The Sinewit Volcanics are an Upper Miocene to Pliocene sequence of poorly consolidated marine and fluviatile fine-grained tuffaceous sediments. Basal lavas and tuffs are here named the Mevlo Member of the Sinewit Volcanics. The two rock units are named from Mount Sinewit (1650 m elevation; 4°38'S, 151°58'E) and the nearby Mevlo River, respectively. Total thickness exceeds 500 m. The Sinewit Volcanics are time equivalents of the Sigule Volcanics which are exposed further east.

South of Mt. Sinewit the Volcanics form a prominent scarp along the northwest side of the Mevlo River, backed by deeply incised dip-slopes which slope gently westwards towards the Toriu River (Fig. 18). Farther south they extend into Wide Bay and Open Bay, unconformably overlying Baining Volcanics and Merai Volcanics; southwest of Wide Bay they are fault-bounded along northwest-trending faults on the north flank of the Kol-Mengen mountain block. Behind Matanakunei village in Open Bay, the volcanics are blanketed by Pliocene Lakit Limestone. Northwest of Mt. Sinewit they extend across the headwaters of the Keravat and Vudal Rivers, into the Toriu River headwaters near Malaseit village. West and north of the Toriu River the Volcanics are faulted against and unconformably overlie Yalam Limestone. Poorly consolidated, soft, clayey tuff(?) in the vicinity of Rangculit village (west of the lower Vudal River) is probably part of the Sinewit Volcanics. The Volcanics are overlain by fluviatile sandstones and conglomerates of the Quaternary Riet Beds in the Keravat River headwaters and at the foot of the northeastern scarp of Mt. Sinewit, where faulting and some uplift of the Volcanics preceeded deposition of the Riet Beds.

The Sinewit Volcanics are composed of soft, light-coloured, friable, unjointed, unbedded or thickly bedded marine and some fluviatile tuffaceous sandstone, siltstone and mudstone (Fig. 19). Minor pebbly sandstone and thin pebble conglomerate interbeds occur in most areas, and rare coarser cobble and boulder conglomerate is interbedded in the succession in the Wide Bay area. Calcareous tuffaceous sandstone with molluscan remains are common in the marine facies in the Wide Bay-Open Bay area, with interbedded calcareous siltstone and mudstone (marl), and minor tuffaceous calcarenite, chalky limestone and reef-shoal limestone. Tuffaceous limestone nodules and lenses are also present in the volcanics in the headwaters of the Vudal and Keravat Rivers. Thin lignite bands are reported from the Sinewit Volcanics immediately north of the lower Toriu River (Stanley, 1922a). Fine-grained limonitic tuff containing fairly abundant small magnetite grains, and displaying prominent, dark, iron-rich pisolites was found by the writer west of the Middle Toriu River. These rocks were probably formed in a deltaic environment.

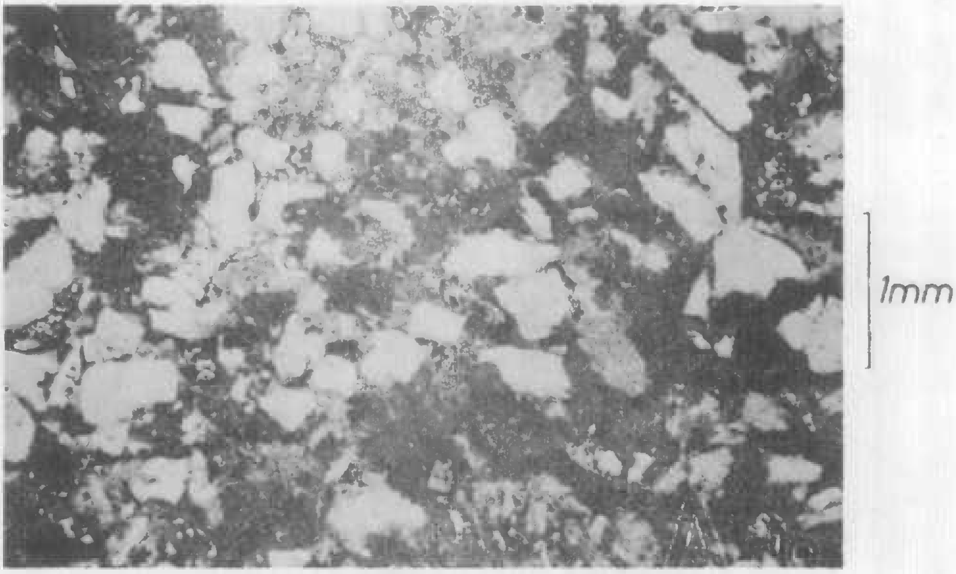

Figure 19. Sinewit Volcanics. Tuffaceous sandstone consists of plagioclase, lava and glass fragments in an indeterminate clay matrix. Plane polarized light. 53NG0384.

Figure 20. Sigule Volcanics. Rounded andesite cobbles in a crystal tuff matrix.

The fine-grained clastic fraction of the Sinewit Volcanics is pyroclastic in origin, comprising angular and subangular fine-grained lava and glass fragments, very abundant plagioclase grains and lesser hornblende and lamprobolite, some augite and biotite, and some quartz, ?orthoclase and magnetite. Pumice is very common in the Wide Bay-Open Bay area where it is the primary constituent of some rocks. Larger fragments are epiclastic, comprising subangular to well rounded pebbles, cobbles and some boulders of generally porphyritic andesite lava.

All clastic material was derived from synchronous volcanic activity, probably centred east of Mt. Sinewit and partly within the area of outcrop of the Sigule Volcanics. There is no evidence of erosion of emergent blocks of older rocks during the deposition of the Sinewit Volcanics, except for the presence of reworked Middle Miocene fauna in some limestones in the Wide Bay-Open Bay area.

In the Mt. Sinewit area soft, massive, fine-grained tuffaceous sandstone at the base of the east-facing scarp in the Mevlo River headwaters, grades upwards into tuffaceous siltstone and mudstone. In the lower part of the section, thin lenses of pebbly sandstone and fine-grained pebble conglomerate are interbedded in the massive sandstone; the pebbles are dacite and some andesite, mostly fairly well rounded but some angular. Thin interbeds of mudstone show soft sediment deformation and fine to fairly coarse bands rich in magnetite exhibit current bedding. These rocks are fluviatile. On the other hand boulders of tuffaceous siltstone shedding from higher in the cliff section contain gastropod and pelecypod remains and algae and are thus marine. Petrographic examination of a fine-grained tuffaceous sandstone from Mt. Sinewit shows it to be made up of tightly packed, angular and subangular fragments of plagioclase (some untwinned or poorly twinned, some zoned), fine-grained cloudy feldspathic and quartzofeldspathic lava, glass and divitrified glass, strongly pleochroic green-brown to dark red-brown lamprobolite, rare strongly pleochroic red-brown biotite, and some quartz and ?orthoclase. The matrix is minor and consists of dark, indeterminate, isotropic clay minerals.

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Shallow-dipping Sinewit Volcanics form the divide between Wide Bay and Open Bay near Awungi village. The succession is predominantly soft, grey-white, fine-grained calcareous tuffaceous sandstone containing sparse molluscan remains, with some interbedded calcareous siltstone and mudstone, and minor pebbly sandstone, pebble, cobble and (rarely) boulder conglomerate. Minor tuffaceous calcarenite and limestone are present in highly calcareous parts of the section, and pumice is a major constituent of some units. In the lowest part of the section examined west of Awungi, very soft, grey, calcareous tuffaceous siltstone with slumped mudstone interbeds is overlain by chalky white limestone, and partly tuffaceous calcarenite and fine-grained grey calcareous tuffaceous sandstone. The calcarenite-sandstone sequence includes hard, crystalline limestone lenses with algal and coral fragments, and Upper Miocene foraminifera (Belford, 1968). Above the thick calcareous unit is several hundred feet of thickly-bedded, very soft, fine-grained pumiceous conglomerate, made up of pumice fragments, hornblende, plagioclase, rare biotite and small lava fragments in a clayey pumiceous matrix; the pumice fragments are generally less than 1 cm across and include scattered hornblende, plagioclase and rare biotite grains. Some beds consist almost entirely of pumice. The pumiceous conglomerate is capped by a moderately resistant unit of agglomerate comprising angular fragments up to 8 cm across of dark, porphyritic lava and some pumice, set in a soft, dark matrix containing plagioclase and augite crystals. The agglomerate is overlain by clayey tuffaceous siltstone; some of the siltstone is regularly bedded with beds 15 cm thick or more. Grey-brown tuffaceous sandstone and brown mudstone are interbedded in the siltstone, and slump deformation is evident in parts of the section; the rocks vary from slightly to very highly calcareous, and fossil fragments from absent to abundant. Higher in the section a bed about a metre thick contains rounded boulders of porphyritic lava up to 50 cm across. Clayey fossiliferous siltstone above this contains rare erratic lava boulders. The traverse was terminated at this point; scree from higher on the slopes includes tuffaceous sandstone and siltstone, pumiceous rocks, and lava boulders rarely up to 1½ m across. Petrographic examination of several lava boulders showed them to be augite andesite with phenocrysts of calcic andesine (some sodic labradorite), augite and rare hornblende and biotite, in a groundmass including microphenocrysts of plagioclase and granular augite and opaque oxide, set in cryptofeldsite (devitrified glass) or interstitial feldspar.

West of Awungi, towards the Toriu River mouth and north of the lower Toriu River, outcrops of Sinewit Volcanics include fine-grained, calcareous tuffaceous rocks, chalky white limestone (?marl), and pumiceous rocks. The latter consist of pumice fragments up to 2 cm across in a pumice dust matrix; both fragments and matrix contain minor augite, biotite and plagioclase. Scree and creek wash includes hard white reef-shoal limestone of Pliocene-Pleistocene age, fine-grained, grey-brown tuffaceous calcarenite, and pebbles, cobbles and boulders of porphyritic lava. In this area Stanley (1922a) reported soft, cross-bedded sandstone, with some interbedded harder calcareous sandstone containing small limestone nodules, several thin beds of nearly pure limestone, and thick interbeds of cross-bedded calcareous mudstone. Many of the rocks contain carbonized plant remains. Thin bands of lignite were reported by Stanley (ibid.) from north of the lower Toriu River, in the low-lying, thickly forested area between the Toriu River and the east arm of the Sambei River; the lignite is interbedded in a predominantly mudstone succession. Farther north, boulders of soft, fine-grained, light brown tuff with scattered small, dark-brown pisolites less than 1 cm across, were found in a small western tributary of the Toriu River. The tuff boulders are made up of fine translucent brown to black fragments (some are recognisable fine-grained lava and glass, many are highly oxidised and some are opaque oxide), a few augite and zeolitised plagioclase grains, and abundant interstitial zeolite. Pisolites in hand specimen are marked in thin section by a slightly denser packing of fragments and, in reflected light, by dark brown instead of light brown oxide staining; the rock may have formed by accumulation of air-fall tuff in a stagnant swamp environment.

South and east of Awungi, in Mumus Creek and the Bera River the succession comprises shallow dipping, massive to thin-bedded, white, grey and yellow, soft tuffaceous mudstone, siltstone and fine to coarse-grained sandstone; it is calcareous and fossiliferous in part, and includes a thick bed of dense white limestone in Mumus Creek. River gravel in the Bera River contains silicified wood. Ages determined by Belford (1968) are Pliocene-Pleistocene in the Bera River, and uppermost Miocene or early Pliocene in Mumus Creek. East of the Bera River, in the Wulwut River, similar rocks contain thin pebble bands (largely porphyritic andesite lava); at one locality fine-grained tuffaceous sandstone with pebble bands contains thin carbonaceous bands. Part of the succession in this area appears to be fluviatile. These outcrops have been briefly described by Noakes (1942).

Northwest of Mt. Sinewit in the Vudal and Keravat Rivers headwaters, the volcanics comprise soft, very fine to coarse-grained tuffaceous sandstone, and some fine-grained pebble conglomerate; minor tuffaceous limestone stream boulders are Pliocene or younger (J.G. Binnekamp, pers. comm., 1969). At one locality there has been some displacement by movement on joints probably in response to nearby major fault movements. Petrographic examination of a light grey, friable, fine-grained tuffaceous sandstone shows it to be made up of tightly packed, angular to subangular fragments of very fine-grained plagioclase lava and cloudy glass, abundant plagioclase grains and fragments (some poorly twinned), some quartz and ?orthoclase, very pale green to green, and brown to green-brown hornblende (minor lamprobolite), some augite, very minor light to dark red-brown biotite, and opaque oxide, in minor indeterminate, isotropic clay matrix.

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Mevlo Member (new name)

Scattered field evidence points to a fairly thick unit of lava flows and tuffs forming the base of the Sinewit Volcanics in the northern part of their outcrop area; these rocks are here named the Mevlo Member of the Sinewit Volcanics. Ash flow tuffs of probable dacitic and andesitic composition, with interbedded pumiceous semi-welded tuffs, crop out at the foot of the Mt. Sinewit escarpment in the Mevlo River headwaters and in the Rapmetka River headwaters a few miles to the northeast. Devitrified glassy lavas of dacitic and andesitic composition are interbedded in the succession, along with a number of flows of coarser-grained holocrystalline augite andesite. Northwest of Mt. Sinewit, augite andesite lavas containing biotite and some hypersthene and olivine occupy the base of the volcanics. Some devitrified glassy dacite and possibly andesite lavas are interbedded or intercalated in the section close to Mt. Sinewit. The base of the volcanics at the foot of the northeastern flank of Mt. Sinewit rests on or is intruded by a biotite-augite diorite pluton.

In outcrop the ash flow tuffs are white, grey or brown rocks, generally thinly "bedded", exhibiting fiamme texture and flow around rare phenocrysts and xenoliths. Petrographic examination shows that the original texture of the rock has been obliterated by recrystallization which is characterized by the growth of small quartzofeldspathic spherulites and less common thin bands and lenses. Unmixing of quartz and feldspar may have taken place, and in some cases subsequent kaolinisation and sericitization of feldspars has also produced small patches of quartz. Bedding visible in one hand specimen shows in thin section as bands and lenses of recrystallized, finely intergrown quartz and feldspar, in a darker indeterminate ?glass with quartzofeldspathic spherulites; thin trails of opaque material parallel the bands, "flowing" through spherulites and around rare plagioclase phenocrysts. In another section, completely recrystallized to mutually interfering spherulites, dark bands in hand specimen are marked in thin section by more advanced kaolinisation and sericitisation of feldspar. Individual spherulites may cross band boundaries.

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Rocks identified as vitric lavas of probable dacitic and andesitic composition are light to dark-coloured, sparsely porphyritic glassy rocks mostly exhibiting a fluidal flow foliation. Autobrecciated flows occur at several localities. In thin section they are seen to be largely recrystallized indeterminate quartzofeldspathic rocks resembling the ash flow tuffs.

Ash flow tuffs in two outliers in the Rapmetka River headwaters are interbedded and underlain by lithic vitric crystal tuffs of dacitic and andesitic composition; tuffs at the base of the southern outlier may be partly marine, and some resemble the Nengmukta Volcanics. Autobrecciated vitric dacite or andesite lava flows are present in the northern outlier.

Streams which cut through the base of the Sinewit Volcanics northwest of Mt. Sinewit contain abundant boulders of fairly coarsely porphyritic andesite. These boulders probably indicate the presence of a fairly extensive basal unit of subaerial intermediate lava flows. Close to Mt. Sinewit they are intercalated with vitric lava flows and related tuffs. Petrographic examination of the porphyritic lavas show them to be biotite-augite andesites, comprising phenocrysts of clear plagioclase, lesser pale green or green-brown augite, and minor pale to dark red-brown biotite with oxidised rims, generally set in a fine-grained holocrystalline groundmass. Minor olivine is present in several sections, and in several others hypersthene. (In one section several of the rare hypersthene grains are rimmed by augite and in another section abundant lamprobolite phenocrysts accompany minor augite.) The plagioclase phenocrysts are mostly less than 3 mm long (rarely up to 6 mm), are well twinned to poorly twinned (An_{40} in three sections), poorly zoned, and many have marginal zones of fine inclusions of glass (rarely augite). Some grains are marginally resorbed. In one section biotite with oxidized rims is marginally altered to highly pleochroic pale yellow-green to dark apple green chlorite; the chlorite also occurs as pseudomorphs after small pyroxene or amphibole phenocrysts, and interstitially in the groundmass. In a number of sections, rare large composite

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xenocrysts and xenoliths are obviously derived from a slowly cooling plutonic source. The composite xenocrysts consist of plagioclase and biotite, or augite and biotite; one 6 mm xenolith consists of plagioclase and augite with a $2\frac{1}{2}$ mm long grain of partly sieved biotite with an oxidized margin. The groundmass of the biotite-augite andesites is generally holocrystalline, comprising subhedral plagioclase laths in interstitial feldspar and chlorite, with accessory opaque oxide and rare apatite. In one lava the groundmass is cryptofeldsitic with fine opaque oxide. In another it comprises microphenocrysts of plagioclase and augite, and fine granular augite and opaque oxide, in a brown glass. In several sections the groundmass contains small patches and radial aggregates of zeolite (colourless, almost isotropic, marked 90° cleavage).

At the foot of the north-eastern scarp of Mt. Sinewit, lavas at the base of the volcanics overlie or are intruded by a medium- to coarse-grained biotite-augite diorite, comprising 80% plagioclase, 10 to 15% augite and biotite, and 5 to 10% interstitial cloudy feldspar and quartz, some calcite, rare fluorite and accessory apatite. The plagioclase forms anhedral to euhedral grains up to 7 mm long, and is poorly to well twinned; composition is An_{46-54} from a number of albite twin extinction measurements. The grains are poorly zoned but with a thin margin of sodic plagioclase, and in some instances extinction is patchy. Pale green augite forms grains up to 4 mm long which are mostly fresh and unaltered. Biotite is pale to dark red-brown, and is a relict mineral with rare associated pale green hornblende; it is largely altered to finely divided green to green-brown biotite and some colourless fibrous chlorite. Masses of finely divided alteration product make up about half the ferromagnesian portion of the rock, probably replacing biotite. A few opaque oxide grains are associated with the ferromagnesian minerals. Minor myrmekitic intergrowth between interstitial quartz and feldspar is present, and some calcite contains masses of fine needles. Elsewhere in the section very dense masses of fine needles form an almost isotropic mass containing small "sheaths" with parallel extinction. Minor

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fluorite occurs generally in cracks in quartz, and some is packed with fine needles. Further fieldwork is required to establish the relationship between the pluton and lavas at the base of the Sinewit Volcanics. Porphyritic augite diorite cropping out 6 km southeast of Mt. Sinewit consists of abundant cognate xenocrysts of plagioclase and some augite, and augite diorite xenoliths, set in finer plagioclase, some augite, rare hypersthene, abundant interstitial chlorite and minor zeolite; the porphyritic intrusion strongly resembles lavas of the Mevlo Member.

Discussion

In the Rapmetka and Mevlo headwaters, Mevlo Member ash flow and semi-welded tuff and vitric lava flows overlie a thin unit of sedimentary rocks which resemble Nengmukta Volcanics. Possibly the Mevlo Member volcanics are products of the final stages of eruption of the Nengmukta Volcanics, and dacitic porphyries which intrude the Nengmukta Volcanics may be feeders for the Mevlo Member volcanics. A short distance to the west and northwest subaerial biotite-augite andesite lavas were erupted; these interfingered with the slightly more acid volcanics in the vicinity of Mt. Sinewit, and were possibly related to the emplacement of the biotite-augite diorite pluton exposed at the base of Mt. Sinewit.

After a relatively short period eruptive activity ceased in the Mt. Sinewit area. At the same time, eruptive activity had probably begun in an area about 25 to 30 km east of Mt. Sinewit; this activity continued on into the Pliocene and gave rise to the Singule Volcanics. The intervening area and that presently occupied by much of the North Baining Mountains were subdued emergent areas, surrounded for the most part by shallow seas. The continuing volcanicsm in the east supplied fine ash, which was deposited as fluviatile tuffaceous sedimentary rocks in the Mt. Sinewit area, to the south, and on the southeast flank of the low island of Yalam Limestone to the west, and as marine tuffaceous deposits in the intervening shallow seas. Gradual subsidence and eventual submergence

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in the Mt. Sinewit area permitted the accumulation of more than 500 m of tuffaceous sediments grading from fluviatile in the lower part to marine at the top.

The source of pumice for the thick pumiceous beds in the Wide Bay-Open Bay area is unknown, but was presumably located with the other eruptive centres t o the northwest.

SIGULE VOLCANICS (new name)

The Sigule Volcanics are poorly jointed, thick-bedded, subaerial pyroclastic rocks and lava flows of andesitic and basaltic composition, with intercalated poorly consolidated tuffaceous marine sedimentary rocks. The latter contain Upper Miocene and Pliocene foraminifera. The Sigule Volcanics form low ranges of hills separating the Kavavas River from the east coast of the Gazelle Peninsula, and crop out southwards along the coast to Eber Bay. They are named for their continuous exposure along the Sigule River (4°35'S, 152°14'E).

The Sigule Volcanics are unconformably overlain in the north (along the Warangoi River) by Recent pumiceous ash of the Rabaul volcanics. To the west in the Kavavas River they are faulted against the Pleistocene to Recent Riet Beds; further south they are faulted against Baining Volcanics along the Baining Fault. A thin veneer of raised Pleistocene coral limestone unconformably blankets the Volcanics north of Simbum village, extending eastwards to the coast. Faulted inliers of Baining Volcanics are exposed northeast and southeast of Marambu village, and partly fault-bounded exposures of Merai Volcanics underlie the Sigule Volcanics in the Merai River.

The Sigule Volcanics are shallow dipping on a regional scale, but are strongly faulted, and dips vary to vertical in rotated fault blocks. Thickness probably exceeds 500 m. The Sigule Volcanics are equivalent in age to the Sinewit Volcanics. Many of the marine tuffaceous rocks of the two units are very similar and probably have a common source area within the present area of outcrop of the Sigule Volcanics.

Thick-bedded subaerial pyroclastic rocks and interbedded lava flows predominate over intercalated marine tuffaceous sedimentary rocks. The subaerial pyroclastic rocks consist of basaltic and andesitic cobble and boulder agglomerate, dark, friable ash fall tuff, and derived fluviatile siltstones sandstones and conglomerates. The tuffaceous rocks are mostly composed of lithic (haematitic red lava), vitric and crystal (plagioclase, augite and other ferromagnesian minerals, rare quartz) fragments, and pumice is recognisable in some outcrops; soft tuff forms the matrix of most agglomerates.

Andesite and basalt lava flows up to 6 m thick are interbedded with the pyroclastic rocks. Feeder dykes and sills to the flows intrude the volcanic pile in some areas. The andesite lavas are mostly fairly coarsely porphyritic, with large translucent brown or white plagioclase phenocrysts in a light coloured (red if oxidised) groundmass. Some lavas have irregular vesicles and amygdales with calcite and zeolite filling. The lavas are augite, hypersthene and lamprobolite andesites, with large plagioclase phenocrysts, fewer smaller phenocrysts of augite, hypersthene (with a wide haematised rim) or lamprobilite, in a groundmass of plagioclase and cryptofeldspar with accessory opaque oxide. The plagioclase phenocrysts are well zoned; many contain a marginal zone of inclusions and some show zonal alteration. Ferromagnesian phenocrysts in some thin sections include chlorite/serpentine pseudomorphs after probable hornblende, and rare brown to red-brown biotite. The groundmass is pilotaxitic or oxidised (haematite stained), and may contain minor augite, lamprobolite, chlorite/serpentine, interstitial glass or corroded ?K-feldspar. Andesites are most common in the Kavavas River headwaters.

The basalt lavas are fine-grained black rocks, some with small phenocrysts, and some highly vesicular (scoriaceous); blocky lava flows (aa) were noted at several localities. Petrographic examination shows them to have an essential composition of plagioclase and smaller augite grains in a groundmass of feldspar, granular augite and opaque oxide. Olivine is present in one section, in which it largely altered to highly birefringent yellow ?serpentine and marginal iddingsite. The groundmass is commonly glassy with plagioclase (some augite) microlites. Vesicles are present in some sections, and may be filled with calcite or zeolite.

Intermittent inundation of the area is evidenced by the intercalation of thick units of soft, light-coloured, massive or thick-bedded tuffaceous marine mudstone, siltstone, sandstone and some fine-grained conglomerate. Pumice is recognizable in some rocks along with the lithic, vitric and crystal fragments which commonly form the clastic fraction. Indeterminate, isotropic, non-calcareous mud generally forms the matrix. Molluscan remains are distributed sparsely throughout, with the sporadic development of strata rich in well preserved gastropod or pelecypod shells (e.g. oyster beds, and beds of conispiral gastropods), ostracods, echinoid spines, algae and colonial (including branching) corals. Limestone development in the marine facies of the Sigule Volcanics is rare. Upper Miocene coral limestone with a base of reworked material is draped over basic agglomerate in the vicinity of a damsite investigated in the Warangoi River (Read, 1968), and thin chalky limestone lenses are interbedded in a succession of fine to coarse-grained tuffaceous sandstone, calcarenite, and fine to medium-grained volcanic conglomerate in the Lat River.

A medium-grained pyroxene dolerite sill intrudes shallow-dipping bedded agglomerate, tuff and lava flows in the Lat River near the east coast. The sill was not systematically sampled but thin section examination of a number of random samples shows it to consist of leucocratic, slightly porphyritic pyroxene dolerite, made up of labradorite and 15 to 30% pyroxene; accessory opaque oxide is present with minor quartz in several sections. Pale green to pale pink hypersthene generally predominates over very pale green augite (some cloudy); both may be extensively altered to pale green, highly birefingent ?mica (2V very low, optically negative, largely parallel extinction). Grainsize is generally less than 1 mm, but varies up to 2 mm. In one section of a lighter-coloured coarser-grained dolerite grainsize varies up to 3 mm and minor kaolinised orthoclase (some micrographic intergrowth with quartz) and rare pyrite, apatite, calcite and red-brown to colourless biotite are present.

LAKIT LIMESTONE (new name)

The Lakit Limestone is a subhorizontal unit more than 200 metres thick of soft, white bioclastic limestone which blankets the southern part of the Lakit Range, behind Matanakunei village in Open Bay. It is named from the Lakit Range and is best exposed in a recent landslide on its northeastern boundary (4°49'S, 151°47'E). The base of the limestone was not examined by the writer, but field relationships suggest that it overlies the Upper Miocene to Pliocene Sinewit Volcanics with a slight angular unconformity. Foraminifera indicate a Pliocene or slightly younger age.

Lakit Limestone crops out over an area of 40 square kilometres, and forms the highest point in the Lakit Ranges, about 845 m above sea-level. Karst topography characterises the undulating limestone surface, which dips northwestwards at a shallow angle; steep slopes or cliffs bound the unit, except on the northwest side.

