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PNG 11

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Geology of the Southeast Papuan Mainland

With an appendix on the micropalaeontology of the area, by D. J. BELFORD

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ABSTRACT

The Papuan peninsula east of 148° 30′ is made up mainly of Upper Cretaceous and middle Eocene submarine basalts with minor associated limestone and chert. Some of the basalts are metamorphosed to low greenschist facies with minor development of minerals characteristic of high pressure/temperature conditions. In the northwest, peridotites and gabbros of the Papuan ultramafic belt are faulted against the basalts and are thought to have originated by thrusting during the Eocene.

Emergence of southeast Papua as a landmass commenced during the Oligocene, and by Miocene times significant thicknesses of sediment had accumulated in basins adjacent to the rising land. Late Cainozoic uplift of the area was accompanied by block faulting and by intrusion and extrusion of characteristically potassium-rich magmas including calc-alkaline and shoshonitic types. The main Pliocene and Quarternary movements involved tilting of fault-bounded blocks which resulted in rapid uplift of most of the coast and submergence of parts of the south coast and eastern islands.

Mineralization in southeast Papua is associated with rocks of the Papuan ultramafic belt (nickel, platinum) and the late Cainozoic intrusives (gold, copper); only gold has been produced in economic quantities. The petroleum prospects of late Cainozoic sedimentary sequences in some offshore areas are being investigated.

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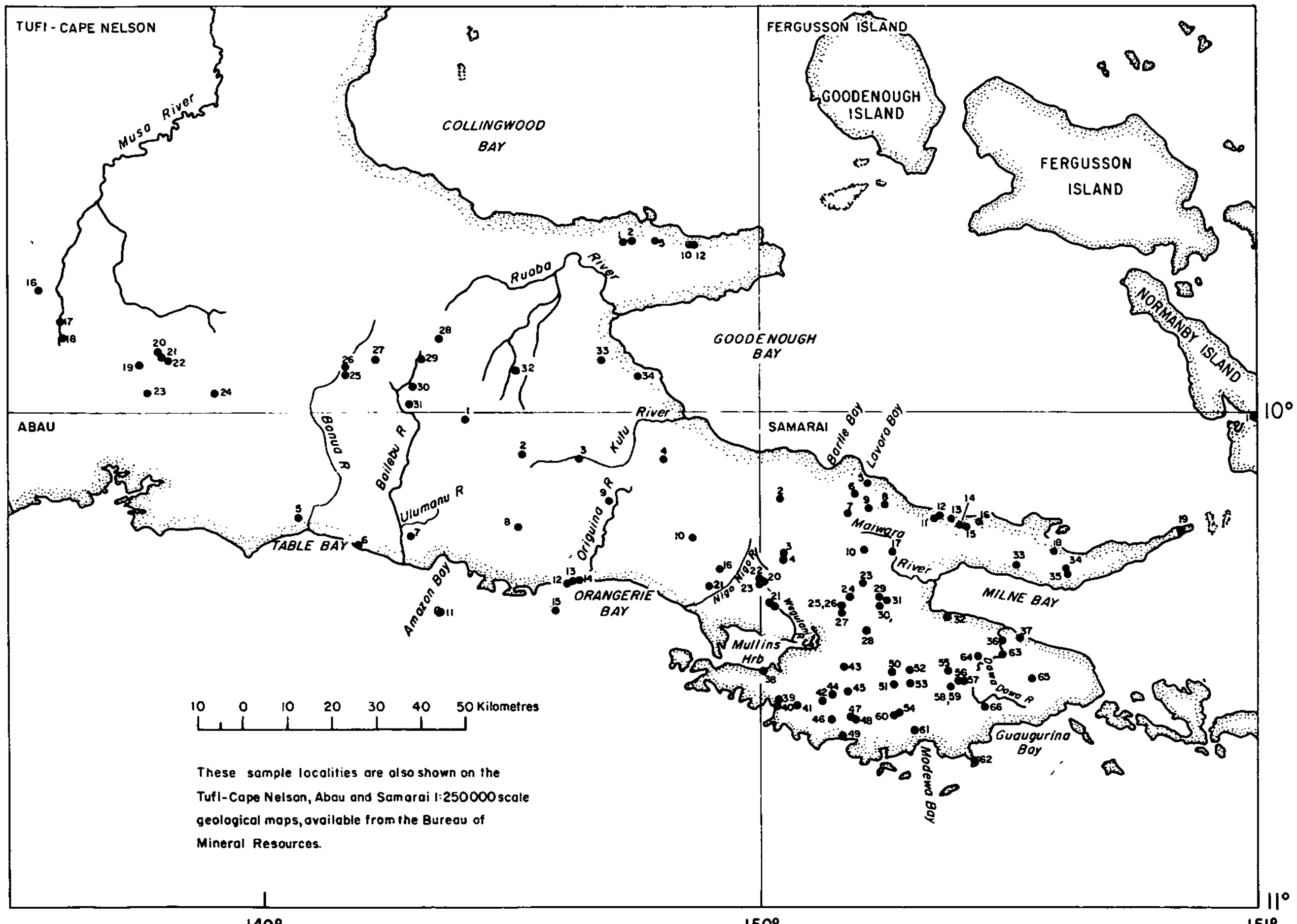
TUFI - CAPE NELSON
FERGUSSON ISLAND
ABAU
SAMARAI
COLLINGWOOD BAY
GOODENOUGH ISLAND
FERGUSSON ISLAND
NORMANBY ISLAND
GOODENOUGH BAY
MILNE BAY
ORANGERIE BAY
TABLE BAY
Musa River
Ruaba River
Kulu River
Bonua R
Bailebu R
Ulumanu R
Origuina R
Amazon Bay
Mullins Hrb
Maiwara River
Barile Bay
Lavora Bay
Modewa Bay
Guaugurina Bay
10 0 10 20 30 40 50 Kilometres
These sample localities are also shown on the Tufi-Cape Nelson, Abau and Samarai 1:250000 scale geological maps, available from the Bureau of Mineral Resources.
149°
150°
151°
10°
11°