Brief examination of part of the landslide section shows the limestone to be massive to thick-bedded, soft, white reef-shoal limestone, composed of poorly consolidated algal, coral, bryozoan and some molluscan debris, in a soft clayey calcareous matrix with finely comminuted organic remains, including planktonic and benthonic foraminifera. Calcite cement is present, and vugs and cavities are common. Terrigenous material is rare.

The Lakit Limestone is correlated with the highly calcareous Sai Beds which crop out 15 km to the south, in the foothills south of the Sai River.

SAI BEDS (new name)

The Sai Beds are shallow dipping, soft calcareous mudstones or siltstones, with limestone lenses and interbeds, which form low hills south of the lower part of the Sai River, in Open Bay. They are named from the Sai River ($5^{o}00'S$, $151^{o}40'E$). Thickness exceeds 150 m. Foraminifera indicate a Pliocene or slightly younger age.

The Sai Beds crop out over an area of about 25 sq. km in the middle reaches of the Mavulu River, extending northeastward into the Sai River drainage system. In the south they are faulted against Yalam Limestone along the northern margin of the Kol-Mengen mountain block, and in the north they are overlain by Quaternary gravels; remnant gravel beds on many hill-tops indicate recent elevation of the Sai Beds. Orientation of the Sai Beds is variable, but dips are mostly shallow; widely spaced horizontal and vertical joints have been noted in several outcrops.

Because of poor outcrop it is not possible to establish a stratigraphic succession within the Sai Beds. The unit consists of very soft, rarely bedded, grey marine mudstone, calcareous mudstone and marl, and yellow-brown and white chalky or clayey argillaceous limestone, all containing scattered to abundant thin-shelled molluscan remains, with uncommon lenses and interbeds of hard, white coralline or bioclastic limestone. Evidence of bedding is almost completely absent from the fine-grained sedimentary rocks, and many units exceed 15 metres in thickness. Sandy interbeds up to $\frac{1}{2}$ cm thick are present in one mudstone outcrop and exhibit fine asymmetrical ripple marks. The coarser clastic debris is deeply weathered, but looks tuffaceous. Hard limestone lenses 15 cm to 25 cm thick occur within calcareous mudstone and marl in one area; the limestone consists of coral and bioclastic debris and isolated colonial corals up to 1 metre across. In the same area a 15 m thick unit of white bioclastic limestone with thin, yellow, clayey interbeds forms a narrow gorge, and further upstream 5 m of thin-bedded, fine-grained limestone with yellowish clayey interbeds is exposed.

The Sai Beds are probably a lateral variation of the Lakit Limestone; it is possible that the mudstones are tuffaceous and that the Sai Beds are laterally equivalent to the upper part of the Sinewit Volcanics, and are thus slightly older than the Lakit Limestone.

PLEISTOCENE REEF LIMESTONE

A raised Pleistocene reef complex crops out along the south and east coast of the Gazelle Peninsula, from the Mevlo River in Wide Bay to Cape Gazelle, and forms most of the Duke of York Islands, 15 km north-northeast of Cape Gazelle. Minor raised Pleistocene coral crops out along the north coast and the northern part of the west coast of the Peninsula.

The Duke of York Islands were not examined by the writer, except for a single landing on Makada Island, at the northwest corner of the group. They were previously thought to be composed entirely of raised Pleistocene reef limestone, but brief examination showed the western end of Makada Island to comprise plutonic rocks draped with Pleistocene coral which forms a hill about 100 m high (the highest point on the Islands). It is probable that eroded plutonic rocks intruding Baining Volcanics form the basement of the raised coral reef which makes up the rest of the islands; basement may be exposed at the northern end of Duke of York Island, adjacent to Makada Island. The Credner Islands, 8 km southwest of the Duke of York Islands, are two small, low-lying islands which are also raised Pleistocene reefs.

On the northeast coast of the Gazelle Peninsula, raised reef limestone forms low cliffs extending from the mouth of the Warangoi River north to Cape Gazelle; maximum thickness of the limestone is exposed in Kabanga Bay where it exceeds 150 metres. The limestone is white and yellow-brown reef coral and fairly coarse bioclastic debris, with a soft, clayey matrix and some calcite cement, containing very common vugs and cavities. A short distance inland it is overlain by ash from the Rabaul volcanic centre. The Pleistocene age of this limestone was confirmed by the Commonwealth Palaeontologist (Noakes, 1942).

South of the lower Warangoi River a thin veneer of Pleistocene reef-shoal limestone unconformably blankets Singule Volcanics inland from Put Put Harbour, and extends southward to Sum Sum Plantation; the limestone crops out as far as 15 kms inland, dipping towards the coast at a shallow angle from about 600 metres above sea level near Simbum village.

Raised Pleistocene coral limestone crops out in a narrow discontinuous strip along the coast south of Sum Sum Plantation, extending westward into Wide Bay. It forms many prominent headlands up to 100 metres high along the southeast coast of the Peninsula, and a number of isolated, steep-sided, flat-topped hills 100 metres high in the narrow plain along the north coast of Wide Bay, as far west as the mouth of the Mevlo River.

At Tavui Point north of Rabaul, reef limestone 50 metres thick contains minor pumice and volcanic debris and is interbedded in the Rabaul Volcanics. It has been uplifted until its base at the present day is close to sea level (Fisher, 1939a). The age of the limestone was determined by the Commonwealth Palaeontologist to be not older than Pleistocene. A similar occurrence of limestone interbedded in volcanics is reported by Fisher from Watom Island, 10 km west of Tavui Point.

Raised Pleistocene coral forms Urara Island in the mouth of Ataliklikun Bay, and several very small islands which lie to the west, along the North Baining coast. The Talele Islands, 7 kms northeast of Cape Lambert, probably consist of Baining Volcanics draped with Pleistocene coral.

Pleistocene reef limestone forms low hills on Seragi and Stockholm Plantations, and inland from Kureindall Bay south of Stockholm Plantation; it has not been identified elsewhere on the west coast of the Gazelle Peninsula.

Raised Pleistocene limestone along the east and south coast of the Gazelle Peninsula is the exposed remnant of a narrow coral reef which fringed the southeast coast of the Pleistocene Gazelle Peninsula, broadening into a wide reef-shoal complex off its northeast coast and extending as far north as several small islands situated in the north of the present day Duke of York Islands. Vulcanism at the Rabaul eruptive centre may have commenced before this period of major Pleistocene reef development was terminated by a eustatic fall in sea level, or by the beginning of uplift which has resulted in the present day elevation of the limestone.

RIET BEDS (new name)

The Riet Beds are poorly consolidated, generally flat-lying, thin- to thick-bedded fluviatile mudstones, sandstones and conglomerates which crop out extensively across the lower headwaters of the Warangoi River and westwards into the Keravat River headwaters. They are named from Riet village ($4^{o}34'$S, $152^{o}06'$E). Thickness may exceed 300 m. Deposition probably began in the Pleistocene and has continued in places to the present day.

In the east, the Riet Beds are faulted against the Sigule Volcanics along a north trending fault in the Kavavas River headwaters; they are folded and steep dipping near the contact. In the south, from the Kavavas River to west of the Nengmukta River, they are faulted against Baining Volcanics and plutonic rocks along the northwest trending Baining Fault; dips in a rotated fault wedge of Riet Beds in the Nengmukta River vary from 30° to 70°N, and carbonized wood from the succession yields a C^{14} age of about 50,000 years* Further west in the Keravat River, Riet Beds crop out south of the Baining Fault to the foot of Mt. Sinewit where they unconformably overlie Nengmukta Volcanics and Sinewit Volcanics. North of the Fault they unconformably overlie Sinewit Volcanics west of the Keravat River. At their northern margin the Riet Beds are overlain by Rabaul Volcanics. In the Keravat River the contact is partly disconformable and partly one of slight angular unconformity, but to the east in the lower Nengmukta River the succession is conformable. Here the division between Riet Beds and Rabaul Volcanics is in places arbitary, because of marked increase in pumiceous material in the uppermost units of the Riet Beds. In the final stages of eruption during collapse of the Rabaul caldera, thin pumice ash deposits blanketed much of the central and western areas of present day outcrop of the Riet Beds; these form the peripheral units of the Rabaul volcanics, but are mapped as Riet Beds because the veneer is sufficiently thin to be easily dissected by small streams, exposing the underlying Riet Beds.

The Riet Beds consist of poorly consolidated, thinly- to thickly-bedded pebble, cobble and some boulder conglomerates, fine- to coarse-grained sandstones, and mudstones, deposited from fast-flowing streams at the foot of rising mountain ranges to the south and southwest. Clasts in the conglomerates vary from fairly well-rounded to angular, from poorly sorted to unsorted. Coarse-grained debris was derived largely from Baining Volcanics and hypabyssal and plutonic intrusive rocks and partly from Yalam Limestone. Finer-grained detritus was derived largely from these units and, in the west, includes reworked tuffaceous material from

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* Specimen P1432 from this locality has a radio carbon age of greater than 41,100 years (95% probability) of greater than 46,700 years (67% probability) (NZDSIR, pers. comm., 8 May, 1968).

the Sinewit Volcanics. Pumice ash from the Rabaul eruptive center is widely distributed in the upper part of the succession. Massive cross-stratification is prominent in the southeastern corner of the outcrop area, where thick-bedded, unsorted, predominantly coarse-grained debris was deposited from the adjacent rapidly rising mountain block southwest of the Baining Fault. Elsewhere debris was transported greater distances, and some consequent rounding and sorting took place before deposition in a relatively quiet environment. Several thin basaltic dykes and sills intrude the Riet Beds in the Nengmukta River.

With the onset of vulcanism in the Rabaul area, primary volcanic detritus from the north became an increasingly important factor in the sedimentation of the Riet Beds. Volcanic outwash and ash showers provided pumice fragments distributed throughout the upper part of the succession. As growth of the Rabaul volcano and the Mt. Varzin eruptive center spread primary volcanic deposits further south, these were intercalated at the margin with the less volcanic upper units of the Riet Beds.

Recent uplift of the Riet Beds in the southeastern corner of outcrop has resulted in fairly deep dissection by larger streams; these are presently being filled by the debris which continues to shed from the northeast flank of the Central Baining Mountains, while smaller streams continue to deposit sands and gravels conformably on the uplifted surface of the Riet Beds.

QUATERNARY VOLCANICS

Quaternary pyroclastic deposits from the Rabaul eruptive centre blanket much of the Northeast Lowland of the Gazelle Peninsula, and finer ash deposits extend into the foothills of the Central and North Baining Mountains; because they are thin, and easily eroded to expose underlying strata, peripheral deposits are not shown on the geological map.

Southwest of the Gazelle Peninsula, but included in the map area, are the Quaternary volcanic centres of Mt. Likuruanga (North Son) and Lolobau Island, which form the east end of the Bismarck Volcanic Arc.

Rabaul Volcanics

The Rabaul volcanics were not closely examined by the writer, except in peripheral areas where field relations were investigated. The eruptive centre was briefly described by Fisher (1939) and the volcanics are currently being studied in detail by R.F. Heming.

The Rabaul eruptive centre is a partly submerged caldera, breached and open to the sea on the southeast side. It is the remains of a large central volcano which collapsed between 1,500 and 1,000 years ago, accompanied by the eruption of large volumes of predominantly pumice ash which spread beyond the edge of earlier deposits, extending more than 35 km to the south and west. Two post-caldera parasite cones rise from the outer caldera wall, two post-caldera parasite cones overlap the rim, and two have grown inside the caldera. The cones inside the caldera are most recently active. Vulcan (Fig. 21) built from a small vent below sea-level to its present height of 224 m in 1937, while Tavurvur erupted simultaneously with Vulcan and again in 1941.

Only three eruptive centres are located away from the Rabaul caldera. These are Mt. Varzin, 20 km south of Rabaul, a less prominent volcanic peak 6 km farther southeast, and Watom Island, 15 km northwest of Rabaul.

From the confluence of the Kavavas and Nengmukta Rivers west to the Keravat River and continuing north-northwest towards Ataliklikun Bay, thin beds of Rabaul volcanics (peripheral units of the central volcano) interfinger with poorly consolidated conglomerates, sandstones and subordinate siltstones of the Riet Beds, which contain an increasing pumice content towards the top.

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A distinctive layer of pumice ash underlies the thin present day soil cover over most of the Northeast Lowland and into the foothills of the Central and North Baining Mountains. Near Arumbum village, 40 km south of Rabaul, fine water-laid pumice ash (Fig. 22) fills a shallow basin, and includes a thin bed of black carbonaceous clay at its base. This is underlaim by a bed of white clay up to 1 metre thick, which is underlain by a second bed of carbonaceous clay. The lowermost carbonaceous band is considered to be the remains of organic material accumulated in a shallow, stagnant basin, which was partly filled by fine pumice ash from a major eruption. The ash subsequently weathered to clay, and a second layer of organic material was preserved by 2 metres of fine, water-laid pumice from the last major eruption. Samples from the carbonaceous layers have been submitted for Carbon-14 age determination.* Air-fall pumice ash is exposed in the villages of Arumbum and Riet, and along numerous tracks in the area. Accretionary lapilli ash with pumice fragments up to 2 cm across underlies the thin soil cover at Rangoulit village, south of Ataliklikun Bay, and forms a bed up to a half metre thick. Road cuts on Vunalama Plantation (west side of Ataliklikun Bay) expose weathered Yalam Limestone overlain by less than a half metre of dark soil, overlain in turn by a similar thickness of fine pumice ash, and 15 to 30 cms of present day soil. The widespread thin pumice layer is considered to have been deposited by a climactic eruption during the formation of the Rabaul caldera, 1000 to 1500 years ago.

North Son and Lolobau Island

The North Son and Lolobau Island have been described by Fisher (1939b, 1957) and by Johnson (1970). The North Son is a large, extinct central volcano, with a caldera breached on the northwest side, and a number of small, extinct parasite cones, mostly low on the northwest flank. Four small volcanic cones rise out of the swamps of the Pandi River delta, southeast of the North Son; they are related to the North Son or to the neighbouring Father (Mt. Ulawun).

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* Specimens P1344 and P1345 have radio carbon ages, calculted to year 1950, of 1450 ± 60 years, and 3500 ± 65 years respectively (NZDSIR, pers.comm., 5 May 1968).

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Figure 21. Vulcan ash cone within the Rabaul caldera. The cone built up from below sea-level in the 1937 eruption.

Figure 22. Fine pumice ash from the Rabaul eruptive centre deposited in the Warangoi River headwaters.

Lolobau Island is the remnant of a large central volcano, which collapsed to form an extensive caldera. Mt. Lolobau is a younger dormant volcano which straddles the west wall of the caldera, and rises to 825 m, dominating the island. Near the east end of the island Mt. Gibu (590 m) is located slightly outside the caldera rim; its age is unknown. Deposits from a number of small, dormant cones inside the north wall of the caldera overlap the wall and partly fill the centre of the caldera. A small lake is located at the foot of the deposits against the south wall of the caldera. Poorly consolidated deposits from a small pyroclastic cone form cliffs at the east extremity of Lolobau Island, and a smaller lava and pyroclastic cone forms the west tip of the island. Tiwongo Island, near the east end of Lolobau Island, and Ban Ban Island, off the west end, are small extinct lava cones. Muli Island, near Ban Ban Island, consists of shallow-dipping, water-laid pyroclastic material.

Small sulphur deposits in the breached crater of Mt. Lolobau have been described by Fisher (1942b).

RECENT ALLUVIUM

The swampy delta plains of the Toriu, Sai and Pandi Rivers in Open Bay are the most extensive alluvial deposits. Coastal alluvium in Ataliklikum and Wide Bays is less extensive. Elsewhere the coastal plain is narrow and discontinuous, or is completely absent. Inland, streams are narrow with a steep gradient, and mostly do not form gravel beds; exceptions are the Warangoi River and the middle reaches of the Mevlo and Toriu Rivers. Alluvial fans deposited by small streams from rising fault scarps occur in the Central Baining Mountains (mapped as part of the Riet Beds), and along the North Baining coast at the edge of the coastal plain. Reworked pyroclastic debris forms an alluvial apron between the Father (Mt. Ulawan) and North Son volcanoes. Derived pyroclastic material is mixed with alluvium largely derived from the Keravat River, at the east end of the narrow coastal plain in Ataliklikun Bay.

South of the Sai River, remnants of sub-Recent gravel beds cap hills of Pliocene Sai Beds, to a height of more than 100 m above sea level. Cross-bedded gravels, sands and mud exposed in the Mavulu River at the edge of the hills dip north at 10 degrees. These gravels were derived entirely from Baining and Merai Volcanics, and plutonic rocks. Apparently the Yalam Limestone flanking the Kol-Mengen mountain block was not yet exposed to erosion at that time. Uplift of the mountain block south of border faults caused the observed slight uplift of Sai Beds and unconsolidated alluvium. River gravel in the middle reaches of the Mavulu River at the present day is composed almost entirely of limestone, and is modified where older gravel beds are eroding at the edge of the hills. Lower downstream, slight uplift has exposed up to 3 m of present day gravel, sand and mud conformably overlying carbonaceous sandy mud with logs and roots; at one locality carbonaceous mud contains abundant thin-shelled marine molluscs, indicating marine inundation of the Sai River delta embayment in very recent times. Elsewhere in the Sai River delta only present day alluvial deposits are exposed; much of the area is flooded in the wet season.

Approximately 50 sq km of fine alluvium have been deposited by the Toriu and Sambei Rivers in a shallow delta embayment 25 km north of the Sai River; reworking of sand and mud by long-shore currents is evidenced by strand-lines extending up to 3 km inland, south of the Toriu River mouth. There has been no recent uplift in the area, and only present day alluvium is exposed along streams; part of the area is permanent swamp.

Immediately west of the Gazelle Peninsula the Pandi River flows into Open Bay through a wide tract of river alluvium, which is bounded to the east by Merai Volcanics, and to the west by Quaternary volcanics; pyroclastic debris from the latter is mixed with normal river alluvium in the delta deposits, and a number of small volcanic cones up to 90 m high protrude through the alluvium. Lagoons formed by the growth of offshore bars are prominent behind the present day coastline; swamps extend inland for some distance behind the lagoons.

Raised boulder beds with some poorly consolidated sand and clay interbeds, form a unit up to 100 m thick, exposed along the edge of the foothills west of the Nambung River mouth, on the North Baining coast.

HYPABYSSAL INTRUSIVE ROCKS

Hypabyssal rocks intrude Baining, Merai, Nengmukta and Sigule Volcanics. They are mostly dark, intermediate to basic porphyries genetically related to the volcanic units they intrude, or to the igneous activity of younger volcanics; some are related to plutonic activity and, rarely, some are apparently unrelated to any of the main igneous events. Brief descriptions of hypabyssal rocks related to individual volcanic rock units have been included in the preceding descriptions of those rock units.

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Intrusive rocks genetically related to the Baining Volcanics are mostly strongly jointed and deformed, having suffered the same deformation as the Volcanics. Less common slightly deformed or undeformed porphyries which are younger than the Volcanics, strongly resemble the older intrusive rocks. Hypabyssal activity may have continued throughout the period of deformation of the Volcanics, terminating before the emplacement of plutonic rocks in a new period of igneous activity. Petrographic examination of the younger hypabyssal rocks shows them to be mostly andesitic plagioclase and augite-plagioclase porphyry, and rarely hornblende porphyry; dolerite is less common. Plagioclase phenocrysts in the andesite porphyries are mostly poorly zoned to unzoned, untwinned labradorite grains from 3 to 6 mm long, which vary from fairly abundant to rare. Subordinate augite, or rarely hornblende, may accompany the plagioclase. The groundmass of the porphyries consists of fine plagioclase and granular opaque oxide, which may be accompanied by granular augite and interstitial fedlspar or chlorite. Dolerites apparently unrelated to large-scale plutonic activity are mostly slightly porphyritic, with scattered plagioclase and rare augite phenocrysts in finer-grained plagioclase, augite, interstitial chlorite and opaque oxide. Plagioclase ranges in composition from bytownite to labradorite, and quartz is rarely present. In the Central Baining Mountains, the Baining Volcanics are intruded by dacite porphyries related to the Nengmukta Volcanics and possibly to the Mevlo Member of the Sinewit Volcanics; rarely the dacite porphyry ("porphyrite") intrusions are autobrecciated. Petrographic examination shows them to consist of phenocrysts of partly kaolinised, fairly sodic plagioclase and strongly corroded, embayed quartz, in a cryptofelsitic or fluidal glassy groundmass.

In most areas of outcrop Merai Volcanics are intruded by genetically related plagioclase and augite-plagioclase andesite porphyries, and less commonly dolerite. Younger intrusives related to the Sigule Volcanics commonly intrude Merai Volcanics in the uppermost area of outcrop in the Merai River.

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In the Central Baining Mountains Nengmukta Volcanics are intruded by abundant dykes, sills and irregular bodies of dark, unjointed to poorly jointed plagioclase and augite-plagioclase andesite porphyries, and considerably less common dacite porphyry. The intrusive rocks are genetically related to the Volcanics, and perhaps to the basal member of the slightly younger Sinewit Volcanics.

Subaerial lavas, agglomerates and tuffs of the Sigule Volcanics are widely intruded by andesite porphyry and dolerite in the central part of their area of outcrop. In the Lat River a sill of 2-pyroxene dolerite displays some evidence of crystal fractionation.

There is no evidence of intrusions into the Yalam Limestone or the Sinewit Volcanics.

PLUTONIC INTRUSIVE ROCKS

Plutonic rocks intrude Baining Volcanics along the North Baining coast and in several areas in the Central and South Baining Mountains. Some are oligocene in age and some are younger. R.W. Page (pers. comm., 1968) has established a K-Ar age of near 14 m.y. (Middle Miocene) on tonalite from the Rapmetka River*. Plutonic rocks exposed at the foot of Mt. Sinewit may belong to a sub-volcanic pluton in the base of the Upper Miocene to Pliocene Sinewit Volcanics.

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* Specimen P1347/Ga 5477 is a tonalite from a partly mineralized intrusive body on the Rapmetka River (see p.101 . R.W. Page (pers. comm., 1968) determined an age of 13.7 ± 0.2 m.y. on biotite, and 14.1 ± 0.2 m.y. on hornblende.

Two distinct calc-alkaline rock series can be recognised, exposed in three main areas. Normal calc-alkaline rocks ranging from leucogabbro to granodiorite in composition crop out mostly in the North Baining Mountains, in contrast with high-K calc-alkaline rocks ranging from leucogabbro to adamellite or granite in composition, which crop out in the Central and South Baining Mountains. Basic plutonic rocks, which are probably genetically unrelated to the calc-alkaline series, are more widespread but occupy a much smaller total area of outcrop than the calc-alkaline rocks.

Several hundred petrographic sections of Gazelle Peninsula plutonic rocks have been briefly examined, and full wet chemical analysis of 33 specimens has been carried out by A.M.D.L., Adelaide.

Calc-alkaline Plutonic Rocks

The calc-alkaline plutonic rocks are high-level intrusions with steep sides and narrow contact metamorphic aureoles. They show no evidence of large-scale stoping of country rock, and little evidence of crustal assimilation.

The largest area of outcrop is in the North Baining Mountains, where plutonic rocks crop out in the hinterland of the North Baining coast, on both sides of the northwest extension of the Baining Fault. They form a linear east-trending belt up to 10 km wide, with an outcrop area of about 250 sq km. In the Central Baining Mountains plutonic rocks crop out over an area of about 40 sq km, in a narrow zone bounded on the northeast side by the central part of the Baining Fault. In the South Baining Mountains they crop out over an area of about 120 sq km, mostly in a linear zone up to 5 km wide, extending eastwards from the middle reaches of the Wulwut River. Small, isolated plutons in all three areas are probably apophyses of the main masses. Sheared plutonic rocks underlie Quaternary limestone on Makada Island in the Duke of York Group.

The plutonic rocks are located in heavily forested areas of moderate to high relief. Streams intersecting them are mostly narrow and swift-flowing, and are subject to sudden flooding; in the upper reaches they have steep gradients and are choked with large boulders. Ridges and spurs between streams are generally narrow and steep-sided. Outcrop of the plutonic rocks is almost entirely restricted to stream exposures, some of which are moss-covered and difficult to examine. In most instances it was not possible to systematically sample areas of plutonic outcrop, or to establish field relations between different rock types. Many of the rocks examined petrographically and by chemical analysis were not collected from outcrop.

Classification of the Calc-alkaline Rocks

There is apparent agreement between most geologists on the broad classification of volcanic rocks, based on both modal (where possible) and chemical compositions. This classification has arisen largely from the study of natural rock suites. In contrast, there is a continuing lack of acceptance of any single system of classification of plutonic rocks.

Most oversaturated calc-alkaline plutonic rock classifications presently in use are based on modal composition, leaning heavily on the relative abundances of quartz, orthoclase (alkali feldspar) and plagioclase, but there is little agreement between workers on the positioning of arbitary boundaries to define rock types (e.g., Streckeisen, 1967). There has been little apparent effort to relate variations in modal composition of plutonic rocks to variations in chemical composition, and little effort to equate plutonic and volcanic rock suites, although it is commonly accepted that there are extrusive equivalents of most intrusive rock types.

In the Gazelle Peninsula the calc-alkaline plutonic rocks are fairly leucocratic, with ferromagnesian minerals mostly aking up only 10-25% by volume. Augite is the most common ferromagnesian mineral, in most instances variably replaced by secondary amphibole. Small amounts of hypersthene occur in some more basic rock types, while small amounts of primary hornblende and, less commonly, biotite occur in more acid rock types. Opaque oxide mostly comprises from 2 to 5% by volume. Because of the relatively leucratic nature of the rocks, and the simple ferromagnesian mineral assemblages, the modal quartz-orthoclase-plagioclase diagram is considered an adequate basis for their classification. An attempt is made to rationalize boundaries imposed on rock types in this diagram, by examination of the limited number of chemical compositions available for the Gazelle Peninsula rocks.

By analogy with the limits used by Taylor (1969) for calc-alkaline andesites, lower and upper limits of 53% and 62% SiO_2 are placed on the composition of diorite. Examination of the distribution of points representing the calc-alkaline plutonic rocks of the Gazelle Peninsula in the modal quartz-orthoclase-plagioclase diagram (Fig. 23a) with reference to their chemical compositions, indicates that 62% SiO_2 corresponds approximately to 20% quartz. (20% quartz on the quartz-orthoclase-albite diagram corresponds to 16% modal quartz in the Gazelle diorites.) This value of 20% recalculated quartz is consequently used to separate diorite from tonalite and granodiorite, and is extended to separate monzonite from adamellite and syenite from granite. The commonly accepted limits of 10%, 33.3% and 66.6% orthoclase of total feldspar is used to define the tonalite, granodiorite, adamellite and granite fields. The resulting modal classification (Fig. 23b) has been adopted for this discussion of the Gazelle Peninsula plutonic rocks.

GAZELLE PENINSULA PLUTONIC ROCKS

Modal Quartz – Orthoclase – Plagioclase Diagram

FIGURE 23a

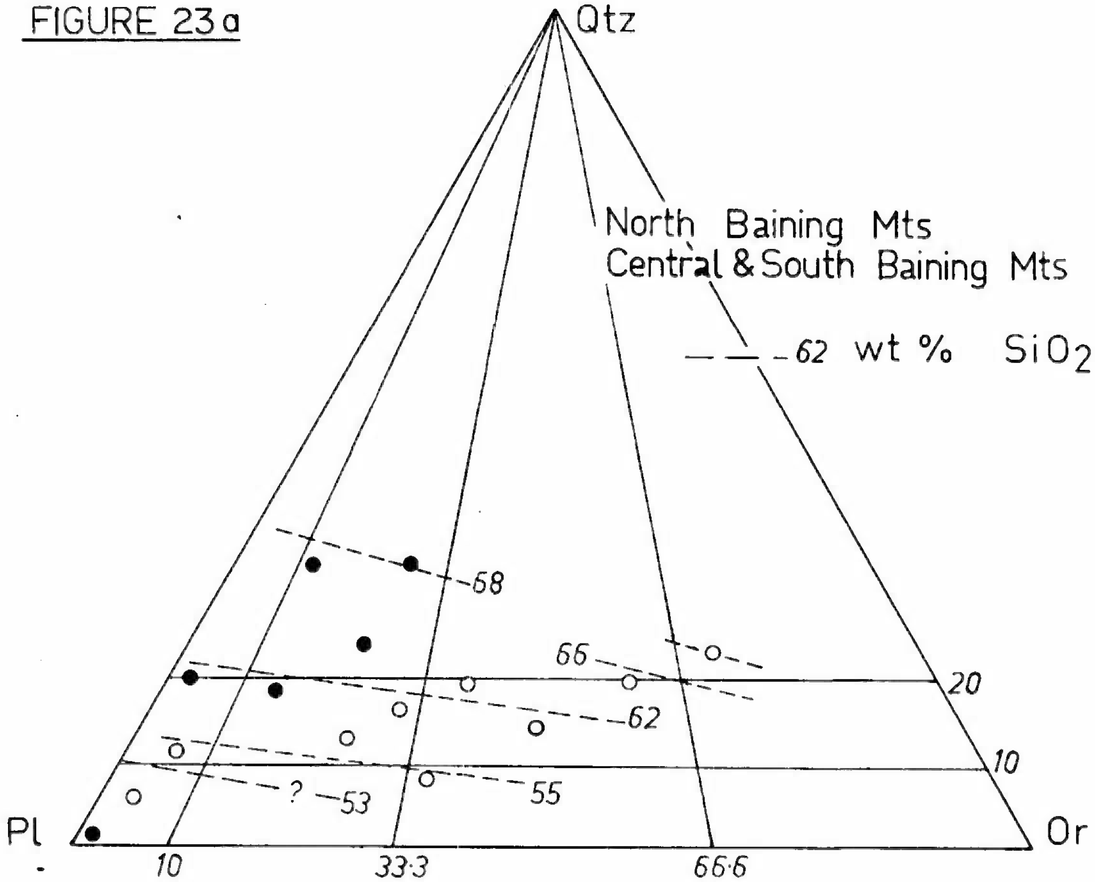
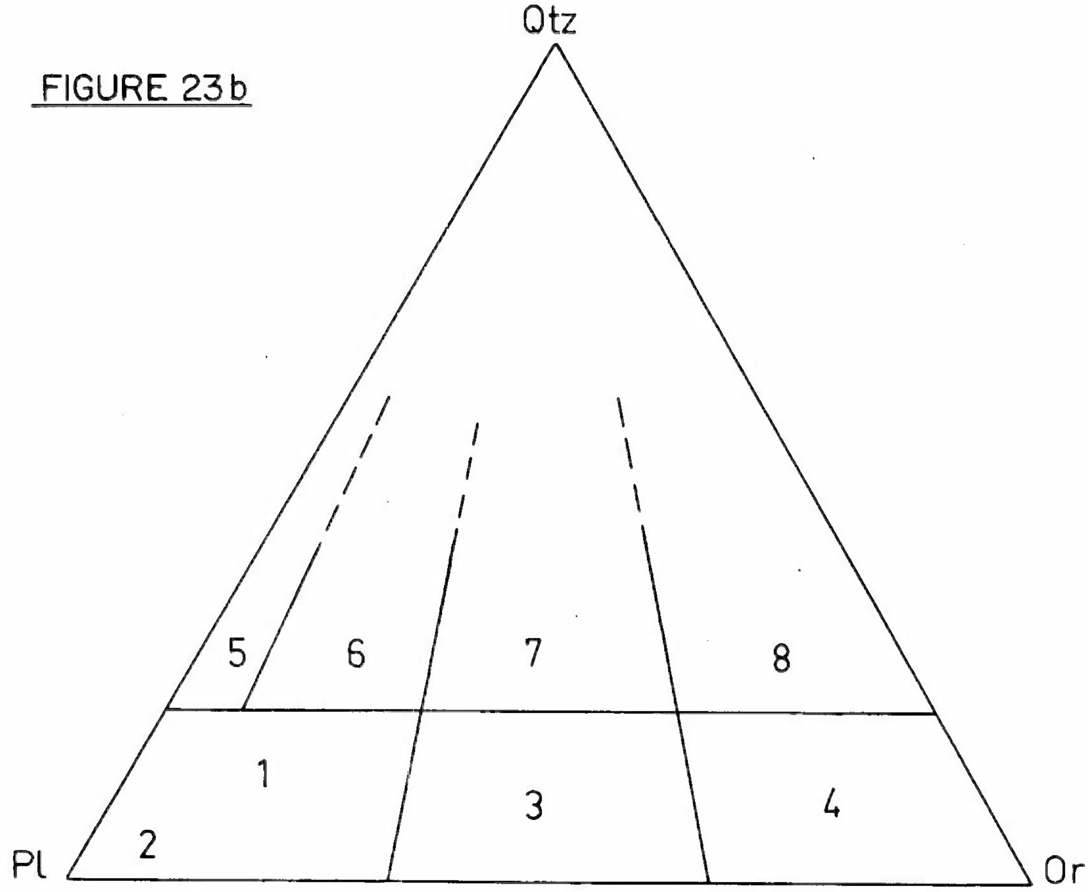


FIGURE 23b



1 Diorite
2 Gabbro, some diorite
3 Monzonite
4 Syenite
5 Tonalite
6 Granodiorite
7 Adamellite
8 Granite

81

R.P.M. 4·70

Interpretation from the small number of modal compositions plotted is inconclusive, but suggests that lines representing constant SiO_2 percentages in the modal quartz-orthoclast-plagioclase diagram have a slight downward inclination towards the orthoclase corner (see Fig. 23a). This is probably caused by a small volume increase in free quartz relative to a large decrease in the volume of ferromagnesian minerals in more potassic (fractionated) rocks with the same SiO_2 content. As a result the 20% quartz line which is used to separate granite from syenite in the modal diagram, represents a chemical composition of 66% SiO_2 at the edge of the adamellite field.

The ratio of orthoclase to plagioclase is critical in the classification of oversaturated plutonic rocks. The ratio K_2O/Na_2O is an approximate representation of the K-feldspar/plagioclase ratio, provided that most of the K_2O and Na_2O are held in the respective feldspars. This is the case with most of the Gazelle Peninsula rocks. Consequently it is possible to broadly define rock types by reference to their K_2O/Na_2O ratios and SiO_2 percentages. Although data are insufficient for rigid definition, examination of plots in the diagram K_2O/Na_2O vs SiO_2 (Fig. 24a), with reference to the classification in Figure 23b, shows the following correlations:

Orthoclase to total feldspar	K_2O/Na_2O ratio
Less than 10%	Less than 0.3
10% to 33.3%	0.3 to 0.9
33.3% to 66.6%	0.9 - 1.4
More than 66.6%	More than 1.4

A lower limit of 53% SiO_2 is placed on the compositions of diorite, monzonite and syenite. An upper limit of 62% SiO_2 at the base of the diorite field (K_2O/Na_2O approaches 0) increases to an upper limit of 66% SiO_2 at the base of the syenite field (K_2O/Na_2O equals 1.4). The fields of the various rock types so defined are illustrated in Figure 24b.

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Although not all K_2O and Na_2O are contained in orthoclase and plagioclase, the K_2O/Na_2O vs SiO_2 diagram appears to be a useful means of classifying the Gazelle Peninsula plutonic rocks, and clearly illustrates probable differentiation trends and the potassic nature of the Central and South Baining plutonic rocks. The possibility of wider application of the classification has not been investigated. Plutonic rocks containing perthitic feldspars, or feldspars with a high K-Na solid solution, are difficult to classify modally but, provided they do not contain a high proportion of sodic or potassic ferromagnesian minerals, might be readily classified by using this diagram.

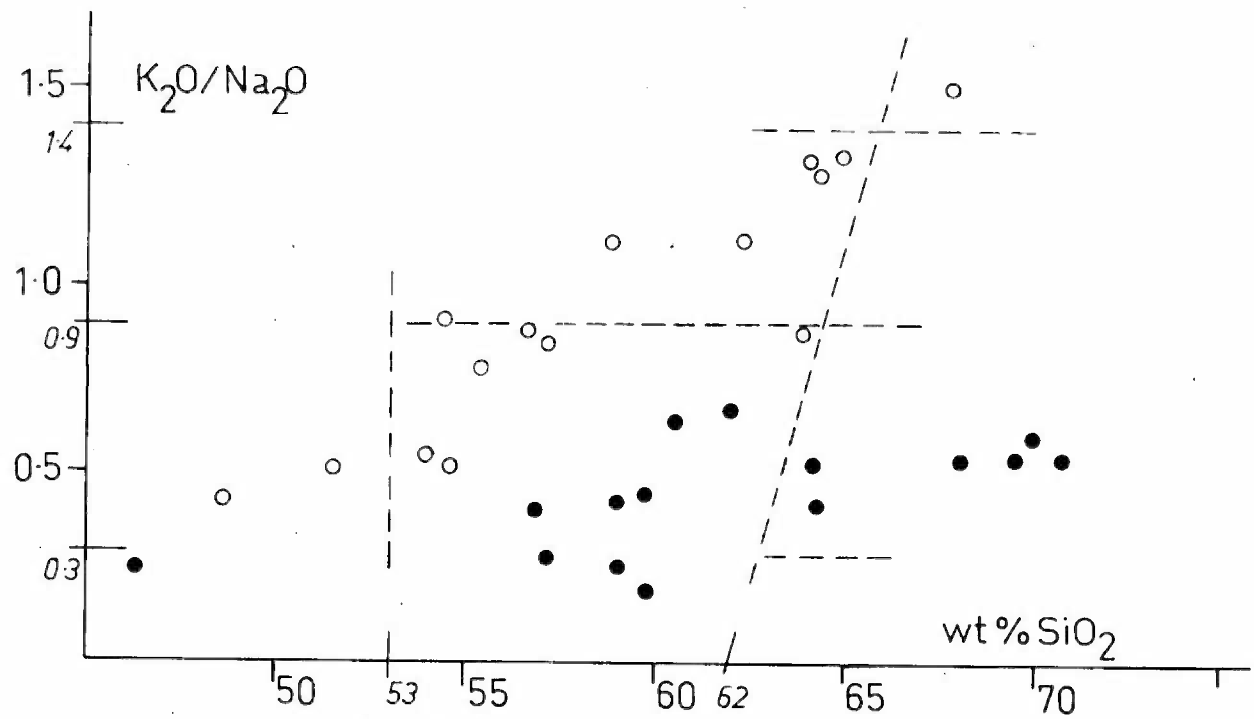
The more basic rocks of the Gazelle Peninsula do not fit readily into a rigid petrographic classification. In some basic rocks characterized by granular texture, less than 25% ferromagnesian minerals, and 0-20% quartz, the plagioclase compositions are predominantly more calcic than An_{50} (identified by albite and Carlsbad-albite twin extinction angles). In other rocks of similar mineralogy, plagioclase compositions vary from more calcic to less calcic than An_{50}, and in others the plagioclase is consistently less calcic than An_{50}. In a smaller group of basic rocks, with 15-40% ferromagnesian minerals there is a recognizable gabbroic (ophitic or subophitic) texture, and the plagioclase composition is invariably more calcic than An_{50}.

Rocks with a gabbroic texture which contain 15-40% ferromagnesian minerals, and have plagioclase more calcic than An_{50}, are called leucogabbros and dolerites. Leucocratic rocks with a granular texture and plagioclase mostly more calcic than An_{50}, are called basic diorites. Similar rocks, with plagioclase compositions mostly more sodic than An_{50}, are diorites. The plagioclase compositions in some tonalites are partly more calcic than An_{50}.

This classification, based principally on plagioclase composition and rock texture, is obviously inadequate, but there are insufficient chemical analyses to allow close examination of the problem.

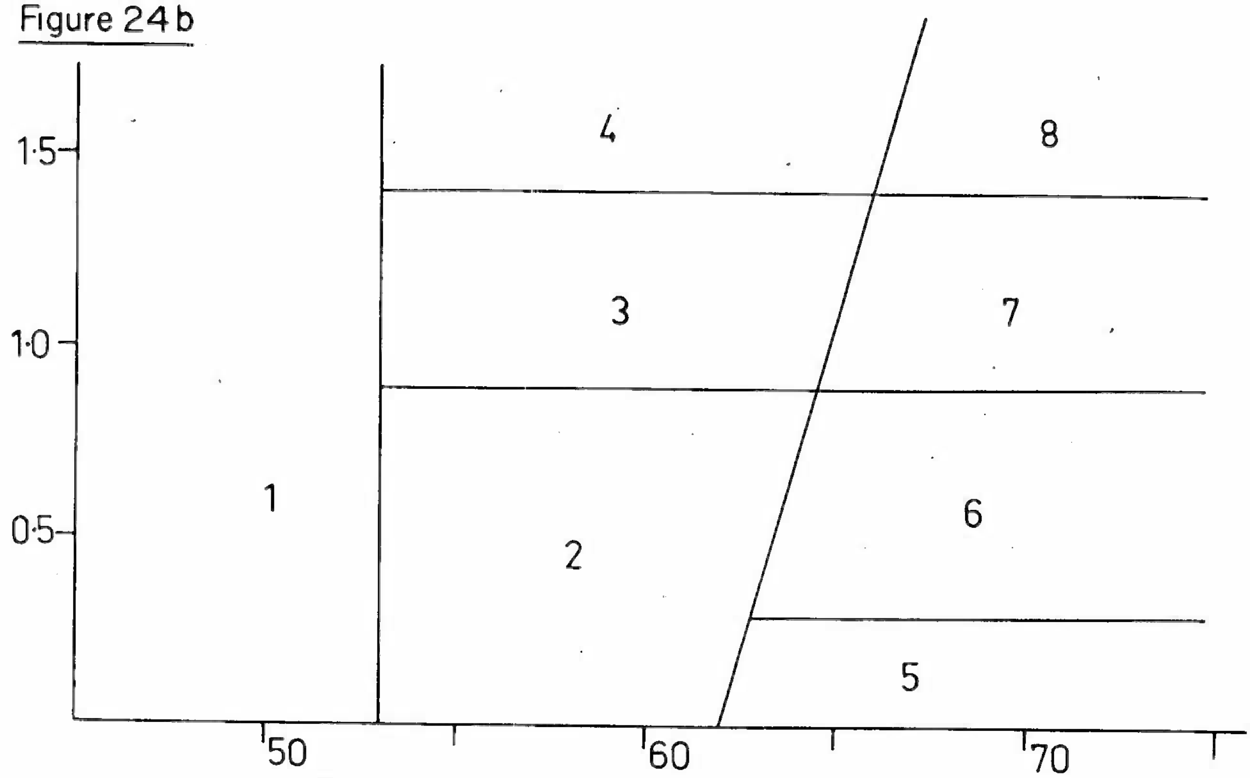
GAZELLE PENINSULA PLUTONIC ROCKS

Figure 24a K_2O/Na_2O vs SiO_2 diagram



North Baining Mountains ●
Central & South Baining Mountains ○
---- field boundaries of rocks classified according to

Figure 24b



1	Gabbroic rocks	5	Tonalite
2	Diorite	6	Granodiorite
3	Monzonite	7	Adamellite
4	Syenite	8	Granite

Leucogabbro has crystallized from basic parent magmas, whereas basic diorite, because of its granular texture, is possibly a cumulate from less basic magma.

North Baining Mountains

Plutonic rocks in the North Baining Mountains form a composite batholith, which crops out over an area of approximately 250 sq km, in an east-trending belt 55 km long. At its western end, outcrop is terminated by the west coast of the Peninsula; at its eastern end plutonic rocks are overlain by poorly consolidated sedimentary rocks. The southern margin of outcrop is the southern boundary of the batholith, while along the northern margin plutonic rocks are overlain by limestone or alluvium. The batholith is disrupted by the Baining Fault.

Rock types making up the batholith include leucogabbro and dolerite, basic diorite, diorite and microdiorite, tonalite and granodiorite, minor adamellite, and rare microgranite or granite aplite, granite granophyre and pegmatite.

Leucogabbro and dolerite crop out principally east of the Batonga River, within the batholith and forming related stocks; a number of specimens were collected west of the Batonga River, notably in the foothills south of Rangarere and Doilene Plantations. Basic diorite forms widespread stocks along the southern margin of the batholith, and crops out within the batholith principally at its eastern end; stocks of basic diorite are exposed as far as 14 km south of the batholith at its western end. Diorite and less common tonalite and granodiorite form the major part of the batholith; diorite and tonalite occur throughout, while granodiorite crops out mainly in the western part. Microdiorite is common in a zone extending from east of the Batonga River to east of the Nambung River. Minor adamellite crops out along the Nambung River, and microgranite or granite aplite veins, and small bodies of fine-grained granite granophyre occur in the same area. Rare aplite and pegmatite veins (composition unknown) invade the batholith in a number of areas.

Petrography - North Baining Mountains

The North Baining plutonic rocks are mostly fine-grained to medium-grained, with maximum grainsize commonly in the range 1 mm to 3 mm; many rocks are slightly porphyritic.

Plagioclase is the dominant mineral in nearly all rock types. Quartz is present in many rocks and may be accompanied by minor orthoclase. Primary ferromagnesian minerals are augite and minor hypersthene, less commonly hornblende, and rarely biotite. Augite is commonly partly or largely replaced by secondary ferromagnesian minerals, including colourless and pale green amphiboles (including some hornblende), chlorite, minor opaque oxide, and epidote. Modal compositions of 6 plutonic rocks are included with their chemical analyses and normative compositions in Appendix 1.

Plagioclase makes up as much as 85% by volume of some basic diorites, and decreases to a minimum of about 40% in some tonalites and granodiorites. It may be fractured and is partly kaolinised in some rocks. In most instances plagioclase forms the largest grains, and many rocks are slightly or strongly porphyritic. Grains are mostly fairly well formed; in some tonalites and granodiorites plagioclase grains are enclosed in optically continuous quartz (Fig. 27). Rarely plagioclase phenocrysts enclose augite granules. Zoning is not always developed but is particularly pronounced in many of the more acid rock types; most zoning is normal, or less commonly oscillatory. Albite and Carlsbad-albite twinning are variably present.

Plagioclase compositions in leucogabbros and dolerites are largely unknown; a small number of determinations are in the range An_{55} to An_{70}. In basic diorite the composition ranges from An_{45} to An_{60} (mostly sodic labradorite), and in diorite from An_{40} to An_{55} (mostly calcic andesine). The range in tonalite is similar to that in diorite. In granodiorite the range is poorly defined, but appears to be An_{35} to An_{45}, and in adamellites An_{30} to An_{40}. Plagioclase more calcic than An_{70} may be present in some leucogabbros

Figure 25. Fragmented porphyritic microdiorite invaded by diorite. Rapmetka River.

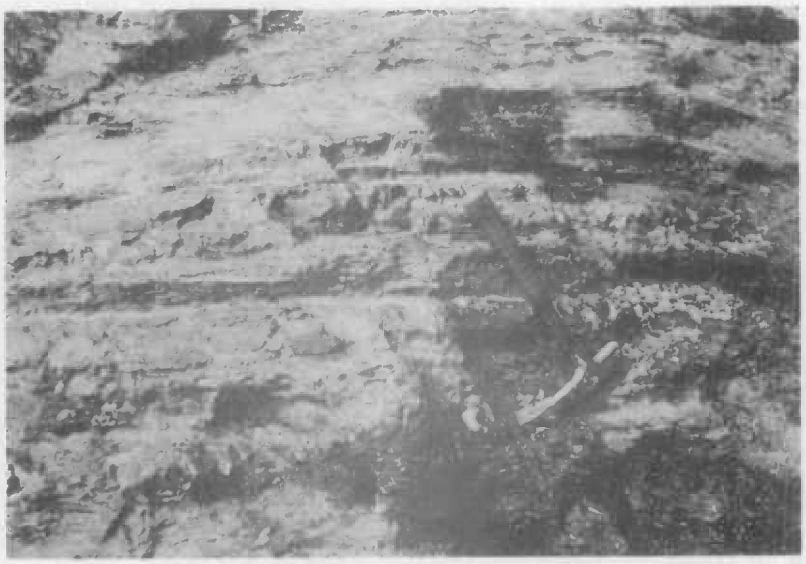
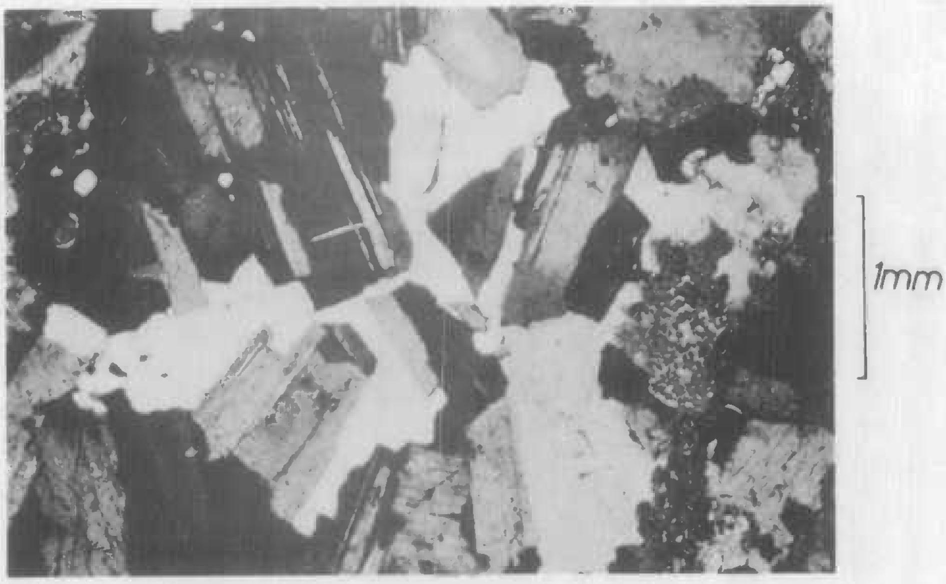
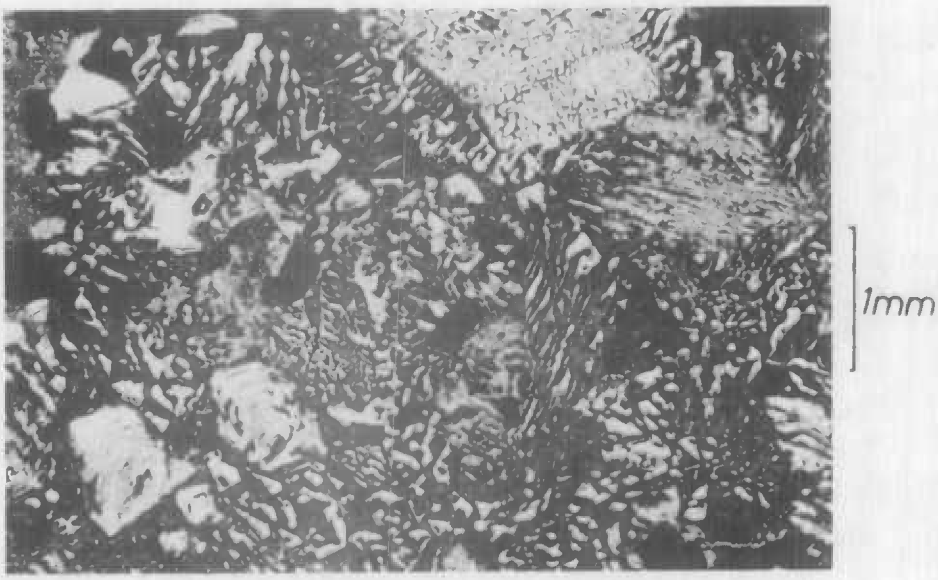


Figure 26. Phyllonite developed from plutonic rocks. Makada Island, Duke of York Islands.



<u>Figure 27</u>. Tonalite from the North Baining batholith shows plagioclase grains in optically continuous quartz. Crossed nicols. 53NG0276A



<u>Figure 28</u>. Granite granophyre from the high-K calc-alkaline series. Crossed nicols. 53NG0435B.

and dolerites. Plagioclase more sodic than An_{30} is probably present in some granodiorites and adamellites. Clear or cloudy plagioclase rimming andesine in some rocks, and infrequently combined with quartz in micrographic intergrowths, may be albite; it has 2V(+).

Quartz is present in small quantities in most rocks, and exceeds 16% by volume * in tonalites, granodiorites and adamellites. It is most abundant in tonalite porphyries from the Usavit and Batonga Rivers. It is mostly interstitial in habit, but forms large irregular grains in some tonalites, granodiorites and adamellites, and large rounded phenocrysts in tonalite porphyries. Quartz commonly forms micrographic intergrowth in rocks with interstitial orthoclase; such intergrowths are rare in basic diorites but abundant in many granodiorites and adamellites. In some rocks all of the quartz and orthoclase present are in intergrowths, and in others some quartz, orthoclase, or both, form small irregular grains which accompany the micrographic intergrowths.

In a large stock of diorite and granodiorite, cropping out inland from Seragi Plantation on the west coast, micrographic quartz-orthoclase intergrowths are less well ordered than those normally encountered, and are accompanied in several sections by subordinate micrographic quartz-plagioclase intergrowths. In these, optically continuous quartz is intergrown with whole grains of twinned plagioclase, or with wide rims of zoned plagioclase. In several sections from other areas, the feldspar in micrographic intergrowths has 2V(+) and is probably albite.

Tonalite porphyries from the Usavit and Batonga River consist of large, rounded quartz and fewer well-formed plagioclase phenocrysts, in a predominantly mosaic quartz groundmass. In one section from the Batonga River, optically continuous outgrowths from quartz phenocrysts, and irregular patches of quartz in the groundmass, enclose numerous small plagioclase and hornblende grains.

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* i.e. exceeds 20% quartz of recalculated quartz + orthoclase + plagioclase, approximately.

Orthoclase is absent or present in very small quantities in basic diorites, some diorites, and in tonalites. It is more abundant in some diorites, and in granodiorites and adamellites, and varies up to 30% (rarely to 40%) by volume in the latter. In most rocks it is cloudy, in several strongly sericitised. Orthoclase commonly forms micrographic intergrowths with quartz, or occurs as small, interstitial grains; in some sections it rims plagioclase, and rarely it forms large grains, some of which are slightly perthitic. It is least abundant in the east end of the batholith, and most abundant in the central part, where veins of granite aplite and small bodies of granite granophyre in the Nambung River probably represent the final stage of crystallization.

Primary ferromagnesian minerals in the North Baining plutonic rocks include augite, hypersthene, hornblende and biotite.

Augite (or its alteration products) is the most common ferromagnesian mineral in leucogabbros, dolerites and basic diorites; it is present, and may predominate, in many diorites and tonalites, and is rarely present in granodiorite.

In leucogabbros and dolerites, augite makes up from 15 to rarely 40% of the rock by volume. It is commonly ophitic or subophitic. Alteration of augite is largely deuteric, and varies from minor to complete; secondary minerals include ragged or fibrous, poorly formed pale green or colourless amphibole, less common chlorite, serpentine and opaque oxide, minor calcite and epidote, and rare sphene. Alteration to hornblende is rare. In some rocks, the ophitic texture is preserved entirely in pale green amphibole, with cloudy and indistinct patches of relict augite. In one section, localized alteration of augite to secondary amphibole was caused by hydrothermal activity in joints.

In basic diorites and diorites, granular augite makes up 10-25% of the rock by volume; in some diorites it is accompanied by primary hornblende. Augite grains in several sections are zoned, poikilitic, or show herringbone texture. In many sections alteration products resemble those in leucogabbros; in others, and particularly in diorites, poorly formed or spongy hornblende forms a wide rim, in some instances studded with fine opaque oxide.

Augite rimmed by pale green amphibole or poorly formed to well formed green hornblende, accompanies primary green hornblende in some tonalites, rarely in granodiorites. In some tonalites and granodiorites, brown biotite accompanies hornblende rimming augite; rarely, biotite flakes rim augite, and hornblende is not present.

Hypersthene is uncommon in the North Baining plutonic rocks. It accompanies augite in some leucogabbros and dolerites, less commonly in basic diorites and diorites and rarely in tonalites. In most sections it is marginally altered to pale green amphibole and chlorite.

Hornblende forms rims on, or completely replaces augite in many diorites and tonalites, and in some granodiorites. When developed in this way as a late magmatic replacement of augite, the hornblende is mostly poorly formed or spongy. Well formed green hornblende is a primary mineral in some diorites and tonalites, in many granodiorites and in most adamellites. In some sections hornblende is partly altered to pale green secondary amphibole, or to chlorite, rarely with concomitant lemon-yellow epidote and sphene formed marginally and in cleavages. Hornblende makes up less than 20% by volume of the rocks in which it occurs, and in many instances less than 10%. Hornblende, altering to or accompanied by pale green amphibole (in some instances rimming relict augite), forms up to 15% by volume of microdiorites.

Biotite is a minor constituent accompanying hornblende in some diorites, tonalites, granodiorites and adamellites. It is mostly strongly pleochroic from red-brown to straw-yellow, and may be partly altered to chlorite, with concomitant lemon yellow epidote and sphene. In several sections augite is charged with fine opaque oxide, and rimmed by opaque oxide granules and flakes of red-brown biotite.

Opaque oxide of undetermined composition forms up to 5% volume of the North Baining plutonic rocks; it is mostly granular in habit, less commonly skeletal, rarely spongy. In some sections it is accompanied by accessory pyrite, rarely by pyrrhotite.

There is little direct evidence of the order of intrusion of individual plutons forming the North Baining batholith. It is possible that intrusion proceeded sequentically from the most basic members to the most acid members. Leucogabbros, dolerites and basic diorites are largely marginal or satellitic to the main intrusive mass, in which more acid rock types predominate. Where igneous xenoliths are present, they are invariably more basic than the host. In the few outcrops displaying multiple intrusion, darker coloured (more basic) rocks are mostly intruded by lighter coloured (more acid) rocks; for example, in the east tributary of the Nambung River near the southern boundary of the batholith. In an outcrop along the middle Batonga River, dark-coloured diorite is intruded by light-coloured diorite and the older rock is hydrothermally altered along joints. Microdiorite appears to have the longest ranging intrusive history. It forms isolated stocks, occurs within the margin of the batholith, and is present as apparently unaltered xenoliths in some marginal phases; it intrudes diorites in the Batonga River, and diorites and granodiorites in the Nambung River.

Possible parent magmas of the North Baining batholith are discussed in the later section dealing with the chemistry of the Gazelle Peninsula plutonic rocks.

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Central and South Baining Mountains

In the Central and South Baining Mountains calc-alkaline plutonic rocks crop out in two main areas. They were not systematically mapped, but sampling of boulders in streams draining areas of plutonic outcrop has broadly outlined the compositional range and distribution of rock types. In the north part of the Central Baining Mountains, rock types resemble those of the North Baining batholith; in the south part, and in the South Baining Mountains, they form a high-K series most of which in petrographically and chemically distinct from the North Baining batholith.

Plutonic rocks crop out over an area of about 40 sq km in the Central Baining Mountains, mostly in a narrow, discontinuous, linear zone bounded on the northeast side by the north-northwest trending Baining Fault. Small stocks crop out more than 6 km west of the main intrusive masses at the north end. The Baining Fault is a post-consolidation structure marked by a zone of intense mylonitization up to 100 m wide; Pleistocene to Recent unconsolidated sediments abut against sheared plutonic rocks at the north end, and upper Miocene to Pliocene volcanic rocks at the south end. Except for the faulted northeast margin, the plutons mostly show intrusive contacts.

Principal rock types in the northern part (Nengmukta and Rapmetka Rivers) are leucogabbro, basic diorite, diorite and microdiorite, minor granodiorite and tonalite, and rare granite aplite and pegmatite veins and dykes. In the southern part (Kavavas and Merai Rivers) they are leucogabbro, basic diorite, diorite, monzonite, adamellite and some granodiorite, and minor granite granophyre.

In the South Baining Mountains plutonic rocks crop out over an area of about 120 sq km, mostly in a continuous linear zone 22 km long and up to 5 km wide, which extends eastwards from the middle reaches of the Wulwut River; isolated plutons crop out near the east end of the main intrusive mass. Poorly consolidated, tuffaceous sedimentary rocks overlie plutonic rocks at the west end of the batholith; elsewhere the boundary is a normal intrusive contact. 93

Leucogabbro, dolerite, basic diorite and diorite predominate in the western and eastern parts of the batholith and in related stocks; diorite, monzonite and minor adamellite predominate in the central part.

Petrography - northern part of Central Baining Mountains

In the northern part of the Central Baining Mountains plutonic rocks resemble those of the North Baining batholith. Orthoclase is absent or minor except in minor granodiorite, and in aplite and pegmatite veins and dykes. Rocks from this northern area are not included in the chemical analyses from the Central Baining Mountains.

Augite diorite predominates in the northernmost area (Nengmukta River). It consists of 65 to 80% plagioclase (mostly calcic andesine, some sodic labradorite), minor quartz, rare interstitial orthoclase, and 15 to 25% augite. In some sections quartz and orthoclase are intergrown, and in some augite is cloudy and largely altered to pale green amphibole, rarely spongy hornblende, chlorite, minor epidote, calcite, or rarely fine biotite. Grainsize is generally less than 3 mm, and many rocks are slightly porphyritic, grading into diorite porphyry. A small percentage of associated rocks contain plagioclase identified optically as mostly more calcic than An_{50}; in these the amount of augite or altered augite varies from minor up to 40% by volume. Some are relatively leucocratic, with a granular texture, and are classified as basic diorites; some have a gabbroic texture, and are classified as leucogabbros. A small amount of leucocratic granodiorite and microgranodiorite occurs in one area, with minor associated pegmatite, aplite and quartz veining. Porphyritic microdiorite commonly forms small intrusions; the rock is made up of phenocrysts of plagioclase (composition mostly not known, but some more calcic than An_{50}) and minor pale green amphibole (rarely with augite cores), set in a groundmass of plagioclase, untwinned interstitial feldspar (probably plagioclase), pale green amphibole (in some instances hornblende), rare relict augite, minor quartz and accessory opaque oxide.

In the Rapmetka River, farther south, hornblende diorite predominates in the main intrusive mass, and grades into tonalite and minor granodiorite; dykes and veins of aplite and pegmatite intrude the mass and the surrounding country rock. Hornblende diorite, porphyritic microdiorite and related porphyries, and basic diorite form small satellitic intrusions. The rocks are mostly not xenolithic, except locally in the Rapmetka River section, where they contain abundant more basic plutonic xenoliths (Fig. 25). Intrusive contacts are steep, and minor stoping of wall rock is apparent. Hornblende makes up 15 to 25% volume of the diorite of the main intrusive mass. It is mostly green-brown and spongy, altering to pale green amphibole and rarely contains relict augite cores. Minor biotite may accompany hornblende in some rocks. With increase in the volume of quartz, the diorite grades into tonalite, or into granodiorite transitional to tonalite if the volume of orthoclase increases significantly. Biotite exceeds hornblende in volume in some tonalites; biotite, and rarely hornblende, may be partly altered to green chlorite, with concomitant lemon-yellow pleochroic epidote and sphene. Minor copper, lead, zinc and molybdenum mineralization of the main intrusive mass is associated with late-stage hydrothermal activity. Tonalite (P1347, Ga5477) from this locality has a K-Ar age of near 14 m.y.

Satellite intrusions are commonly porphyritic microdiorites and related porphyries. Most microdiorites resemble those of the Nengmukta River; some are augite microdiorites and some grade into diorite porphyries. Porphyries related to microdiorite contain plagioclase phenocrysts, rarely accompanied by pale green amphibole pseudomorphs, in a groundmass which may include plagioclase laths, interstitial feldspar quartz, chlorite, pale green amphibole, augite, calcite, epidote, zeolite and accessory opaque oxide. Many of the satellitic porphyritic rocks are slightly epidotised or chloritised. Augite andesite porphyries in the region are considered to be generally unrelated to the plutonic igneous rocks. Minor basic augite diorite forms small stocks cropping out several kilometres distant from the main intrusion in the Rapmetka River. Hornblende diorite stocks, on the other hand, are mostly more closely related to the main intrusive mass, and in several instances are strongly intruded by microdiorite.

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Fairly coarse-grained biotite-augite diorite crops out at the foot of the east flank of Mt. Sinewit, in the Nengmukta River headwaters. Although exposure is poor, and field information is insufficient, the diorite appears to be part of a sub-volcanic pluton, roofed by or intruded into tuff and lava of the basal Mevlo Member of the Upper Miocene to Pliocene Sinewit Volcanics. The diorite comprises 80% plagioclase (An_{45-55}), 10 to 15% moderately altered augite and biotite, and 5 to 10% interstitial cloudy feldspar and quartz, some calcite, rare fluorite and accessory apatite. Biotite-augite andesite lavas of the basal volcanic member, which are exposed north and west of Mt. Sinewit, contain numerous cognate xenocrysts and xenoliths similar in composition to the underlying diorite, and this points to a possible genetic relationship. About 6 km southeast of Mt. Sinewit, porphyritic basic augite diorite crops out on the watershed between the Nengmukta, Rapmetka and Mevlo Rivers. The diorite includes abundant cognate xenocrysts up to 2.5 mm long of plagioclase and minor augite, and xenoliths up to 6 mm across of augite diorite (plagioclase and augite), in a finer-grained groundmass of plagioclase, some augite, rare hypersthene, abundant interstitial chloritic material and minor zeolite; plagioclase compositions determined by albite twin extinction angles are mostly sodic labradorite. The porphyritic intrusion strongly resembles lavas of the Mevlo Member. From stratigraphic evidence the subvolcanic pluton is younger than the other plutonic rocks in this area.

Petrography - southern Central and South Baining Mountains

In the southern part of the Central Baining Mountains and in the South Baining Mountains the plutonic rocks form a distinctive high-K calc-alkaline series which ranges in composition from leucogabbro and basic diorite, through diorite to monzonite and some adamellite. The series is characterised petrographically by the presence of orthoclase as a major mineral. The more leucocratic rocks tend to be enriched in orthoclase rather than quartz.

In the Central Baining Mountains, in the Kavavas and Merai Rivers minor leucogabbro and basic diorite grade into diorite and monzonite, some adamellite and minor granite granophyre. The rocks are medium-grained (up to 5 mm grainsize).

Plagioclase forms up to 70% by volume of some leucogabbros, basic diorites and diorites; it decreases to 40% (rarely to 30%) in some monzonites, to 30 (rarely to 25%) in adamellites, and varies from 25% to minor (rarely absent) in granite granophyres. It is mostly well formed, and may be strongly zoned (generally normal zoning). Twinning is well developed in many grains, and the composition of some grains may be determined from albite and Carlsbad-albite twin extinction angles. In leucogabbros and basic diorites the plagioclase is mostly sodic labradorite, and some calcic andesine, which may be zoned to oligoclase. In diorites, calcic andesine predominates, some sodic labradorite may be present, and a number of grains are zoned to oligoclase. Plagioclase composition in monzonites is andesine or oligoclase; in adamellites and granite granophyres it was not determined.

Orthoclase is absent or a minor component in leucogabbros and basic diorites; it varies from absent to 25% volume in diorites, from 25 to 40% in monzonites, up to 50% in adamellites, and up to 70% in granite granophyres. It varies in habit from small, interstitial grains, to large grains partly enclosing other minerals, and to small and large well-formed grains. In many rocks some of the orthoclase forms micrographic intergrowths with quartz, especially in the granite granophyres. In some rocks orthoclase is present as well formed grains, as large and small interstitial grains, and in minor micrographic intergrowth with quartz. In some sections it rims plagioclase and in one section large, well-formed grains of orthoclase have plagioclase cores, and orthoclase grains also enclose small patches of micrographic intergrowths. Orthoclase has a slightly perthitic appearance in some rocks, and in some is partly to highly kaolinised.

Quartz may be present in small amounts in leucogabbros and basic diorites; it is mostly less than 10% volume in diorites, and varies from 5 to 20% in monzonites, rarely up to 25% in adamellites, and up to 30% in granite granophyres. Because of the marked increase in orthoclase relative to quartz, which is characteristic of the suite, diorite rarely grades into granodiorite; several specimens examined petrographically are granodiorite transitional to adamellite in composition, comprising 40 to 50% plagioclase, 15 to 20% orthoclase, and 15 to 20% quartz. Quartz mostly forms ragged, interstitial grains. Micrographic intergrowth with orthoclase is present in many rocks, varying from a minor component in basic diorites and diorites, to major in granite granophyres (Fig. 28); it is mostly coarser than in the rocks of the North Baining batholith, and may contain all the quartz, but not all the orthoclase present in the rocks.

Ferromagnesian minerals mostly make up less than 20% volume of any thin section and rarely up to 30% of some of the more basic rocks. Augite is the predominant ferromagnesian mineral in leucogabbros and basic diorites, and is variably altered to secondary amphibole (some fibrous), chlorite, minor opaque oxide, and rarely calcite, epdiote or biotite. In rare leucogabbros it has a sub-ophitic texture, and in basic diorites a granular texture. In diorites and monzonites, augite may be rimmed by green hornblende (late magmatic replacement), or altered as in the more basic rocks; many sections contain small patches of chlorite, secondary amphibole, epidote, zeolite and opaque oxide, which may be pseudomorphs after augite. Primary hornblende accompanies relict augite in diorite and monzonite, or is the only primary ferromagnesian mineral present; it varies from spongy to well formed, and in some instances, is studded with fine opaque oxide. In some specimens hornblende is partly altered to pale green amphibole or rarely to chlorite. Primary green hornblende, variably altered to secondary amphibole or, less commonly, chlorite, makes up less than 10% of most adamellites. Granite granophyres mostly contain no ferromagnesian minerals. Minor biotite may be present in diorites, monzonites and adamellites. Opaque oxides make up from 2 to 5% of the plutonic rocks, but decrease to accessory in granite granophyres.

Petrographic examination of a composite plutonic rock from the Kavavas River headwaters shows it to consist of fairly coarse-grained adamellite (well-formed plagioclase and orthoclase, interstitial quartz, and rare hornblende and biotite) with unaltered xenoliths of slightly porphyritic hornblende microdiorite. The adamellite is invaded by fine-grained hornblende monzonite transitional to adamellite in composition; this consists of a mosaic of cloudy orthoclase, quartz and minor plagioclase, with scattered larger plagioclase grains and green hornblende (mostly studded with opaque oxide granules, some spongy, and some with cores of augite partly altered to calcite). In other thin sections, poorly-formed, large orthoclase grains are irregularly distributed.

Plutonic rocks in the South Baining batholith and in related stocks strongly resemble those which crop out in the southern part of the Central Baining Mountains.

Predominantly basic rocks are exposed in the east end of the batholith and in a number of related stocks. They are fairly dark in colour, doleritic in appearance, and form large intrusions as far as 15 km inland from Marunga on Wide Bay. Plutonic debris is swamped by volcanic debris shedding downstream from intrusions, and is mostly rare in river gravels on the coastal flats. Petrographic examination shows the plutonic rocks to be slightly altered, fairly fine-grained, commonly porphyritic dolerites, leucogabbros and some basic diorites, and in one area minor leucocratic monzonite. The basic rocks contain phenocrysts up to 2½ mm long of plagioclase and less common augite, with minor hypersthene, in an indistinct groundmass of cloudy plagioclase, interstitial feldspar and accessory opaque oxide; the groundmass may include interstitial chloritized mesostasis, minor quartz, and small patches of zeolite. Plagioclase phenocrysts are fractured and cloudy, kaolinised, partly chloritised or epidotised; their compositions are unknown. Pyroxenes generally make up less than 20% of any rock, and are unaltered or variably altered to pale green amphibole and some chlorite. Some pyroxenes are accompanied by aggregates of chlorite, pale green amphibole, serpentinous material, opaque oxide and minor epidote. In one thin section pyroxene is accompanied by an unidentified phyllosilicate(?), strongly pleochroic from straw-brown to green-brown and dark brown, with anomalous red-brown interference colours. In one thin section there is a 7 mm xenocryst of augite which optically encloses several plagioclase grains.

A small stream 5 km northeast of the east end of the batholith contains boulders of basic plutonic rocks, and some leucocratic monzonite. The monzonite consists of 40% plagioclase, 50% large, slightly perthitic orthoclase grains and interstitial orthoclase and quartz, and 10% lemon-yellow epidote and chlorite aggregates; fine micaceous haematite is associated with the ferromagnesian aggregates, and occurs in hair-like veins.

An olivine-bearing gabbro boulder in river gravel near Marunga is thought to have shed from a basic intrusion unrelated to the South Baining batholith, and is described in the later section concerned with basic plutonic rocks. The possible relations between calc-alkaline rocks and spatially related basic rocks are discussed in the later section concerned with parent calc-alkaline magmas.

In the central part of the South Baining batholith (Wulwut River and its east tributaries), plutonic rocks are mostly medium- to fairly coarse-grained leucocratic diorites, monzonites and minor monzonites transitional to adamellites; some darker leucogabbros and basic diorites are present.

Plagioclase in diorite makes up 50-85% of the rock; in monzonites, 30-50%. Grainsize varies from 1 to 4 mm, rarely up to 6 mm. In some rocks plagioclase is fresh, in others cloudy with incipient kaolinization or sericitization. Some grains are strongly zoned (normal zoning), and many display good Carlsbad-albite and albite twinning. Compositions determined from twin extinction angles vary from calcic andesine to less common sodic labradorite or rare calcic labradorite; in some instances, andesine is zoned to calcic oligoclase. In monzonites the compositions are generally slightly more sodic than in diorites; this is more apparent in some monzonites transitional to adamellites.

Orthoclase varies in abundance from 0-25% in diorite, and from 25-55% in monzonites. It occurs as small interstitial grains, as large irregular grains which may partly or completely enclose other minerals, and as well-formed small to large (6 mm long) grains, in some instances molded around small, well-formed or partly resorbed plagioclase cores. In many rocks it forms minor relatively coarse (rarely fine) micrographic intergrowth with quartz. Many large grains appear slightly perthitic. Orthoclase is mostly cloudy, varying from partly to highly kaolinised.

Quartz varies from 0-15% in diorites, from minor to 15% in monzonites, and from 15-20% in monzonites transitional to adamellites. It commonly forms small, interstitial grains, or is partly intergrown with orthoclase.

Ferromagnesian minerals vary from 15 to less than 5% by volume. Augite is the most common primary ferromagnesian mineral. It forms fairly large grains, which may be fresh or variably altered to aggregates of pale green or, rarely, colourless amphibole (some fibrous), chlorite and granular opaque oxides epidote calcite or biotite; some aggregates are charged with fine opaque oxide. In some sections, green hornblende rims augite (late magmatic replacement), or forms individual grains; it may be partly altered to secondary amphibole. Rare small flakes of biotite are apparently primary.

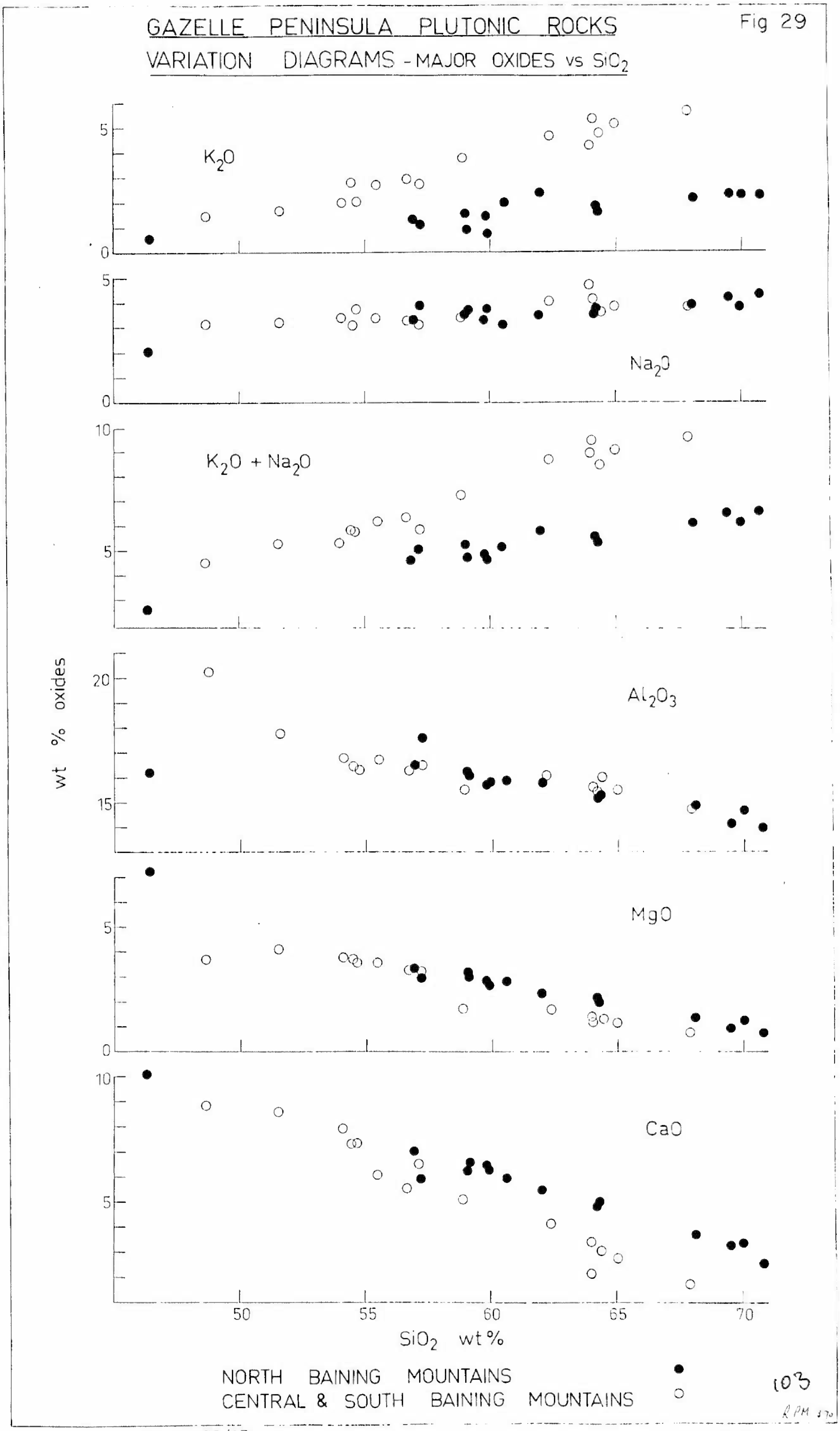
A monzonite-adamellite, from a small western tributary of the Wulwut River contains xenoliths of unaltered hornblende microdiorite and several poorly defined patches of microadamellite (containing more quartz and less plagioclase than the host).

Minor basic rocks are found in the gravels of the Wulwut River, and at the west end of the batholith; these are leucocratic diorites. They consist of 70 to 85% plagioclase, from 25 to less than 10% ferromagnesian minerals, up to 5% opaque oxide, and rare quartz and orthoclase. Plagioclase in many rocks in slightly porphyritic, varying up to 5 mm grainsize. It may be fractured, cloudy or indistinct, and is mostly strongly zoned (normal zoning) and poorly twinned. Composition appears to vary from more calcic to less calcic than An_{50}. Ferromagnesian minerals are primary augite, and its secondary replacement minerals (predominantly amphibole, which may be fibrous, with associated opaque oxide, which is granular or spongy). In some rocks, a sub-ophitic texture is apparent.

In the Duke of York Islands, sheared, leucocratic plutonic rocks crop out near the northwest corner of Makada Island. One sample examined petrographically is a fairly coarse-grained granite granophyre; the rocks are correlated with the high-K calc-alkaline plutonic rocks of the Central and South Baining Mountains. Phyllonites exposed on the coast (Fig.25) appear to have been developed by extreme mylonitization of the plutonic rocks; they consist of albite, quartz and some amphibole.

Chemistry of the Calc-alkaline Rocks

Major oxide analyses of thirty calc-alkaline plutonic rocks from the Gazelle Peninsula were carried out by A.M.D.L., Adelaide, using wet chemical techniques. Fifteen of the specimens analysed were collected from the North Baining batholith, and fifteen from the southernmost plutonic exposures in the Central Baining Mountains and from the South Baining batholith. Chemical analyses, C.I.P.W. norms, and modes (where determined), are tabulated in Appendix 1. Major oxide variation diagrams are presented in Figures 29 and 30; analyses were not recalculated water-free before plotting.



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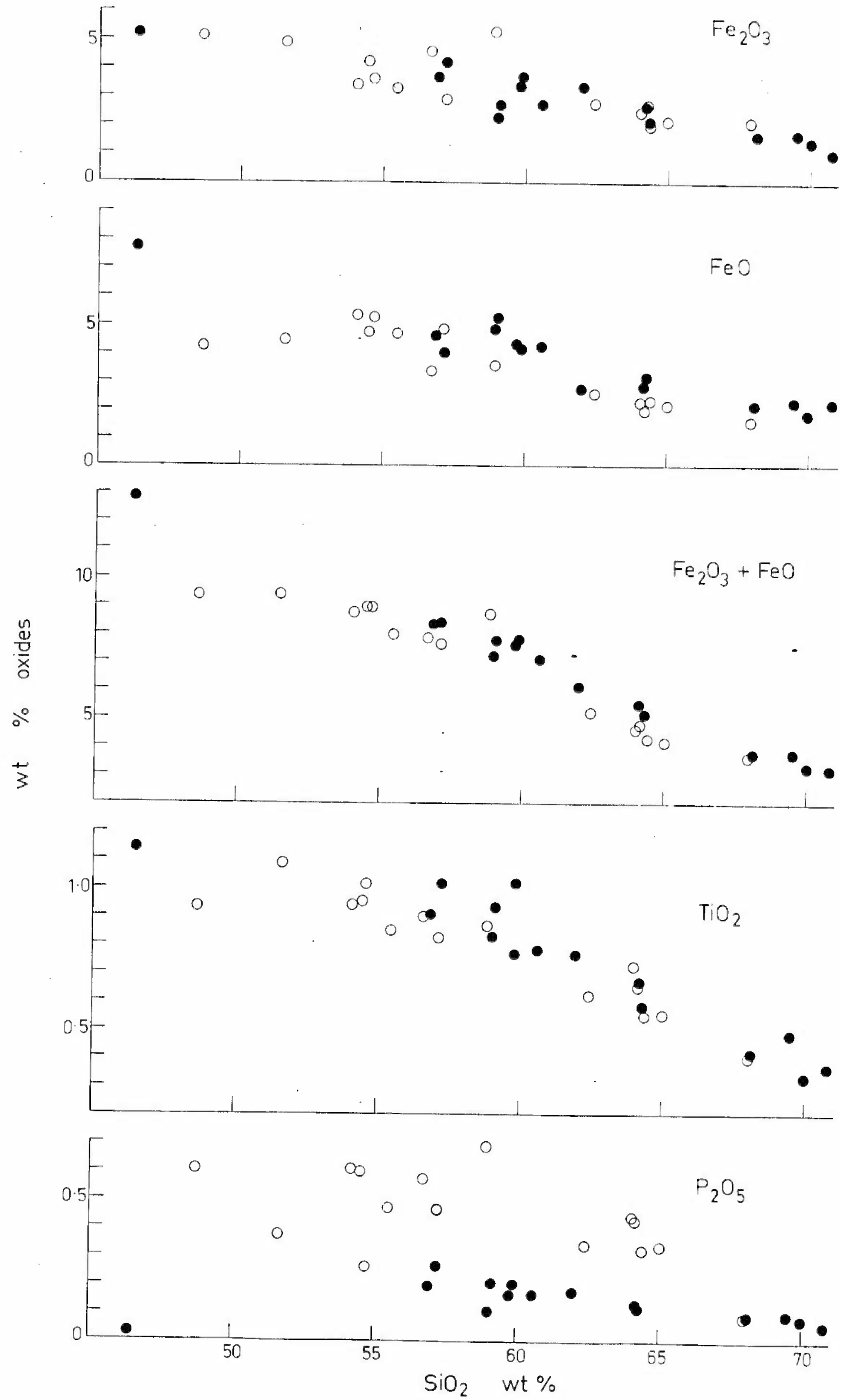
GAZELLE PENINSULA PLUTONIC ROCKS

Fig 30



NORTH BAINING MOUNTAINS ●
CENTRAL & SOUTH BAINING MOUNTAINS ○

The analyses substantiate petrographic conclusions, by defining two distinct calc-alkaline series, a normal series in the North Baining Mountains, and a high-K series in the Central and South Baining Mountains. The high K_2O content, along with a more rapid increase in K_2O with fractionation, cause the marked increase in modal orthoclase relative to quartz observed in the Central and South Baining rocks (diorite trends to monzonite and adamellite), in contrast with the greater increase in modal quartz relative to orthoclase observed in the North Baining rocks (diorite trends to tonalite and granodiorite).

The more basic rocks in the North Baining batholith are not adequately represented in the chemical analyses, and late stage vein and dyke differentiates from neither suite have been analysed, but examination of variation diagrams, along with petrographic information, suggests that SiO_2 varies in both from about 48% to slightly more than 70% (highest in the North Baining batholith). Al_2O_3 and Fe_2O_3 are comparable in the two series, FeO and MgO are slightly lower in the high-K series, and CaO is significantly lower in the high-K series, particularly in the more acid rocks. Na_2O is slightly higher in the high-K series. TiO_2 and MnO (the latter not plotted) are comparable, and P_2O_5 is higher and more variable in the high-K rocks.

The FMA diagram (Fig. 31) shows that the Gazelle Peninsula rocks are richer in iron, relative to alkalis and magnesia, than are many other calc-alkaline associations, e.g. Cascades volcanics (Carmichael, 1964) and Snoqualmie and Southern California batholiths (Erickson, 1969). If we assume that the Gazelle Peninsula rocks are comagmatic then the points on the FMA diagram may be taken to represent a fractionation trend. This trend is characterized by lack of progressive iron enrichment and is similar to other calc-alkaline fractionation trends such as that for the Cascades volcanics.

The KCN diagram (Fig. 31) illustrates the high-K (relative to Na) property of the Central and South Baining plutonic rocks. Late stage K-enrichment, characteristic of many calc-alkaline trends, is not evident in the K_2O vs SiO_2 and KCN diagrams of the Gazelle Peninsula rocks. Potash-enriched granite aplites and granite granophyres of the North Baining batholith are not represented in the chemical analyses.

Normative anorthite-orthoclase-albite and quartz-orthoclase-albite diagrams are presented in Fig. 32. Both diagrams illustrate the high-K characteristic of the Central and South Baining plutonic rocks. This is particularly evident in the quartz-orthoclase-albite diagram, in which the plots for the North Baining plutonic rocks show fractionation towards a fairly low-pressure ternary minimum typical of many high-level calc-alkaline plutons, while the plots for the high-K series show an anomalous trend, possibly indicating fractionation under higher pressure, in addition to the characteristic high-K.

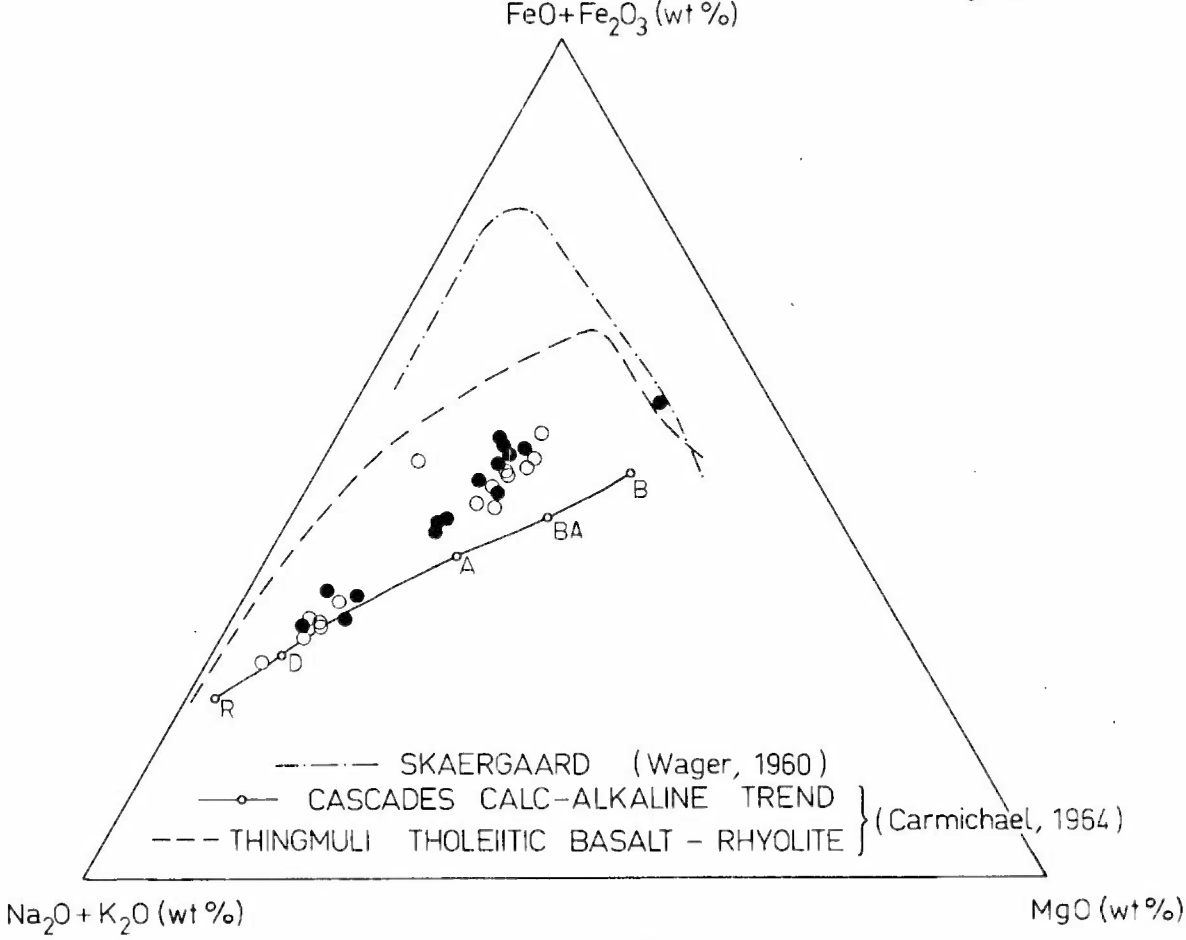
Modal quartz-orthoclase-plagioclase and K_2O/Na_2O vs SiO_2 diagrams are presented in the earlier section discussing rock classification (Figs 23-24).

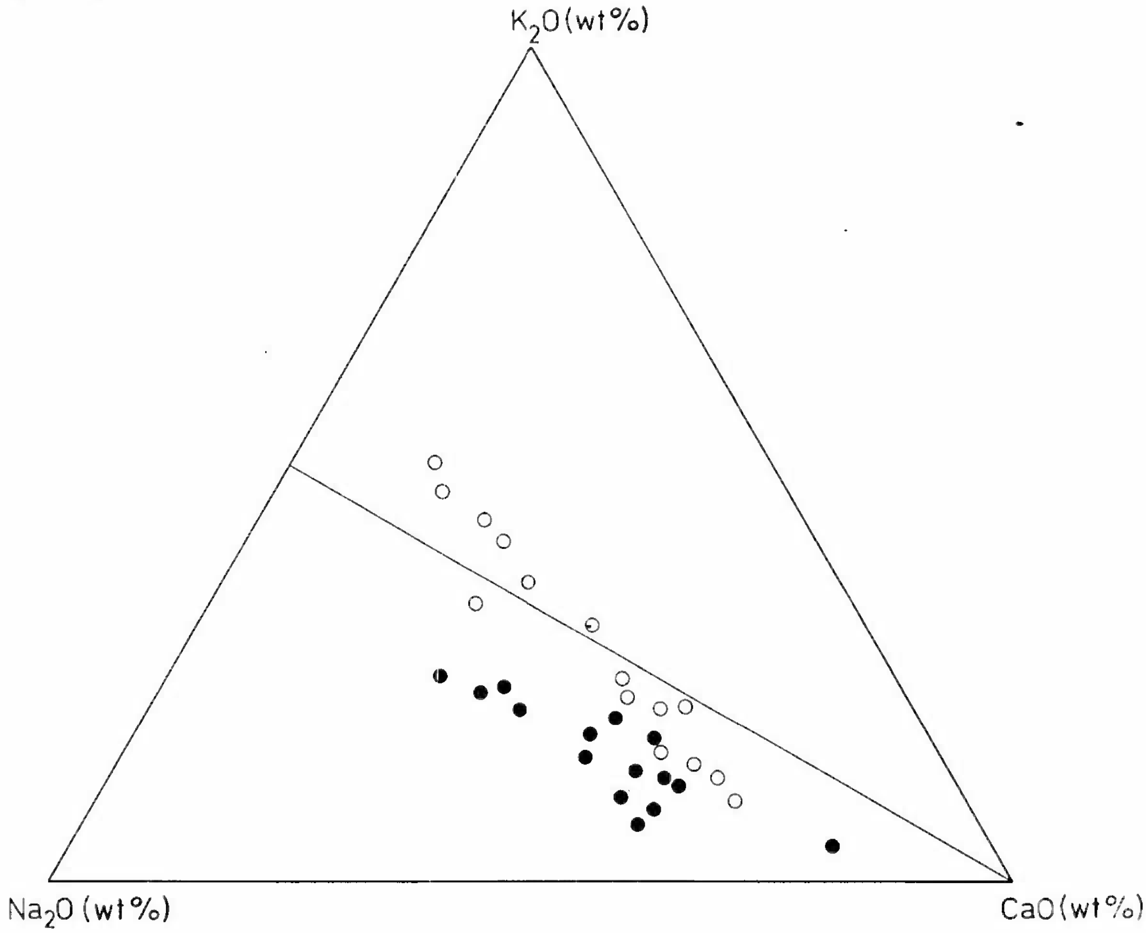
Discussion of Chemistry

The Gazelle Peninsula plutonic rocks intrude indurated, deformed Eocene marine volcaniclastic sedimentary rocks, which were probably deposited on oceanic crust. Their age is uncertain, but most intrusions probably took place between early Oligocene and early Middle Miocene (Tertiary 'c' and 'f' stages). The magma was presumably generated in the mantle. Interpretation of the crustal structure of the eastern part of the Bismarck Archipelago is presently nearing completion, following several deep seismic surveys carried out by the Bureau of Mineral Resources. A gravity map, detailing Bouguer Anomalies, has been prepared by the Geophyrical Branch of the Bureau of Mineral Resources.

GAZELLE PENINSULA PLUTONIC ROCKS - FMA & KCN DIAGRAMS

Fig. 31





NORTH BAINING MOUNTAINS ●
CENTRAL & SOUTH BAINING MOUNTAINS ○

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The role of K_2O in mantle derived igneous rocks is the subject of much conjecture. Because it does not substitute in the major mineral phases of the upper mantle (olivine, aluminous pyroxenes), K_2O must be partitioned into minor components (for example, phlogopite), which may be heterogeneously distributed (e.g. Green, 1968; Green and Ringwood, 1967).

Ocean floor and mid-ocean ridge tholeiites are typically K-poor (e.g. Engel et al. 1965). The K_2O content is higher in ocean island tholeiites (Macdonald and Katsura, 1964), and in continental tholeiites (McDougal, 1962; Waters, 1962; Carmichael, 1964). Rocks of the alkali olivine basalt suite have a higher and more variable K_2O content (Abbott, 1969; Manson, 1967; Baker et al., 1964). Shoshonitic rocks in areas of newly stabilized crust (Joplin, 1968) have a very high and variable K_2O content. Calc-alkaline rocks typically have a variable K_2O content similar to tholeiite, but in some it is considerably higher (Taylor, 1969; Moore et al., 1963).

Correlation between petrochemistry (including K_2O content) of basaltic volcanic rocks, and vertical depth to the Benioff Zone, was established in the Japan island arc by Kuno (1959); K_2O relative to SiO_2 increases westward towards and across the margin of continental crust. More recent studies in the circum-Pacific orogen have shown that K_2O relative to SiO_2 in calc-alkaline volcanic rocks increases with increasing vertical depth to the Benioff Zone. (Dickinson and Hatherton, 1967; Dickinson, 1968; Hatherton and Dickinson, 1969). The K_2O content of andesites may vary by a factor of four or five, for a constant SiO_2 content (Dickinson, 1968).

In northwestern North America it has long been recognised that K_2O increases in calc-alkaline plutonic rocks with similar SiO_2, away from the present day continental margin; this led to the concept of the quartz diorite line (Moore, 1959; Moore et al., 1963). K_2O relative to total alkalies also increases inland across the quartz diorite line (Moore, 1962). Writers correlated the increase in K_2O with assimilation of increasingly potassic country rock, or with increasingly potassic source material producing anatectic magmas. Recently Bateman and Dodge (1970) re-examined the petrochemistry of the Sierra Nevada batholith, and verified that K_2O relative to SiO_2 increases systematically from west to east. The writers briefly considered the commonly accepted anatectic model (e.g. Bateman and Eaton, 1967) and the inclined seismic plane model (Dickinson and Hatherton, 1967) as means of generating progressively more potassic magmas; they concluded that neither theory could be disproved on existing evidence. Hamilton (1970) has proposed that several thousand kilometres of Pacific crust underthrust the west margin of the Mesozoic North American continent, causing, among other effects, the eastward generation of increasingly more potassic intrusive and extrusive igneous rocks. This model is acceptable within the framework of presently accepted global textonics (e.g. Isacks et al. 1968; Le Pichon, 1968). The observed increase in K_2O relative to SiO_2 in the calc-alkaline plutonic rocks of northwestern North America may thus be the result of primary high-level crystallization of more potassic mantle-derived magmas, or later recycling of more potassic primary products (volcanic and plutonic) by anatexis or assimilation.

The observed petrochemical features, including partitioning of K_2O, in igneous rocks formed in characteristic tectonic environments, suggest control of magma composition by factors other than the chemistry of heterogeneous source material. Experimental data at the present day give some indication of the possible role of physical controls, principally total pressure, water pressure and temperature. World-wide systematic variations in petrochemistry imply systematic variations in physical controls in a fairly homogeneous source material (rather than systematic variation in the composition of a chemically heterogeneous source). For this reason, the correlation of magma composition in island arcs, with the vertical depth to downthrust oceanic lithosphere, represented by the Benioff Zone (Isacks et al., 1968), suggests that the magma is generated in the downthrust plate, and that its chemistry is controlled largely by physical parameters in the plate, which vary directly with vertical depth. This would also satisfy the two-stage model of calc-alkaline magma generation, proposed by Green and Ringwood (1968) from experimental data, and by Taylor (1969) from trace element data. Thus, in island arcs, calc-alkaline magmas with higher K_2O contents relative to SiO_2 are generated at increasing depths in the upper (oceanic crust) part of fairly steeply dipping underthrust lithosphere, the upper part of which is represented by a seismic envelope (Benioff Zone).

In the Gazelle Peninsula the crust is probably insufficiently thick for magma generation by partial melting near its base. The plutonic rocks are thus products of mantle-derived magmas. The magmas were intruded into country rock which is uniform in composition, and consists predominantly marine volcaniclastic rocks of fairly basic calc-alkaline (leucocratic augite andesite) to basic (subordinate spilite) composition, which was indurated and slightly deformed before emplacement of the plutons. There is no evidence of large-scale assimilation of country rock in the plutons. For these reasons, the contrasting petrochemistry of the North Baining and Central and South Baining plutonic rocks is considered to be a primary feature, reflecting different physical conditions at the magma source.

The present-day tectonic environment of the Gazelle Peninsula was imposed in response to a tectonic cycle which began late in the Pliocene. The Tectonic environment at the time of plutonic intrusive activity (Oligocene?) is not known, but we might infer from a study of the potash content of the intrusives that the area was then vertically above a south-dipping Benioff zone. Comparison with Figure 6 of Hatherton and Dickinson (1969) of K_2O values for 55 and 60% SiO_2 in the North Baining plutonic rocks

(1.0 and 1.4% K_2O) and in the Central and South Baining plutonic rocks (2.5 and 3.6% K_2O), yields vertical depths to the centre of a hypothetical Benioff Zone of 125 mm for the former, and 255 and 300 km for the latter. The depths estimated in the case of the North Baining batholith coincide; the difference in depths in the case of the Central and South Baining plutonic rocks may reflect fractionation or crystallization under higher pressure, which caused the anomalous fractionation trend in the normative quartz-orthoclase-albite diagram (Fig. 32).

Taylor (1969) proposed the following chemical limits for andesites: Low-silica andesite: 53-56% SiO_2; 0.7-2.5% K_2O Andesite: 56.62% SiO_2; 0.7-2.5% K_2O: Low-K andesite: 53-62% SiO_2; less than 0.7% K_2O: High-K andesite: 53-62% SiO_2; more than 2.5% K_2O: (Dacite: 62-68% SiO_2)

Table 1 presents average compositions of the two Gazelle Peninsula plutonic rock suites at 53, 56, 62 and 68% SiO_2 (read from the silica variation diagrams, Figs 29-30)

T	1	2	3	4	5	6	7	8
SiO_2	53.0	53.0	56.0	56.0	62.0	62.0	68.0	68.0
Al_2O_3	17.2	16.9	16.7	15.8	15.8	15.8	14.7	14.9
Fe_2O_3	4.3	4.3	3.85	3.85	2.8	2.8	1.9	1.9
FeO	5.8	5.2	5.1	4.5	3.5	2.8	2.3	1.6
MgO	4.2	3.9	3.7	3.4	2.4	1.8	1.4	0.7
CaO	8.25	8.05	7.3	6.45	5.5	3.7	3.7	1.7
NaO	2.9	3.25	3.25	3.65	3.55	3.9	3.8	4.1
K_2O	0.95	2.1	1.1	2.7	1.5	4.1	1.95	5.65
TiO_2	1.07	0.98	0.98	0.91	0.75	0.71	0.47	0.44
P_2O_5	0.24	0.55	0.22	0.50	0.15	0.40	0.10	0.28

Table 1. Analyses 1, 3, 5, 7 North Baining Mountains.
2, 4, 6, 8, Central and South Baining Mountains.

GAZELLE PENINSULA PLUTONIC ROCKS

Fig 32a NORMATIVE An – Or – Ab DIAGRAM

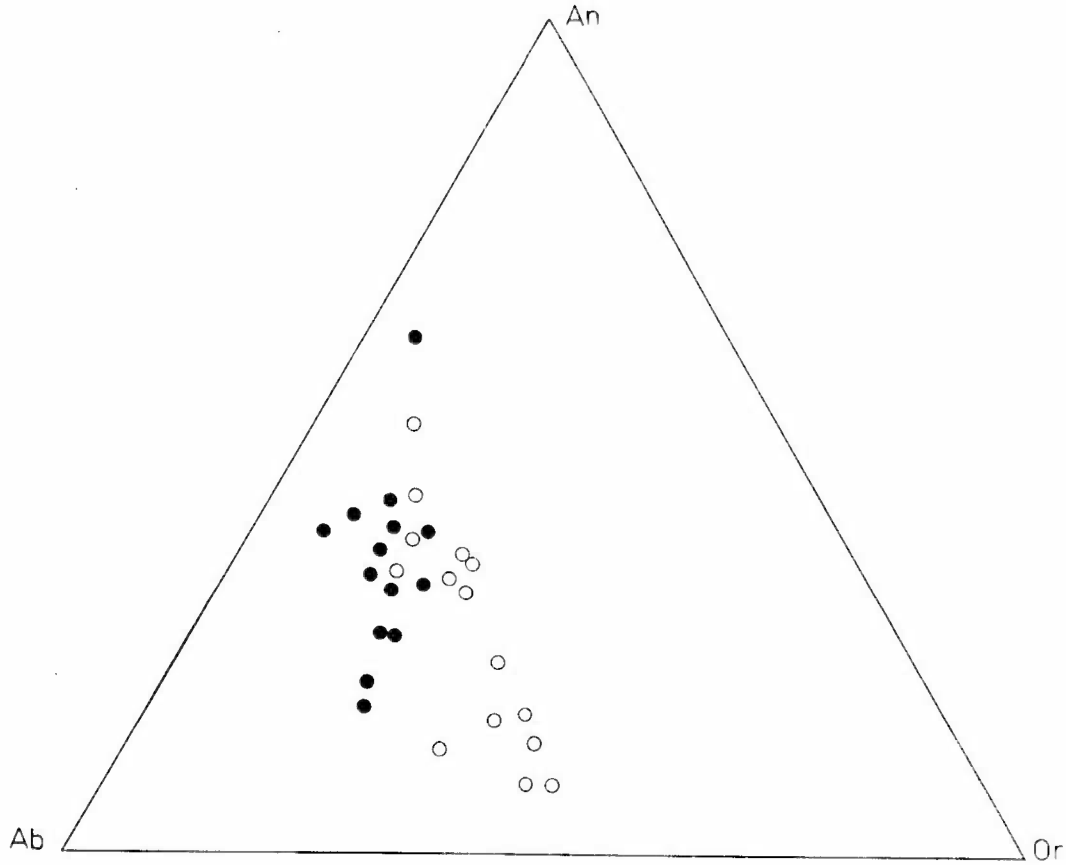
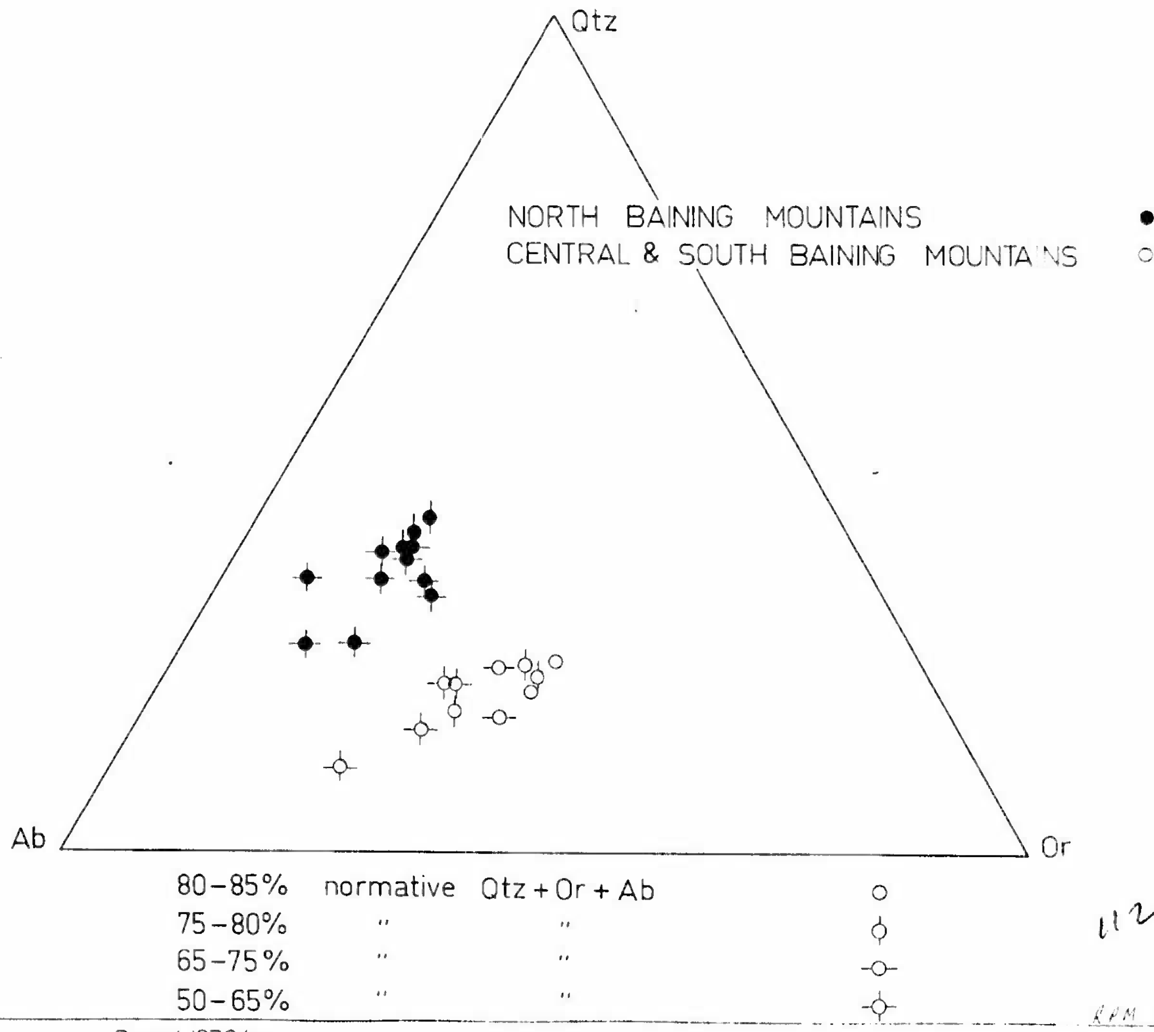


Fig 32b NORMATIVE Qtz – Or – Ab DIAGRAM



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The North Baining plutonic rocks strongly resemble normal calc-alkaline volcanic rocks. Except at 53% SiO_2, the Central and South Baining plutonic rocks resemble high-K calc-alkaline volcanic rocks: because of the normal increase in K_2O with SiO_2 displayed during fractionation of calc-alkaline rocks, the arbitary line separating andesites from high-K andesites should be inclined, not horizontal (2.5% K_2O) as imposed by Taylor (Taylor, 1969; Fig. 3 in Taylor et al., 1969).

High-K andesites are known from Bougainville Island, Indonesia and Japan but are not common. Table 2 presents chemical compositions of two high-K andesites from Bougainville Island, and an average andesite composition (all from Taylor et al., 1969), along with the relevent compositions of the high-K and normal Gazelle Peninsula plutonic rocks, determined from the variation diagrams.

	1	2	3	4	5	6
SiO_2	58.8	58.8	60.8	60.8	59.5	59.5
Al_2O_3	16.6	16.1	16.8	15.9	17.2	16.1
Fe_2O_3	3.95	3.6	2.20	2.9	total	3.4
FeO	2.95	3.7	3.15	3.2	6.10	4.1
MgO	3.25	2.7	2.15	2.1	3.42	2.8
CaO	6.35	5.2	5.60	4.4	7.03	6.3
Na_2O	3.60	3.4	4.10	3.8	3.68	3.5
K_2O	2.75	3.4	3.25	3.8	1.60	1.45
TiO_2	0.81	0.82	0.77	0.76	0.70	0.85
H_2O	0.42	-	0.31	-	-	-

Table 2 1, 3 Bougainville Island high-K andesites (Taylor et al., 1969).
2, 4 Gazelle Peninsula high-K calc-alkaline plutonic rocks, determined from variation diagrams.
5 Average andesite (Taylor et al., 1969).
6 Gazelle Peninsula normal calc-alkaline plutonic rocks, determined from variation diagrams.

Table 2 demonstrates petrochemical similarity between the Gazelle Peninsula high-K calc-alkaline plutonic rocks, and the Bougainville Island high-K calc-alkaline lavas; the plutonic rocks contain slightly higher K_2O, and lower CaO. The normal calc-alkaline plutonic rocks of the Gazelle Peninsula resemble Taylor's average andesite in composition, except for a higher total FeO content.

Parent Magmas

The compositions of parent magmas of the Gazelle Peninsula calc-alkaline plutonic rocks can not be estimated with any degree of accuracy. A major problem is to establish the role played by basic rocks spatially related to the calc-alkaline plutons.

Ophitic, sub-ophitic and related gabbroic textures in many leucogabbros and dolerites of the North Baining batholith point to crystallization of these rocks from a basic magma which possibly represents the parent magma for less basic members of the batholith. The predominance of diorite, tonalite and granodiorite, however, suggests a more acid parent. Petrochemical data and field relations indicate that the magma of the North Baining batholith fractionated at fairly low pressure (shallow depth), before high-level emplacement a short distance above the magma chamber. Fractionation from a basic parent would imply the accumulation of an improbably large volume of basic plutonic rocks at depth, beneath the exposed part of the batholith. If we assume a fairly basic andesite composition for the parent magma (say 56 to 58% SiO_2), then the granular basic rocks (basic diorites and some diorites) may be crystal cumulates, and the more acid rocks may be the products of liquid fractionation. On this scheme the leucogabbros and dolerites might be earlier formed, unrelated intrusives.

The initial intrusion of genetically unrelated basic rocks characterizes many calc-alkaline batholiths (Joplin, 1959) and smooth curves in major element variation diagrams are not positive proof of cosanguinity (Rhodes, 1969; Taubeneck, 1957). Without trace element and isotope data, it is not possible to positively establish the relationship between leucogabbros and dolerites forming part of the east end of the North Baining batholith and peripheral intrusions, and the less basic bulk of the batholith.

Plutonic rocks in the northern part of the Central Baining Mountains resemble those of the North Baining batholith; rare basic rocks with gabbroic textures are probably related to widespread basic plutonic activity, which preceeded intrusion of the calc-alkaline plutons. There are no chemical analyses from the area, but the parent magma for the calc-alkaline rocks was probably similar in composition to that of the North Baining batholith (and may have formed in the same phase of plutonic activity). The sub-volcanic pluton underlying Mt. Sinewit is a younger intrusion of similar composition.

Basic rocks with gabbroic textures are less closely associated with the high-K plutonic rocks, in the southern part of the Central Baining Mountains and in the South Baining Mountains. Porphyritic basic rocks (dolerites, leucogabbros, basic diorites) which form the greater part of the eastern end of the South Baining batholith, and related stocks, may be either cumulates from a calc-alkaline parent magma, or primary basic rocks crystallized from a basic magma. It is not possible to verify either mode of origin without further chemical analyses, but petrographic data might be interpreted to indicate accumulation of early formed crystals in a calc-alkaline melt, The parent magma of the Central and South Baining plutonic rocks might be basic high-K andesite (around 55% SiO_2). Although the plutons were emplaced at shallow depths, the trend displayed in the normative quartz-orthoclase-albite diagram suggests fractionation at considerably greater depths.

Basic plutonic rocks

Small stocks of gabbro, leucogabbro and dolerite widely intrude Baining Volcanics in the Gazelle Peninsula; individual bodies are mostly too small to be shown on the geological map. South of Open Bay, coarse-grained grey dolerite intrudes the Merai Volcanics.

In the North Baining Mountains gabbro, leucogabbro and some dolerite intrusions are widespread in the Toriu River headwaters; quartz dolerite crops out extensively on the watershed between the Toriu River and streams draining into Ataliklikun Bay, and leucogabbro and dolerite form satellitic stocks and crop out in the east end of the North Baining batholith.

Dark, coarse-grained gabbros in the Toriu River headwaters consist of large, fractured and partly altered plagioclase grains, ophitically enclosed in augite (partly altered to secondary amphibole). More common leucogabbros are mostly porphyritic in plagioclase; groundmass plagioclase and augite are set in interstitial chloritised mesostasis. Dolerites commonly contain less than 20% augite; some contain up to 5% quartz, for example, the large intrusive mass exposed on the watershed north of the Toriu River headwaters. Ophitic and sub-ophitic textures are common in leucogabbros and dolerites spatially associated with the North Baining batholith (they are discussed more fully in previous sections on the North Baining batholith); some basic rocks with granular textures which crop out near the batholith may be related to the earlier basic intrusion.

Small stocks of leucogabbro and dolerite in the Central Baining Mountains belong to a period of basic intrusive activity earlier than the emplacement of the calc-alkaline plutons.

Chemistry of basic rocks

In the South Baining Mountains dolerite and leucogabbro intrusions are widespread east of the South Baining batholith. Three specimens collected at Cape Archway on Wide Bay, were submitted to A.M.D.L., Adelaide, for wet chemical analysis. The specimens are typical of the plutonic fraction common in gravel bars at river mouths along the southeast coast from Eber Bay to Marunga; they are considered representative of basic rocks which form stocks in the east part of the South Baining Mountains. Chemical compositions and C.I.P.W. norms are presented in Table 3.

The basic intrusives are typically fairly leucocratic porphyritic dolerites and leucogabbros (dark grey in hand specimen) consisting of phenocrysts (up to 6 mm long in leucogabbros, rarely up to 6 mm long in dolerites) of calcic plagioclase, and subordinate

	1	2	3		1	2	3
SiO_2	48.1	51.9	52.8	Qtz	-	6.49	5.86
Al_2O_3	20.2	16.9	18.8	Or	2.13	5.79	9.81
Fe_2O_3	2.3	2.05	2.95	Ab	27.06	20.72	27.49
FeO	6.7	6.2	5.15	An	39.69	32.22	31.81
MgO	4.35	5.0	2.9	Di-Wo	3.79	4.53	2.21
CaO	10.2	9.35	8.25	-En	2.03	2.61	1.21
Na_2O	3.2	2.45	3.25	-Fs	1.64	1.71	0.92
K_2O	0.36	0.98	1.66	Hy-En	5.79	9.84	6.01
H_2O+	2.9	2.7	2.1	-Fs	4.69	6.44	4.56
H_2O-	0.45	0.55	0.43	Fo	2.11	-	-
CO_2	0.06	0.13	0.16	Fa	1.88	-	-
TiO_2	0.99	0.93	0.93	Mt	3.33	2.97	4.28
P_2O_5	0.22	0.38	0.43	Il	1.88	1.77	1.77
MnO	0.14	0.18	0.15	Ap	0.52	0.90	1.02
Total	100.17	99.7	99.96	Ct	0.14	0.30	0.36
				H_2O	3.35	3.25	2.53

Table 3 Chemical and C.I.P.W. normative compsoitions of 3 South Baining Mountains basic rocks. Number 1 (field number 53NG0865B) is a porphyritic gabbro; numbers 2 and 3 (field numbers 53NG0865C and A) are porphyritic dolerites.

smaller augite and, rarely, hypersthene phenocrysts, in a groundmass of plagioclase, less common augite and granular opaque oxide, some interstitial feldspar and common chloritised mesostasis, and, in some instances, minor quartz. Petrographic examination of a black porphyritic gabbro (specimen collected from a river boulder in gravel beds near Marunga) shows it to comprise more than 50% phenocrysts of augite with resorbed margins (up to 4.5 mm long, rarely up to 8 mm), smaller plagioclase grains, and subordinate olivine with green serpentine rims (and some serpentine pseudomorphs after olivine), in a fine-grained groundmass of plagioclase grains, granular augite and opaque oxide, and minor chlorite. The basic intrusives are tholeiitic; olivine accompanies hypersthene in the norm of the analysed gabbro, and quartz accompanies hypersthene in the norms of the dolerites.

Dolerites intruding Merai Volcanics south of Open Bay are described in the section on Merai Volcanics.

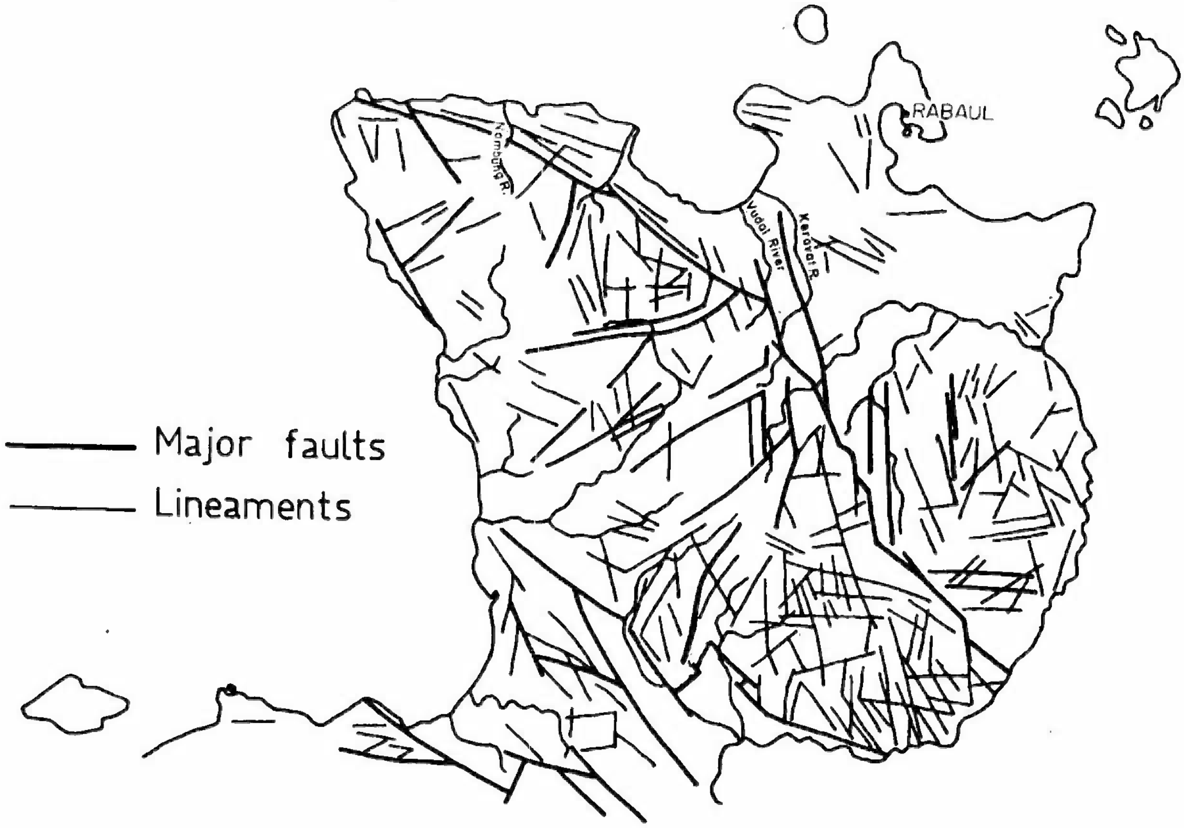
STRUCTURE

High-angle faulting of mostly Quaternary age dominates the structure of the Gazelle Peninsula, and controls present day topography. Large vertical displacements can be demonstrated across a number of major northwest-trending faults, and transcurrent displacement can be inferred but not measured across several of these. Large vertical displacements can be demonstrated across several northeast-trending faults. Many faults are active at the present day, and the Gazelle Peninsula is an area of high seismicity.

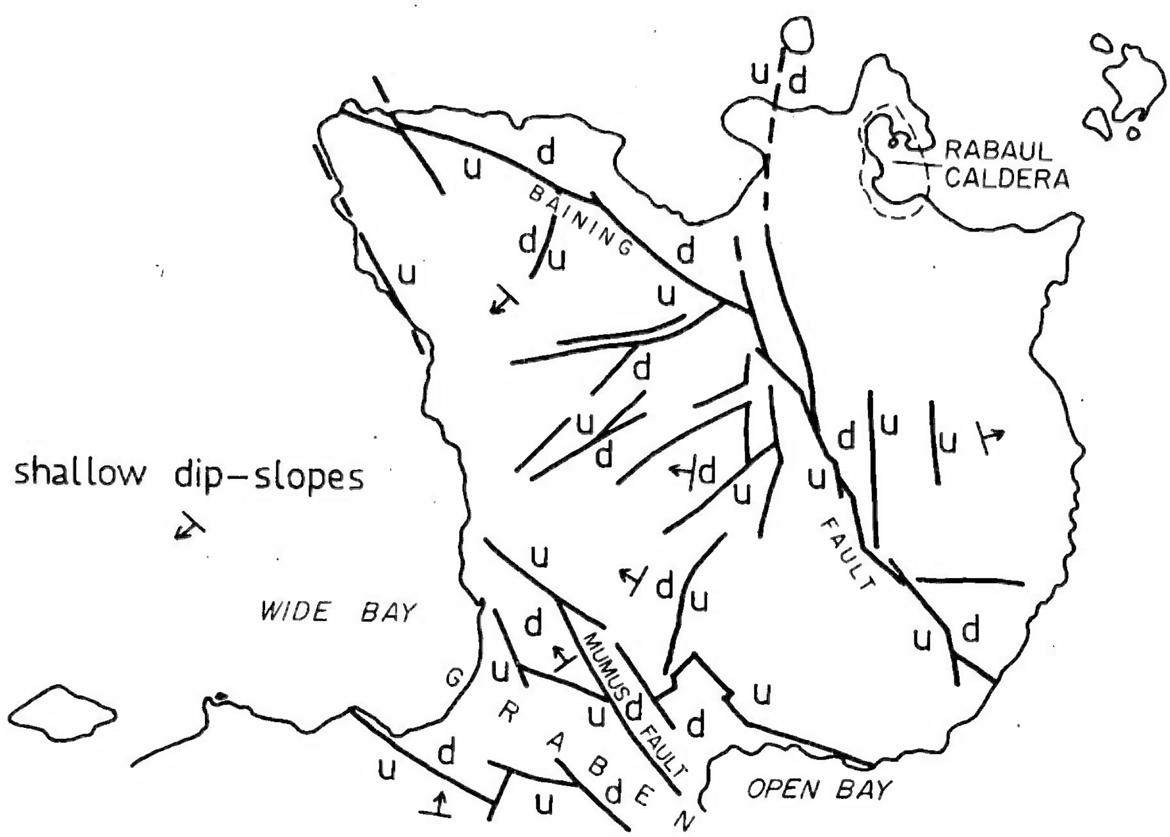
The broad structural features of the Gazelle Peninsula are (i) an elongate, northwest-trending, up-faulted block, flanked to the northeast by (ii) a composite block of dominantly low elevation, and to the southwest by (iii) a complex northwest-trending graben, forming the isthmus between the Peninsula and the main part of the island of New Britain. Major faults and lineaments (probable faults) are detailed in Figure 33.

Fig. 33

GAZELLE PENINSULA STRUCTURAL MAP



Major Structural Elements



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(i) The fault-bounded mountain block is roughly wedge-shaped, and forms the core of the Peninsula. It includes most of the North and South Baining Mountains, and the west part of the Central Baining Mountains. In the northeast it is bounded by the Baining Fault, and in the southwest by a complex system of faults extending from north of Wide Bay to the Toriu River mouth (and possibly northwest along the coast of the Peninsula). Major northeast-trending faults and a graben structure (enclosing the lower and middle reaches of the Toriu River) separate the North Baining Mountains from the west part of the Central Baining Mountains. Uplift of the mountain block is greatest along the Baining Fault, reaching a maximum in the South Baining Mountains (evidenced by outcrop patterns, dip-slopes and present day topography). Present day drainage in the South Baining Mountains is largely controlled by strong lineaments (Fig. 34).

(ii) The area northeast of the Baining Fault can be divided into three structural domains. Major faults in this area have a more northerly trend than elsewhere in the Peninsula.

(a) In the Northeast Lowland and in the lower headwaters of the Warangoi River, all but the most recent structures are concealed by volcanic ash (former area) or unconsolidated sediments (latter area). A small number of lineations indicate very recent movements, probably on older, buried faults.

(b) West of the Northeast Lowland are several north-trending splay faults of the Baining Fault; farther west, along the North Baining Coast, lineations and small faults parallel the Baining Fault.

(c) South of the Northeast Lowland, and east of the Warangoi River headwaters, Upper Miocene to Pliocene lavas, pyroclastics and derived sedimentary rocks are strongly deformed by rotation of blocks between numerous, intersecting high-angle faults. Dips are predominantly shallow, but vary from near horizontal to vertical.

Upfaulted blocks of Baining Volcanics are exposed in several areas, in one area intruded by basic plutonic rocks; a short distance to the south partly fault-bounded inliers of Merai Volcanics are exposed. Several major north-trending faults are apparent, obscured in the north by ash from the Rabaul eruptive centre. The westernmost of these may be a splay fault of the Baining Fault; it forms the boundary with the Riet Beds, which are folded and deformed near the contact.

(iii) A complex, northwest-trending graben forms the Wide Bay - Open Bay isthmus. North of Wide Bay faults juxtapose poorly consolidated, predominantly marine Upper Miocene to Pliocene sedimentary rocks against uplifted Baining Volcanics. East of Open Bay there is a single less prominent boundary fault; uplift of the moutain block was less, and the fault is entirely within the younger sedimentary rocks. Northwest of Wide Bay, Merai Volcanics are uplifted along the Mumus Fault; the Mumus Fault forms splay faults south and southwest of the Lakit Range. A prominent system of faults forms the south border of the graben and these are probably still active, for the mountain block south of the graben was elevated in late Pleistocene to Recent time. Some transcurrent movement may have taken place on the Mumus Fault and on the southern boundary faults of the graben.

The Baining Fault is a major active fault and is marked by a zone of intense mylonitisation up to 100 m wide. Uplift on the southwestern side of the fault is reflected in present-day topography (Fig. 35). In its southern and central part, the Fault trends north of northwest, and is characterised by a series of sharp offsets; major splay faults trend north along the Kavavas and Keravat Rivers, and slightly west of north along the Vudal River. West of the Vudal River the fault is slighgly sinuous with no offsets; it trends northwest to near the Batonga River, and west of northwest to the north coast near Cape Lambert.

Figure 34. Drainage controlled by faults and joints in the South Baining Mountains (two stereoscopic pairs). Scale 1:100,000 approx.

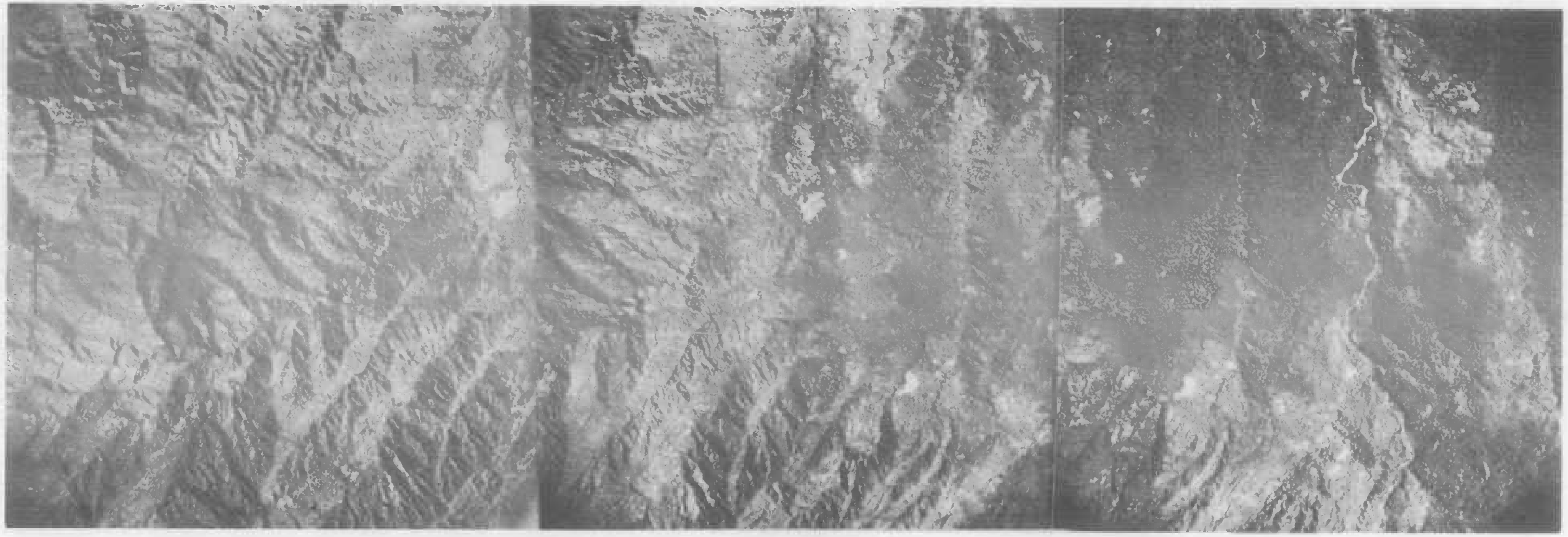

Figure 35. Fault-bounded mountain block southwest of the Baining Fault, in the headwaters of the Rapmetka and Kavavas Rivers (two spereoscopic pairs)
Scale: 1:100,000 approx.

Vertical uplift of the block south of the Fault is apparent in the hinterland of the east part of the North Baining coast: the base of the Yalam Limestone north of the Fault is more than 500 m lower than the projected base of the limestone south of the Fault. To the south, in the Warangoi and Merai Rivers headwaters outcrop patterns and present day topography indicate 2000 m uplift of the southwest block since Pliocene times. Uplift of Yalam Limestone west of the north extension of the Keravat River splay fault was probably the main cause of the formation of Rembarr Range.

Possible transcurrent movement on the Baining Fault is indicated by the presence of a large fault wedge of Yalam Limestone in the intricate zone of the fault close to the Nambung River. The fault wedge is downthrown 500 m. The downthrow appears to be the result of oblique slip rather than dip slip. The configuration of the Baining Fault indicates that any strike-slip movement might have had an anticlockwise sense.

In the Central Baining Mountains the Baining Fault dips steeply to the northeast. Poorly consolidated Riet Beds which abut against it show evidence of very recent disturbance. Carbonized wood collected from a fault wedge differentially rotated up to 60° from the horizontal (Nengmukta River), yielded a C^{14} age of about 50,000 years. Hot meteoric water flows from the Baining Fault at several localities in the Central Baining Mountains, and from several north-trending faults east of the Kavavas River.

<u>1941 earthquake on the Baining Fault</u>

In the early morning of January 14th, 1941, the Gazelle Peninsula was shaken by the most severe earthquake experienced in the area this century. Seismic instruments in the Rabaul Volcanological Observatory were put out of action in the initial stages of the main shock, but were restored to record many of the aftershocks; careful collection of data from various sources has permitted partial reconstruction of the event (Fisher, 1944). The earthquake was centred on or near the Baining Fault in the Keravat River headwaters, and phenomena reported by Fisher point to transference of the shock (or even movement) along much of the Baining Fault system. The main shock, of 2 to 3 minutes duration, was accompanied by loud rumbling noises. Aftershocks occurred every few minutes for several hours and in many instances were accompanied by loud rumbling or deep booming sounds. The aftershocks tailed off over a period of several weeks; most were located mostly in the same areas as the main shock, but some epicentres were up to 30 km distant.

Damage to buildings, and small gravity collapses were widespread in the Northeast Lowland. Phenomena which were directly related to the main shock included:

(i) Formation of several dams; the largest was in the headwaters of the Vudal River and is partly preserved at the present day. Fisher considered movement here was so severe that the epicentre must have been located nearby, and that part of the collapse was due to rupturing of the rock. The dammed stream follows the trace of the Vudal River splay fault, and the dam is located near where it separates from the Baining Fault, which displays a sharp northwest change in trend.

(ii) Numerous severe landslides in the Kavavas and Merai Rivers headwaters in the steep country immediately southwest of the Baining Fault.

(iii) Northwest-trending cracks in the ground near the east side of Ataliklikun Bay, and the formation in the same area of hot water springs, which soon cooled off and dried up. These events were probably related to minor movement on the north extension of the Keravat River splay fault. The cracks could not be ascribed to simple gravity subsidence.

(iv) Subsidence of up to 1 m along the west side of Ataliklikun Bay (again not ascribed to gravity phenomena).

At that time the Baining Fault was not known to exist. From topographic and seismic evidence Fisher deduced that the earthquake was caused by movement in a linear zone of weakness between Ataliklikun Bay and the mouth of the Warangoi River.

GEOLOGICAL HISTORY

Seafloor vulcanism in the Eocene constructed an island or series of islands in the area now occupied by New Britain. The volcanic products were andesitic with minor spilitic tephra and lava (Baining Volcanics); these were cut by contemporaneous andesite porphyry and dolerite dykes.

Moderate deformation in the late Eocene or early Oligocene produced steep tilting (possibly folding) about east-west axes, strong jointing, shearing, and local dynamic metamorphism to biotite and hornblende schists.

Vulcanism resumed in the Upper Oligocene to Lower Miocene (Tertiary e stage Merai Volcanics) in an environment of volcanic islands with some limestone reefs and shoals. Plutonic rocks which range in composition from leucogabbro to adamellite were emplaced at about this time and were possibly comagmatic with the Merai Volcanics. A tonalite from this suite has a radiometric age of 14 m.y. (Middle Miocene). Potash content of the plutonic rocks is higher in the southern part of the Gazelle Peninsula; this might indicate that there was a south-dipping Benioff zone under New Britain in Oligocene to Miocene times.

Vulcanism ceased abruptly before the Middle Miocene and a blanket of limestone (Yalam Limestone) more than 1000 m thick was deposited over the volcanic islands. Deposition continued through the Middle Miocene (Tertiary lower f stage) and possibly into the Upper Miocene (Tertiary upper f stage). Probably the islands subsided slowly throughout this period.

Vulcanism resumed in the Upper Miocene and Pliocene with the deposition of marine tuffaceous sediments (Nengmukta Volcanics) followed by marine and subaerial tephra and lavas (Sinewit and Sigule Volcanics). Limestone and fine calcareous sediments were laid down in the Wide Bay area in the Pliocene (Lakit Limestone, Sai Beds).

The present tectonic regime was established in the late Pliocene; it is characterized by vertical and possibly some horizontal displacements. The vertical movements have elevated the Gazelle Peninsula landmass and depressed parts of the Wide Bay - Open Bay graben to produce the two bays. The major faults are northwesterly and thus Gazelle Peninsula appears to have more structural affinities with New Ireland and the Solomon Islands than with the remainder of New Britain.

The Rabaul volcanic centre has been active since Pliocene or Pleistocene time and has mantled much of the northeastern part of the peninsula with ash. The Rabaul caldera developed by collapse 1000 - 1500 years ago. Volcanic cones have formed within and around the caldera and some are still active. Lolobau Island and North Son are other Quaternary volcanic centres.

ECONOMIC GEOLOGY

Except for small amounts of gold there has been no mineral production in the Gazelle Peninsula. Base metal mineralization is known and systematic exploration is continuing.

Small quantities of river gravel and various quarried materials are crushed to privide aggregate for road surfaces and concrete. Sulphur, pumice and limestone deposits have been investigated.

Gold

In the early 1900s a small amount of alluvial gold was won from streams near the west end of the North Baining coast, shedding mostly from quartz veins in plutonic rocks. In 1933 a small, apparently payable lode was discovered and an area of 2.5 sq km mile was proclaimed the Talele Provisional Goldfield. In the following several years production from the goldfield and adjoining areas was low. The area was visited in 1936 by Fisher (1942a) who concluded that there was little chance of finding either lode or alluvial gold in commercial quantities. There has been no recorded gold production in the area since the late 1930s.

Colours of gold have been reported from a number of streams intersecting plutonic rocks in the Central Baining Mountains.

Iron Ore

The occurrence of iron ore near the west end of the North Baining coast was known before 1914. The deposits were briefly examined in 1922 by Stanley (1922b) and in 1936 by Fisher (1942a). Continuing interest led to their re-examination by geologists of the Bureau of Mineral Resources (Randon, 1956), and subsequent drilling (Gardner, 1957).

The iron ore deposits crop out in the vicinity of Rangarere Plantation, on low spurs rising from the narrow coastal plain towards the main ranges of the hinterland. Baining Volcanics in the general area are intruded by plutonic rocks of the North Baining batholith, and mineralization is related to the plutonic activity. The Volcanics consist of indurated, massive, fine-grained volcanic conglomerate, greywacke and siltstone, with some interbedded lava flows and minor limestone. Strong faulting and the general lack of bedding prevent a clear understanding of local structure. Recent uplift south of the most westerly extension of the Baining Fault (a short distance south of the mineralized area) has caused the deposition and subsequent uplift of extensive boulder beds along the edge of the coastal plain.

The mineralized area was examined only very briefly by the writer; the following interpretation is drawn from observations by Fisher and Gardner, and the writer's knowledge of the regional geology. Intrusion of the plutonic rocks caused widespread thermal and hydrothermal alteration of the Baining Volcanics, accompanied by several phases of mineralization. The iron ore deposits were formed from hydrothermal solutions, by fracture infilling and partly by replacement in recrystallized limestone (and possibly siltstone). Alteration products of the limestone vary from nearly pure marble to skarn deposits. A later phase of mineralization introduced quartz-pyrite veins which, in some instances, contain minor copper, lead and zinc sulphides; gold mineralization in the area was probably also introduced in this phase of hydrothermal activity.

The iron ore deposits consist of magnetite (part altered to haematite) in small steep-dipping lenticular bodies, rarely up to 30 m wide. Assay results from a number of sources show the ore to be high quality with 60 to 72% Fe, mostly less than 3% SiO_2, less than 0.1% TiO_2, mostly trace P_2O_5, and variable amounts of S (mostly less than 2%, rarely up to 8%). Reserves are small, and drilling proved less than 100,000 tons probable ore, with little more than 50,000 tons possible ore (Gardner, 1957).

Magnetite ore like that at Rangarere is exposed on a steep spur in the Rapmetka River headwaters, in the Central Baining Mountains; hydrothermal alteration of Baining Volcanics is similar in the two areas. The occurrence was not closely examined by the writer.

Copper, Lead, Zinc and Molybdenum

Minor copper, lead and zinc sulphides occur with pyrite in narrow quartz veins in the vicinity of Rangarere Plantation. Mineralization is associated with hydrothermal activity accompanying the emplacement of nearby plutons. There seems little prospect of large ore bodies (Stanley, 1922b; Fisher, 1942a; Gardner, 1957).

Copper and related mineralization in the Warangoi River headwaters was investigated by the writer in 1966 (Macnab, 1967). In the middle reaches of the Rapmetka River, minor base metal sulphide mineralization occurs throughout a dioritic pluton which crops out over an area of about 5 sq km, and is bounded to the northeast by the Baining Fault. The intrusive mass grades in composition from fairly leucocratic hornblende-biotite tonalite to hornblende diorite and granodiorite; mineralization pre-dated movement on the Baining Fault, which shows no evidence of mineralization. Quartz, quartz-calcite and pegmatite veins and dykes irregularly distributed throughout the pluton contain patchy mineralization with chalcopyrite, some bornite, galena, low-Fe sphalerite, molybdenite and, rarely, tetrahedrite. The veins are up to 0.5 m across and occupy irregular fractures within the pluton and the immediately adjacent country rock. Small patches of slightly to highly altered (K-alteration) plutonic rock contain disseminated bornite, chalcopyrite and molybdenite, with abundant magnetite, closely associated with aggregates of altered ferromagnesian minerals. Alteration and mineralization is closely related to veining in some instances, but in others there is no obvious channel for introduction of late magmatic fluids.

Stream sediment sampling demonstrated that Cu values in streams within the pluton rarely exceed 250 ppm, while a low anomaly (values in excess of 100 ppm) occurs within the pluton in a narrow zone mostly about a half kilometre wide, along the intrusive margin. Cu values in stream sediment samples reflect the relative abundance of very fine grains of Cu minerals, and not the degree of precipitation of Cu compounds on fines, which are mostly absent from the sediment. Analyses of stream sediment samples for Mo demonstrated anomalous values throughout the pluton, rarely in excess of 100 ppm (with a background value outside the pluton of less than 10 ppm).

A limited soil sampling programme verified the existance of a Cu anomaly along the margin of the intrusive body; Cu values in weathered bedrock vary mostly from 200 to 600 ppm, rarely to 6,000 ppm over patches of mineralization. Values vary considerably within single soil profiles; samples should be collected from depths of about a half metre or from weathered bedrock which lies at 0.6 to 2 m depth in the area sampled.

Because the greater part of the pluton is completely barren, and is not altered except for some incipient alteration of ferromagnesian minerals, there is little prospect of locating large ore reserves. The mineralized area was held under Authority by a syndicate of Baining natives from a nearby village, along with a European plantation owner. In 1968 it was investigated on their behalf by ASARCO, who concluded that the area showed little promise.

In the Nengmukta River there is minor malachite staining of plutonic rocks within the adjacent to the Baining Fault zone, and copper, lead and zinc sulphides are sparsely scattered through a quartz-healed fault breccia in Nengmukta Volcanics.

In the South Baining Mountains, in an area adjacent to the South Baining batholith, vein quartz in brecciated Baining Volcanics contains minor bornite.

(3)

In the east arm of the Batonga River (which flows into the sea at the east end of the North Baining coast), stream boulders of very highly sericitised, coarse-grained tonalite porphyry contain abundant pyrite and, in several instances, minor chalcopyrite and molybdenite. The tonalite porphyry consists of rounded grains of quartz and fewer plagioclase phenocrysts, in a groundmass of mosaic quartz and abundant sericite.

Several plutonic boulders in the Sai River (which flows into Open Bay from south of the Gazelle Peninsula) were found to contain disseminated chalcopyrite similar to some samples from the Warangoi River headwaters. A specimen of sericitised hornblende-biotite tonalite assayed 0.7% Cu.

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APPENDIX 1

GAZELLE PENINSULA PLUTONIC ROCKS

CHEMICAL ANALYSES C.I.P.W. NORMS, AND MODES

Chemical Analyses

	1	2	3	4	5	6	7	8	9	10
SiO_2	56.9	69.5	46.4	57.2	59.9	70.0	62.0	60.6	64.3	68.1
Al_2O_3	16.5	14.1	16.2	17.6	15.8	14.7	15.8	15.9	15.3	14.9
Fe_2O_3	3.65	1.68	5.2	4.2	3.7	1.43	3.3	2.75	2.05	1.68
FeO	4.65	2.2	7.7	4.15	4.15	1.83	2.75	4.3	3.15	2.1
MgO	3.3	0.96	7.2	2.95	2.65	1.26	2.3	2.8	2.0	1.34
CaO	7.0	3.25	10.1	5.95	6.3	3.35	5.5	5.95	5.0	3.75
Na_2O	3.3	4.25	2.05	3.9	3.85	3.8	3.5	3.1	3.75	3.95
K_2O	1.32	2.25	0.51	1.1	0.75	2.25	2.3	1.95	1.55	2.1
H_2O+	1.62	0.85	3.05	1.23	0.9	0.43	1.13	1.03	1.17	0.89
H_2O	0.21	0.18	0.21	0.12	0.11	0.13	0.17	0.21	0.35	0.3
CO_2	0.04	0.04	0.17	0.09	0.21	0.04	0.05	0.04	0.18	0.04
TiO_2	0.9	0.48	1.14	1.08	1.08	0.32	0.76	0.77	0.58	0.41
P_2O_5	0.18	0.09	0.04	0.26	0.2	0.08	0.17	0.16	0.11	0.08
MnO	0.19	0.1	0.25	0.13	0.18	0.05	0.14	0.17	0.13	0.08
	99.76	99.93	100.22	99.96	99.78	99.67	99.87	99.73	99.62	99.72

C.I.P.W. Normative Compositions

	1	2	3	4	5	6	7	8	9	10
Q	13.04	27.85	0.42	13.08	18.16	29.83	18.91	17.75	22.82	26.83
Or	7.8	13.29	3.01	6.5	4.43	13.29	13.59	11.52	9.16	12.41
Ab	27.91	35.95	17.34	32.98	32.56	32.14	29.6	26.22	31.72	33.41
An	26.32	12.76	33.5	27.25	23.62	15.84	20.61	23.72	20.34	16.73
Cor	–	–	–	0.01	–	0.21	–	–	–	–
Di-Wo	2.91	1.05	6.37	–	2.09	–	2.19	1.88	1.09	0.46
-En	1.83	0.57	4.12	–	1.36	–	1.66	1.1	0.63	0.28
-Fs	0.9	0.44	1.83	–	0.58	–	0.31	0.69	0.4	0.15
Hy-En	6.38	1.82	13.81	7.34	5.23	3.14	4.07	5.87	4.34	3.06
-Fs	3.14	1.41	6.13	2.37	2.21	1.65	0.76	3.67	2.73	1.64
Mt	5.29	2.44	7.54	6.09	5.36	2.07	4.78	3.99	2.97	2.44
Il	1.71	0.91	2.17	2.05	2.05	0.61	1.44	1.46	1.1	0.78
Ap	0.43	0.21	0.09	0.62	0.47	0.19	0.4	0.38	0.26	0.19
Ct	0.09	0.09	0.39	0.2	0.48	0.09	0.11	0.09	0.41	0.09
H_2O	1.83	1.03	3.26	1.35	1.01	0.56	1.3	1.24	1.52	1.19

Chemical Analyses

	11	12	13	14	15	16	17	18	19	20
SiO_2	64.2	59.8	70.8	59.1	59.0	67.9	54.7	48.7	62.4	64.0
Al_2O_3	15.2	15.8	14.0	16.0	16.2	14.7	16.3	20.3	16.1	15.6
Fe_2O_3	2.7	3.35	1.0	2.55	2.2	2.1	3.65	5.15	2.7	2.35
FeO	2.8	4.2	2.2	5.25	4.9	1.54	5.25	4.2	2.55	2.25
MgO	2.1	2.85	0.84	2.95	3.1	0.74	3.6	3.7	1.7	1.48
CaO	4.95	6.45	2.55	6.6	6.25	1.75	7.4	8.9	4.1	3.4
Na_2O	3.65	3.3	4.3	3.7	3.65	3.8	3.75	3.15	4.1	4.75
K_2O	1.88	1.45	2.3	0.95	1.55	5.7	1.95	1.35	4.6	4.1
H_2O+	1.01	1.15	0.68	0.78	1.14	0.42	1.27	2.2	0.58	0.58
H_2O-	0.26	0.24	0.32	0.18	0.36	0.48	0.16	0.39	0.32	0.4
CO_2	0.05	0.12	0.23	0.28	0.23	0.07	0.12	0.13	0.05	0.05
TiO_2	0.67	0.77	0.36	0.93	0.82	0.40	1.01	0.93	0.61	0.71
P_2O_5	0.12	0.16	0.06	0.20	0.10	0.09	0.26	0.60	0.34	0.43
MnO	0.07	0.17	0.05	0.16	0.15	0.05	0.21	0.18	0.08	0.13
	99.66	99.81	99.69	99.63	99.65	99.74	99.63	99.88	100.23	100.23

C.I.P.W. Normative Compositions

	11	12	13	14	15	16	17	18	19	20
Q	22.56	17.45	29.89		13.32	19.71	5.70	2.28	11.35	13.09
Or	11.11	8.57	13.59		9.16	33.68	11.52	7.98	27.18	24.22
Ab	30.87	27.91	36.37		30.87	32.14	31.72	26.64	34.68	40.17
An	19.54	24.02	10.8		23.25	6.23	21.89	37.27	11.95	9.14
Cor	–	–	0.48		–	–	–	–	–	–
Di-Wo	1.63	2.57	–		2.36	0.59	5.16	0.89	2.44	1.92
-En	1.12	1.6	–		1.29	0.44	3.14	0.67	1.68	1.37
-Fs	0.39	0.83	–		0.98	0.1	1.74	0.14	0.57	0.38
Hy-En	4.11	5.5	2.09		6.42	1.41	5.82	8.55	2.56	2.31
-Fs	1.42	2.85	2.62		4.85	0.33	3.22	1.78	0 .87	0.64
Mt	3.91	4.86	1.45		3.19	3.04	5.29	7.47	3.91	3.41
Il	1.27	1.46	0.68		1.56	0.76	1.92	1.77	1.16	1.35
Ap	0.28	0.38	0.14		0.24	0.21	0.62	1.42	0.81	1.02
Ct	0.11	0.27	0.52		0.52	0.16	0.27	0.3	0.11	0.11
HaO	1.27	1.39	1.0		1.5	0.9	1.43	2.59	0.9	0.98

Chemical Analyses

	21	22	23	24	25	26	27	28	29	30
SiO_2	51.6	54.1	55.5	57.2	54.5	65.0	58.9	64.4	56.7	64.1
Al_2O_3	17.8	16.8	16.8	16.5	16.4	15.5	15.5	16.0	16.3	15.5
Fe_2O_3	4.95	3.4	3.25	2.85	4.25	2.1	5.3	2.0	4.55	2.85
FeO	4.4	5.3	4.65	4.85	4.7	2.1	3.5	2.25	3.3	1.96
MgO	4.05	3.8	3.65	3.25	3.7	1.18	1.62	1.36	3.3	1.22
CaO	8.7	7.95	6.05	6.55	7.35	2.8	5.05	3.05	5.6	2.00
Na_2O	3.3	3.45	3.45	3.15	3.05	3.85	3.4	3.7	3.35	4.05
K_2O	1.69	1.89	2.65	2.6	2.75	5.1	3.75	4.7	2.9	5.3
H_2O+	1.33	1.24	1.76	1.15	1.22	1.08	1.02	0.87	1.44	0.9
H_2O-	0.37	0.26	0.44	0.31	0.3	0.44	0.42	0.69	0.56	0.96
CO_2	0.18	0.07	0.24	0.06	0.12	0.04	0.04	0.12	0.07	0.14
TiO_2	1.08	0.94	0.85	0.82	0.95	0.55	0.86	0.55	0.9	0.65
P_2O_5	0.37	0.6	0.46	0.46	0.59	0.33	0.69	0.32	0.57	0.42
MnO	0.17	0.17	0.19	0.16	0.18	0.11	0.14	0.12	0.12	0.22
	99.99	99.97	99.94	99.91	100.04	100.18	100.19	100.13	99.66	100.27

C.I.P.W. Normative Compositions

	21	22	23	24	25	26	27	28	29	30
Q	4.15	5.78	7.47	10.44	7.29	16.17	14.26	16.86	11.24	15.67
Or	9.98	11.17	15.66	15.36	16.25	30.13	22.16	27.77	17.13	31.31
Ab	27.91	29.18	29.18	26.64	25.8	32.56	28.76	31.29	28.33	34.25
An	28.77	24.78	22.53	23.21	22.94	9.96	15.96	12.28	20.88	6.29
Cor	-	-	-	-	-	-	-	0.33	-	0.8
Di-Wo	4.52	4.3	1.23	2.46	3.72	0.64	1.81	-	1.14	-
-En	3.35	2.59	0.78	1.43	2.48	0.42	1.4	-	0.92	-
-Fs	0.73	1.47	0.38	0.92	0.96	0.17	0.22	-	0.09	-
Hy-En	6.73	6.87	8.31	6.66	6.73	2.52	2.64	3.39	7.3	3.04
-Fs	1.47	3.9	4.07	4.28	2.59	1.04	0.41	1.57	0.72	0.17
Mt	7.18	4.93	4.71	4.13	6.16	3.04	7.68	2.9	6.6	4.13
Il	2.05	1.79	1.61	1.56	1.8	1.04	1.63	1.04	1.71	1.23
Ap	0.88	1.42	1.09	1.09	1.4	0.78	1.64	0.76	1.35	1.0
Ct	0.41	0.16	0.55	0.14	0.27	0.09	0.09	0.27	0.16	0.32
H_2O	1.7	1.50	2.2	1.46	1.52	1.52	1.44	1.56	2.0	1.86

Modal Compositions (where determined)

Spec. No.	*Q	*Or	Plag	*Q/Or	*Fm	Aug	Hbe	Bi	Op
1	14	10	55	-	18	-	-	-	4
4	31	17	45	-	6	-	-	-	1.5
5	-	-	62	-	33	-	-	-	5
7	20	16	47	23	14	-	-	-	3
9	28	7	49	-	5	-	10	-	2
14	15	1.5	57	-	-	-	17	8	2
16	23	52	22	47	3	-	-	-	-
18	4	2.5	69	-	15	4	-	-	5
19	16.5	27	42	-	4	4	-	-	2.5
22	8	4	61	-	14	10	-	-	2.5
24	9.5	17	50	-	13.5	8	-	-	2
25	6	27	48	10	8.5	6.5	-	-	4
26	17.5	45	30	-	5.5	-	-	-	2
27	12	37.5	40	-	9	-	-	-	1.5
29	13	22	47.5	12	11.5	3	-	-	3.5

*Q/Or is micrographic intergrowth. *Q includes quartz in micrographic intergrowth, as well as free quartz. Similarly *Or is total orthoclase.

+Fm is ferromagnesian minerals, which may be primary, or secondary (late magmatic or deuteric). Where augite, hornblende or biotite are recorded seperately, Fm is mostly secondary, including pale green amphibole, some poorly formed hornblende, chlorite, opaque oxide, rarely biotite and epidote.

Localities of Plutonic Rocks

Number	Field Number (53NG)	Rock Type	Co-ordinates	Remarks
1	0230	diorite	4°18'S, 151°40'E	Outcrop Nambung River
2	0670A	grano-diorite	4°20'S, 151°48'E	Float Batonga River
3	0683A	leuco-gabbro	4°16'S, 151°47'E	Float near Gunter-shoche Ptn.
4	0692	diorite	4°14'S, 151°38'30"E	
5	0694	diorite	" " "	Outcrop Gavit River
6	0695	grano-diorite	" " "	
7	0723A	diorite	4°23'S, 151°53'30"E	Float near Rang-oulit village
8	0723B	diorite	" " "	" " "
9	0731A	grano-diorite	4°20'S, 151°51'30"E	Float near Mandres Plant-ation
10	0731B	grano-diorite	" " "	" " "
11	0850A	grano-diorite	4°18'S, 151°49'30"E	Float near Batonga River
12	0850B	diorite	" " "	
13	0851A	grano-diorite	4°15'S, 151°42'E	Float Nambung River
14	0851B	diorite	" " "	" " "
15	0851C	diorite	" " "	" " "
16	0861A	adamellite	4°37'S, 152°09'E	Float in Kavavas River half mile below Lemingi village. Representative of plutons in Kavavas River headwaters
17	0861C	diorite	" " "	
18	0861D	leuco-gabbro	" " "	
19	0861E	monzonite	" " "	
20	0861F	monzonite	" " "	
21	0861G	leuco-gabbro	" " "	
22	0861H	diorite		
23	0863A	diorite	4°46'S, 152°13'30"E	Float in northern headwaters of Merai River
24	0863B	diorite	" " "	
25	0867A	diorite/monzonite	4°54'30"S, 151°57'30"E	Representative float Wulwut River
26	0867B	monzonite	" " "	
27	0867C	monzonite	" " "	
28	0867E	monzonite	" " "	
29	0867F	diorite/monzonite	" " "	
30	0868A	monzonite	4°57'S, 151°59'E	Southeast tributary of Wulwut River

APPENDIX 2

PETROGRAPHY OF THE BAINING VOLCANICS

The Baining Volcanics are mainly volcaniclastic marine sedimentary rocks, with minor lava flows and related near-surface intrusives; these rocks accumulated rapidly within and marginal to an area of extensive volcanism. Basic andesite makes up the bulk of the clastic debris and the sporadic interbedded lava flows, with spilitic flows and debris locally prominent, notably in the North Baining Mountains. Limestone is rare but is found at a number of widely separated localities; most of it is derived fragmental material.

In the following discussion the volcanic greywackes are described first, followed by the other major clastic rock types. Description of lava flows and related intrusives follows and then a description of metmorphic rocks developed from the Baining Volcanics.

The volcanic greywackes are composed of angular to subrounded lithic and vitric fragments, and fewer crystal grains and fragments, set in an abundant microcrystalline matrix. Grainsize varies from fairly fine to coarse, the greywacke grading arbitarily with further increase in grainsize into pebbly greywacke and pebble conglomerate; silt-size fragments are absent or uncommon, resulting in a marked division between clasts and matrix. Most rocks show poor to moderate size sorting of clasts, but some are unsorted. Unsorted greywacke in Wide Bay consists of angular fragments which range from fine silt-size (matrix) to 2 mm. Adjacent volcanic conglomerate and breccia includes abundant silt and sand-sized fragments.

The most common lithic fragments in volcanic greywackes are fine-grained, generally porphyritic andesite, comprising fairly abundant to rare plagioclase phenocrysts or microphenocrysts, set in a very fine-grained holocrystalline or vitric (mostly oxidised, altered or devitrified) groundmass. The plagioclase phenocrysts are small and are mostly clear and fairly fresh, but may be cloudy and partly kaolinised, sericitised or zeolitised, less commonly altering to epidote, chlorite or calcite. Subordinate augite phenocrysts may accompany the plagioclase. These are fresh or rarely, slightly altered to chlorite along fractures. In rare cases chlorite with some calcite pseudomorphs unidentified primary ferromagnesian minerals. Minor hornblende is present in one section only, from Wide Bay. The groundmass is very fine-grained and varies considerably in appearance and composition. Fragments in individual sections of most greywackes show a tendency towards similarity of groundmass, rather than complete variation Groundmass is devitrified glass or microcrystalline plagioclase, quartz, indeterminate feldspars, and less commonly granular augite with interstitial chlorite. Flow foliation is common and is defined in the groundmass by alignment of elongate grains and microlites, and by preferred orientation of incipient feldspathic and quartzofeldspathic crystallization. Rare to abundant small vesicles or amygdales are present in some fragments, infilled by chlorite, zeolite or calcite, in some instances by epidote, rarely by prehnite; highly vesiculated lavas grade into scoria. Spilitic lava fragments are abundant in some volcanic greywackes, particularly in the North Baining Mountains. They are very fine-grained and consist of generally divergent, small sodic plagioclase grains and needles, set in interstitial feldspar and chlorite or dark (oxidised), greenish (chloritised) or light-coloured (indeterminate devitrified ?feldspathic) glass. Minor calcic plagioclase and augite accompany larger sodic plagioclase grains in some fragments, and incipient augite granules and crystallites may be present in the groundmass; calcite, chlorite or zeolite-filled vesicles and amygdales are present in many fragments, and the groundmass may contain calcite patches and epidote grains. Sodic plagioclase microlites are present in some fragments identified as andesite.

Vitric fragments vary from rare to abundant in volcanic greywackes. These have been derived from sparsely porphyritic and non-porphyritic glassy andesite lavas. They display the considerable variation in devitrification and alteration described above, and are variably vesiculated, grading in some cases into scoria. Chlorite, zeolite and calcite commonly infill vesicles and flow foliation may be apparent in devitrified fragments. Glass shards are present in the matrix of one fine-grained sedimentary breccia containing abundant glassy scoria fragments; the scoria is partly devitrified and contains sodic plagioclase needles, and the shards are largely replaced by chlorite, zeolite and calcite.

Crystal grains and fragments are absent, rare or fairly abundant in different volcanic greywackes and fine-grains conglomerates. They are most commonly plagioclase, with minor augite and rare quartz. Plagioclase generally occurs as well formed grains up to 2 mm long, showing little evidence of attrition; many grains are cloudy and fractured, with an uneven extinction, and some grains are zeolitised or partly replaced by chlorite, calcite or rarely epidote. Fragmentation of fractured grains has given rise to small angular plagioclase clasts; these are particularly abundant in finer-grained greywacke and siltstone. The plagioclase grains of the clastic fraction are mostly considerably larger than phenocrysts and microphenocrysts in accompanying lava fragments. Minor augite grains accompany plagioclase in a number of sections, generally in association with lava fragments containing small augite phenocrysts. Small angular quartz fragments are rarely present and are most abundant in the finer-grained rocks; porphyritic intermediate lavas are considered to be the source of the clastic quartz, although quartz phenocrysts have been identified in lava fragments in only one thin section. Authigenic quartz is present in the recrystallized matrix of some rocks.

Minor detrital limestone fragments and microfossil remains are present in greywackes and siltstones from several widely separated areas. Small fragments of reworked, fine-grained sedimentary rock of penecontemporaneous age have been identified in several sections.

The matrix makes up 15% to more than 80% by volume of the volcanic greywackes. It is completely recrystallized to microcrystalline chlorite, sericite, illite, indeterminate almost isotropic and low birefringent clay minerals, zeolite and probably feldspar and quartz, and some fine ?sphene. Very fine opaque material (?rock dust) may mask the matrix, or form thin streaks and trails parallel to poorly defined bedding or to flow caused by compaction of the matrix while poorly consolidated. Flared-out patches and streaks of optically aligned micaceous minerals (birefringent illite, sericite and ?chlorite, rarely isotropic ?chlorite) may accentuate the poorly expressed bedding or compaction of the matrix, appearing in hand specimen as translucent pale green or white patches or small dark shaley lenses. Colourless, almost isotropic indeterminate clay minerals are partly recrystallized in some sections to small patches and lenses of larger grains, lying within the bedding; trails of opaque dust may flow around these lenses. Fine-grained zeolite, feldspar and quartz are probably present in the indeterminate material in many sections but remain unidentified because of grainsize; zeolite in some sections forms small patches and mosaics of ragged grains. Very fine, indistinct, high relief, high birefringent patches common in many sections may be sphene. Finely disseminated calcite is present in the matrix of some greywackes and siltstones in areas of limited carbonate development. Very small silt-sized fragments of lava, plagioclase and minor quartz are included with the matrix in several sections, because of a gap in grainsize between these fragments and the rest of the clastic fraction; in some instances some quartz and feldspar grains may be authigenic.

Marginal reaction between clasts and the recrystallized matrix varies from minor to extreme. In many instances it is difficult to distinguish between clasts and matrix under crossed nicols; in some instances many clasts are also indistinct in plane polarized light, and it is difficult to define the matrix of the rock. Some volcanic greywackes in which reaction between matrix and clasts is extreme, appear non-clastic in hand specimen.

Bedding in the volcanic greywackes is generally absent or poorly developed; when present it is defined by subparallel alignment of elongate clasts, by variation in size or density of packing of the clasts, or by compaction flow and alignment of micaceous minerals in the recrystallized matrix.

With decrease in grainsize volcanic greywacke grades into siltstone, in which microcrystalline matrix is particularly abundant, and the clastic fraction comprises angular, generally indistinct, fine-grained lava and vitric fragments, plagioclase fragments and detrital quartz. In some rocks, plagioclase dominates the clastic fraction. At several localities on the North Baining coast, light-coloured silicified siltstones comprise marginally resorbed quartz clasts in excess of plagioclase and indistinct lava, in a matrix of fine, ragged quartz with some kaolinised feldspar, fine sericite and calcite. Graded bedding is apparent in petrographic sections from some thin-bedded siltstone and fine-grained greywacke and arenite successions.

Greywacke grades with decrease in matrix volume into volcanic arenite, which differs petrographically only in containing less than 15% matrix. In some arenites clasts appear to be derived from a single lava source, while in others a mixing of fine-grained debris from more than one primary source is apparent. Some arenites of the former type have the appearance of volcanic grits, comprising for example tightly packed, angular clasts of oxidised, variably vesiculated glass (some with small plagioclase phenocrysts and microlites which may be sodic) set in very minor chloritic and zeolitic matrix or cement. Other arenites contain fine debris of variable composition including differing lavas, glass, plagioclase, minor augite and quartz, and, rarely, clastic calcite and microfossil remains.

With increase in grainsize volcanic greywacke grades into pebbly greywacke, pebble conglomerate and, rarely, fine-grained sedimentary breccia. In these rocks the coarser clastic fraction is made up of porphyritic and some aphanitic brown to black lava fragments, some vesicular, and the finer fraction is made up of lava and glass fragments and some crystal grains. The microcrystalline matrix is similar to that of the greywackes but is generally less abundant. Sorting is fairly poor and grainsize may vary considerably, but there is generally a marked gap in grainsize between matrix and smallest clasts.

Cobble and some boulder conglomerates are present, differing from the finer-grained rocks only in grainsize. Petrographic examination of clasts in the volcanic conglomerates shows them to be mostly fine-grained andesite lavas, which are generally porphyritic in plagioclase and in some instances subordinate augite; the groundmass is more commonly holocrystalline than is the case with clasts in greywackes. Some more basic spilitic lavas accompany the andesite.

Fine-grained limestone clasts are sparsely present in pebble-conglomerates at a number of localities, in some instances accompanied by minor calcite in the matrix, or calcite cement; with increase in calcite these rocks grade into partly recrystallized allochthonous limestone. Very rarely conditions favoured the deposition of nearly pure limestone, which has subsequently recrystallized or has been thermally metamorphosed or hydrothermally altered.

Petrographic examination of interbedded lava flows in the Baining Volcanics shows them to be mostly porphyritic andesite and some spilite, comprising essentially plagioclase and subordinate augite phenocrysts in a fine-grained groundmass; accurate classification is generally not possible petrographically.

The andesites are sparsely to abundantly porphyritic in plagioclase, some with subordinate augite, and a few with minor pseudomorphs in chlorite, calcite and some zeolite, serpentine and fine haematite; these replace primary ferromagnesian minerals; minor hornblende accompanies augite in only one section, from Wide Bay, and rare small quartz phenocrysts occur with plagioclase in a fragmented vitric lava from the North Baining Mountains. Rare fine-grained plagioclase lava xenoliths occur in one coarser-grained lava. Plagioclase phenocrysts vary in size up to 3mm long and are mostly slightly cloudy, altering partly to kaolin or sericite, and rarely epidote, chlorite or calcite; zoning is very poor or absent and twinning is generally poor or rarely absent (in one section extinction angles on albite twins indicate compositions An_{40} to An_{60}). Small glass and rarely augite inclusions are present in plagioclase phenocrysts in several sections; in some lavas the phenocrysts are shattered. Augite phenocrysts are colourless or rarely pale green-brown; some are fractured, with chlorite alteration along cracks. The groundmass of the andesites commonly comprises fine plagioclase laths, interstitial feldspar and some chlorite, granular opaque oxide and, in some instances granular augite; some are colourless devitrified glass or brown incipiently devitrified glass, altered to fine quartzofeldspathic material which may contain plagioclase microlites. Flow banding is common and several lavas are pilotaxitic; one lava has a trachytic texture, comprising rare plagioclase microphenocrysts in trachytic acicular plagioclase, interstitial chlorite and feldspathic material, and very fine granular opaque oxide and augite. In several lavas accessory fine-grained sphene is present in the groundmass and, in one, accessory pyrite. Amygdales are common and are infilled by zeolite (in some instances, several generations are apparent), calcite and chlorites; they are mostly small, but in one section amygdales range up to 8mm long.

Spilite flows are uncommon, and are identified only in the North Baining Mountains. They comprise generally divergent laths of clear sodic plagioclase, which may be resorbed marginally and is rarely accompanied by minor calcic plagioclase and augite, set in interstitial feldspar and green chlorite, mostly with fine opaque oxide (in one section haematite). Calcite patches and a few epidote grains may be present in the groundmass, and vesicles are infilled by chlorite, calcite, zeolite or rarely prehnite. Very minor interstitial quartz is present in one section.

Penecontemporaneous hypabyssal rocks intruding the Baining Volcanics are plagioclase and augite-plagioclase porphyries of intermediate composition. Petrographic examination shows them to have an essential composition of plagioclase phenocrysts up to 3mm long, which are rare to abundant and may be accompanied by minor augite, and, rarely, primary ferromagnesian phenocrysts pseudomorphed by chlorite and calcite. The groundmass is plagioclase, interstitial feldspar and in some instances chlorite, granular oxide and, in some sections, granular augite. Several sections exhibit flow foliation and vesicles may be sparsely present. These rocks differ little from many younger hypabyssal intrusives, but are considered to be penecontemporaneous because intrusion pre-dates deformation of the volcanics.

Metamorphic rocks developed from the Baining Volcanics are hornfelses in narrow aureoles surrounding high-level plutons, and schists with related hornfelses in a narrow linear zone in the Central Baining Mountains.

The hornfelses formed in the contact aureoles of plutonic intrusions are mostly very low-grade metamorphic rocks in which the original texture (siltstone, greywacke, conglomerate, porphyritic lava or intrusive) is still poorly preserved. Albite, quartz, chlorite, actinolite and minor biotite and epidote are the common metamorphic minerals, in some instances accompanied by poikiloblastic cordierite. Quartz, plagioclase and green-brown hornblende have replaced clasts in an unusual hornfelsed volcanic pebble conglomerate in the Wulwut River, in which the matrix and finer-grained glassy fragments have recrystallized to fine-grained quartz and plagioclase, and very fine, granular amphibole and lesser opaque oxide, with some brown garnet and calcite, and rare epidote.

In two small areas, in the vicinity of Rangarere Plantation on the North Baining coast and on the north flank of the Central Baining Mountains, thermal and hydrothermal alteration of country rock by the high-level plutons is more extensive than observed elsewhere. In the Rangarere Plantation area the country rock on the north side of the pluton comprises massive and thin-bedded dark siltstone with some interbedded volcanic greywacke and fine-grained volcanic conglomerate, and abundant interbedded porphyritic augite andesite; nearly pure limestone occurs in a number of fairly small lenticular bodies which may have formed as one or more continuous units, and abundant penecontemporaneous and younger plagioclase and augite-plagioclase porphyries intrude the succession. Thermal and hydrothermal alteration caused many of the dark volcanic and volcaniclastic rocks to assume a hornfelsic appearance, and some were strongly epidotised or partly chloritised; the limestone was recrystallized and partly altered to skarn, containing small lenticular deposits of hydrothermal iron ore, and some vein sulphide mineralization. The area was not examined in detail by the writer, and the following petrographic information is drawn largely from Appendix I of a report on the ore mineralization by Gardner (1957). Petrographic examinations show that (i) fine-grained volcaniclastic rocks altered partially or wholly, with fairly good preservation of texture, to pale green chlorite, plagioclase, actinolite and epidote; (ii) alteration of the porphyritic lavas and intrusives was characterised by the replacement of augite by actinolite, and the growth of patches of epidote, chlorite, actinolite and, rarely, prehnite in the groundmass; and (iii) limestone recrystallized to dense, medium-grained marble, in places metasomatically altered to skarn (both massive and along joints and fractures) which comprises, in one section, garnet, scapolite and vesuvianite. Hydrothermal solutions also introduced small tabular iron ore bodies and minor sulphide mineralization into the metasomatised limestone. Quartz veining is common in the area, with associated epidote or chlorite, rarely prehnite or plagioclase.

Boulders in streams draining the north flank of the Central Baining Mountains, between the headwaters of the Rapmetka and Kavavas Rivers, indicate an area of fairly widespread thermal and hydrothermal alteration of country rock along the west margin of a dioritic pluton, similar to that on the North Baining coast. Fine-grained, dark volcaniclastic and igneous rocks are very hard with a splintery fracture, have a hornfelsic appearance, and are commonly epidotised. Very minor white recrystallized coral limestone contains small rare garnets. Quartz-epidote veining is common, with associated hornblende and, in some instances, small aggregates of granular magnetite. Iron ore similar to that on Rangarere Plantation crops out on a narrow spur in the Rapmetka River headwaters, and may be related to the hydrothermal activity, but the area was not mapped in detail and little is known of the extent and true nature of the alteration.

A short distance to the north, strongly foliated rocks with near vertical dips trend slightly east of north in a narrow zone along the Rapmetka River. Within the zone hornblende and biotite schists were developed from massive, indurated siltstones and interbedded porphyritic lavas or intrusive rocks; plagioclase and some quartz accompany the ferromagnesian minerals, and one thin section of biotite-plagioclase-quartz schist includes small cordierite poikiloblasts. Metamorphic differentiation resulted in the formation of some banded schist; crenulations and lineations are locally present, and in some instances have suffered subsequent deformation (a result of local and not regional strain). Towards the edge of the zone there are poorly foliated semi-schists and unfoliated hornfelses; hard, dark, structureless albite-quartz hornfels with minor biotite and opaque oxide has developed from the siltstone, and albite-actinolite-quartz hornfels with corroded relict calcic plagioclase phenocrysts from the porphyritic igneous rocks. At the northern end the zone is truncated obliquely by younger plutonic intrusives. At several localities relatively small, angular blocks of schist are seen to have been stoped off by the intruding melt. Minor retrogressive metamorphism of the schists has taken place in the narrow contact aureole of the pluton.

APPENDIX 3

PETROGRAPHY OF MERAI VOLCANICS

Petrographic examination of fine-grained conglomerates, greywackes and arenites of the Merai Volcanics shows them to be derived from an intermediate to basic volcanic provenance similar to that of the Baining Volcanics. Fragments of andesitic lava predominate in the clastic rocks (accurate petrographic identification of many fragments is not possible), accompanied in some areas by spilite, with basalt fragments common in the area south of the Pondo River; clasts are mostly unsorted or poorly sorted, and range from angular to subrounded. The larger clasts are mostly porphyritic, composed essentially of small plagioclase phenocrysts, in some instances accompanied by subordinate augite, set in a very fine-grained holocrystalline or vitrophyric groundmass. The smaller clasts are subangular vitric and sparsely porphyritic vitrophyric lava fragments, accompanied by plagioclase and rare augite grains. Vitric fragments are strongly oxidized, chloritized, zeolitized or devitrified to very fine-grained quartzofeldspathic material; vesicles are uncommon. The matrix is sparse to abundant, and consists of largely indeterminate microcrystalline clay minerals, chlorite and zeolite; minor calcite or zeolite cement may be present. Fine bioclastic debris is common in rocks from the Open Bay area, with calcite in the matrix and, in some instances, abundant calcite cement. South of the Pondo River the volcanic provenance is more basic than elsewhere. Minor detrital olivine accompanies augite in some lithic crystal tuffs and fine-grained conglomerates, and olivine is present in stream boulders derived from lava flows or coarse breccias. One boulder examined petrographically is a coarsely porphyritic amygdaloidal augite - olivine basalt.

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Boulders of fine-grained, dark porphyritic rocks are common in most streams draining Merai Volcanics in the Wide Bay - Open Bay area. Most of these boulders are eroded from lava flows and related shallow intrusions, but some may be from younger hypabyssal intrusives, or from rare boulder beds in the base of the Sinewit Volcanics. Andesitic rocks with plagioclase and some augite phenocrysts predominate; these are probably lavas and porphyries of the Merai Volcanics. Less common boulders with phenocrysts of green hornblende with oxidized rims, lamprobolite, or minor pale green hypersthene, are unlike any of the Merai Volcanics rock types. They may be derived from intrusives related to the Merai Volcanics, or possibly from the Sinewit Volcanics. Fine and coarse-grained grey dolerite intrudes the Merai Volcanics in the ranges south of Baia village; these rocks consist of plagioclase, less common augite and rare hypersthene phenocrysts, with opaque oxide granules, in a fine-grained feldspathic groundmass.

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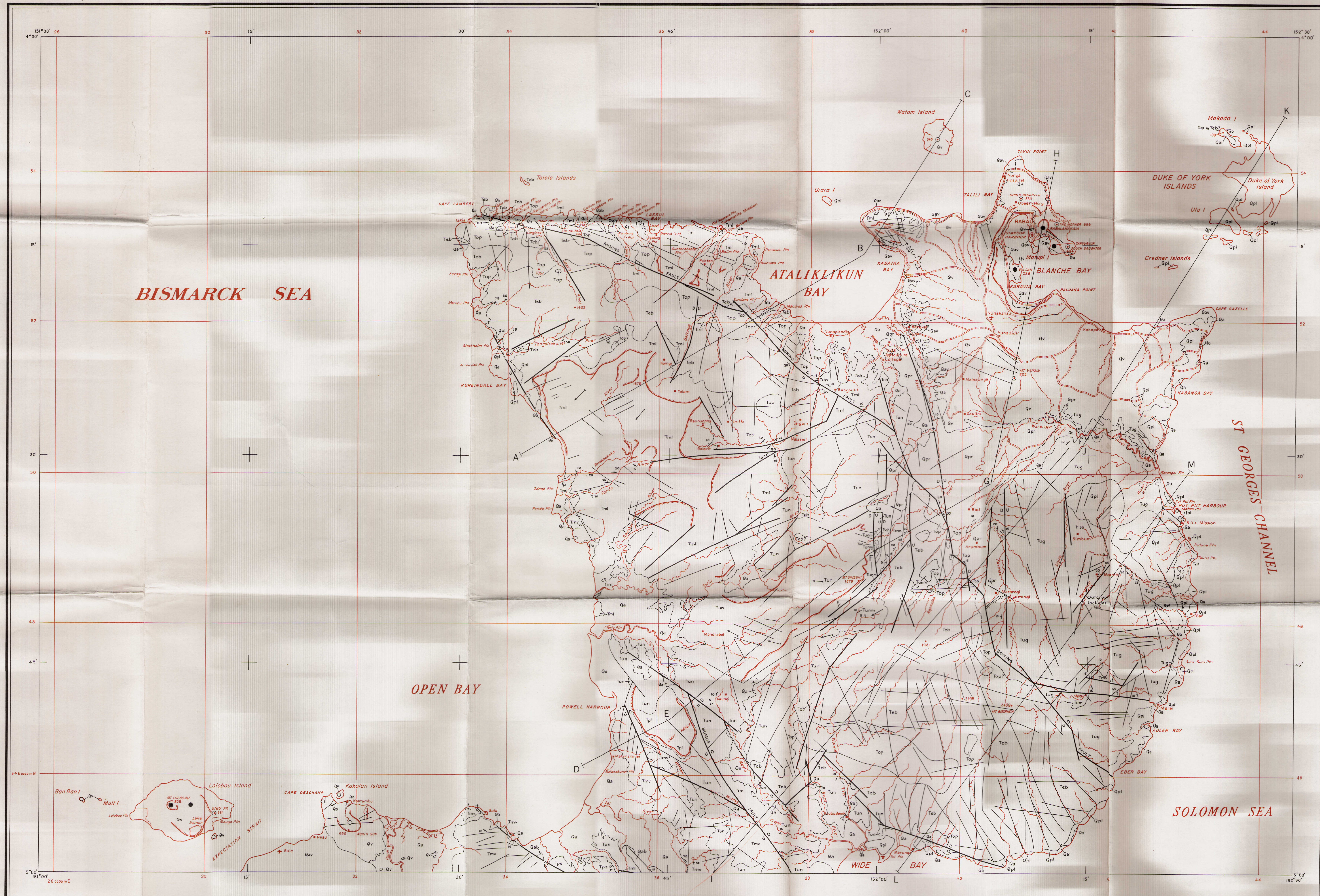


Reference

CAINOZOIC	QUATERNARY	RECENT		Qa	River and coastal alluvium
				Qab	Fanglomerate and raised boulder beds
				Qav	Volcanic outwash and minor primary ash
		PLEISTOCENE TO RECENT		Qv	Pumiceous ash and minor lava
			Riet Beds	Qpr	Fluviatile conglomerate, sandstone and mudstone, partly tuffaceous
		PLEISTOCENE		Qpl	Raised coral
	TERTIARY	PLIOCENE	Sai Beds	Tps	Calcareous mudstone with limestone lenses
			Lakit Limestone	Tpl	Limestone
		UPPER MIOCENE TO PLIOCENE	Sigule Volcanics	Tug	Subaerial lava, agglomerate and tuff, marine calcareous tuff
			Sinewit Volcanics	Tun	Terrestrial and marine tuffaceous sandstone, some calcareous facies
			Mevlo Member	Tunm	Welded tuff, ash flow tuff and lava
		UPPER MIOCENE	Nengmukta Volcanics	Tmn	Marine tuffaceous sandstone and siltstone with volcanic conglomerate interbeds
		MIDDLE MIOCENE Tertiary 'f' stage	Yalam Limestone	Tml	Limestone
		UPPER OLIGOCENE TO LOWER MIOCENE Tertiary 'e' stage	Merai Volcanics	Tmv	Massive marine volcanic conglomerate, sandstone, minor siltstone and subordinate lava
		OLIGOCENE TO PLIOCENE		Top	Leucogabbro, basic diorite, diorite, microdiorite, tonalite, granodiorite, monzonite and adamellite
		EOCENE Tertiary 'a' and 'b' stages	Baining Volcanics	Teb	Massive, indurated, marine volcanic conglomerate, greywacke, minor siltstone and subordinate lava

Geological boundary

Fault (D, U indicates relative movement down, up)

Where location of boundaries and faults is approximate, line is broken; where inferred, queried; where concealed, faults are shown by short dashes

Lineament — probable fault

Strike and dip of strata

Vertical strata

Overturned strata

Dip slope

Strike and dip of foliation

Active volcanic vent

Extinct volcanic vent

Escarpment

Road - sealed

Road - unsealed

Airport

Landing ground

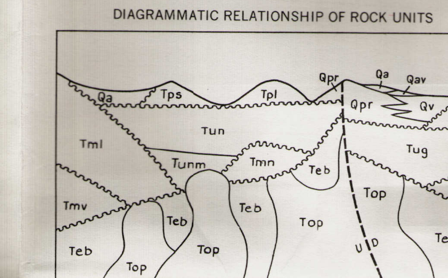
Village

Mission

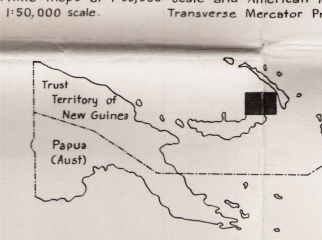
Plantation

Elevation in metres

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS

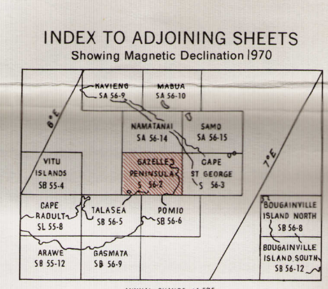


Compiled by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Issued under the authority of the Hon. R. W. Swartz M.B.E., E.D., Minister for National Development.
Base map compiled by BMR from photomaps prepared for Dept. of Forests, T.P.N.G. and U.S. Metals Ref. Co. at 1:50,000 scale; U.S. Army wartime maps at 1:63,360 scale and American Map Service photography at 1:50,000 scale. Transverse Mercator Projection.



INDEX TO ADJOINING SHEETS

Showing Magnetic Declination 1970

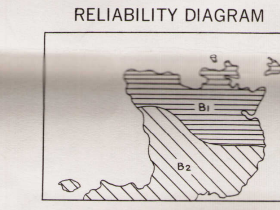


Scale 1:250,000

5 0 5 10 15 20 25 KILOMETRES

5 0 5 10 MILES

RELIABILITY DIAGRAM



Geology B1 Detailed reconnaissance: numerous traveses, and air-photo interpretation

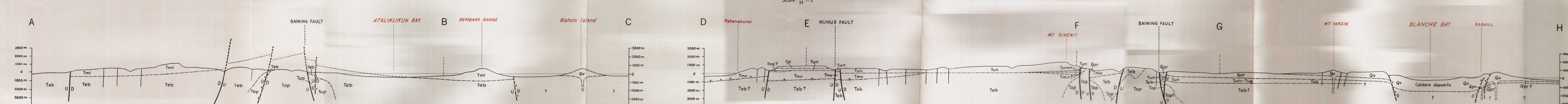
B2 General reconnaissance: some traverses and air-photo interpretation

Geology 1966 by R.P. Macnab
Compiled 1970 by R.P. Macnab
Cartography by Geological Branch BMR
Drawn 1970 by J. M. Wedgbrow

Sections

Recent sediments omitted

Scale: $\frac{V}{H} \simeq 1$



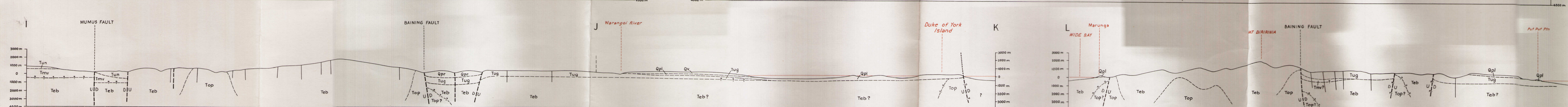


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PLATE 2

PLUTONIC ROCKS SPECIMEN LOCALITY MAP