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SUMMARY

This Bulletin describes the geology of the southeast Papuan mainland and some adjacent islands between 148°30'E and 151°30'E (Tufi, Abau, and Samarai 1:250 000 Sheet areas). Most of the information was gathered in 1967-69 by Bureau of Mineral Resources (BMR) field parties which included geologists of the Geological and Volcanological Branch of the Department of Lands, Surveys and Mines, Port Moresby (now the Geological Survey of Papua New Guinea).

The southeast Papuan mainland is a mountainous peninsula up to 120 km across, dominated by the Owen Stanley Range, which, in the area mapped, rises to 3576 m at Mount Suckling. Rainforest covers most of the area except for some grassland, swamp vegetation and, on the higher peaks, alpine scrub and grassland. The climate is humid tropical, with an annual rainfall between 1000 and 4500 mm.

Most of the peninsula consists of Upper Cretaceous and middle Eocene submarine basalts, which are at least 3000 m thick, with minor lenses of Cretaceous and limestone and chert. All the sediments were laid down in deep water, except for an isolated lens of shallow-water limestone north of Milne Bay (Touiawaira Limestone Member). Some of the Cretaceous basalts and limestones are metamorphosed to low greenschist facies, with the development of rare lawsonite, crossite, and metamorphic aragonite (Goropu Metabasalt). In the northwest the peridotites and gabbros of the Papuan ultramafic belt are associated with the Cretaceous? basalts, and there are several smaller Cretaceous or Eocene gabbro intrusives (Yau and East Cape Gabbros) in the basalts. The submarine basalts and associated gabbros and peridotites are thought to be part of the oceanic crust and underlying mantle which was thrust to the southwest in the Eocene over sialic sediments (now Owen Stanley Metamorphics) and the adjacent oceanic crust (Goropu Metabasalt).

Small stocks and dykes of middle Miocene age intrude the main body of Cretaceous and Eocene basalt. The upper Oligocene to middle Miocene tuffs and marine sediments, which overlie the Cretaceous and Eocene rocks in places, are possibly related to the stocks and dykes. On the Cape Vogel peninsula and in the adjacent offshore basins the sequence consists of middle Miocene and younger sediments resting on upper Oligocene submarine basalt. Upper Miocene or lower Pliocene and younger terrestrial volcanics are widespread.

The tectonic episode which led to the emplacement of the Papuan ultramafic belt is thought to have taken place during the Eocene time. Uplift probably began in middle or late Oligocene time, and a mountainous landmass had been formed and was being rapidly eroded by the middle Miocene. The late Oligocene to middle Miocene uplift was accompanied by terrestrial and marine volcanism and the emplacement of hypabyssal shoshonitic intrusives. During the predominantly terrestrial volcanism in the Pliocene and Quaternary both shoshonitic and calcalkaline magmas were involved. The main Pliocene and Quaternary movements included rapid uplift of most of the north coast, submergence of parts of the south coast and eastern islands, and the development of grabens in Milne Bay and Mullins Harbour.

Alluvial gold and platinum have been produced from Suzy Creek, the Keveri valley, Magavara River, Imudat River, and the Sagarai/Dawa Dawa area south of Milne Bay, and a small quantity of lode gold has been won in the last-named area. The concentration of nickel in the lateritic soils on the peridotites is apparently too low to be economic. The lenticular bodies of nickel sulphide associated with peridotite and gabbro in Doriri Creek are partly high-grade, but are too small to be of economic interest. Minor copper mineralization has been recorded at a number of localities, generally within the Cretaceous and Eocene basalts. The beach sands along the south coast contain titaniferous magnetite, much of which is intimately intergrown with rock fragments. Some of the sediments in the Badila Beds are phosphatic, but even the highest grades recorded are uneconomic. The petroleum prospects of offshore areas east of Milne Bay and north and east of Cape Nelson are being investigated.

INTRODUCTION

This Bulletin describes the geology of the southeast Papuan mainland and near-shore islands between 148°30′ and 151°30′E. The area is covered by the Tufi, Abau, and Samarai 1:250 000 geological Sheets, each of which has been briefly described in the Explanatory Notes accompanying the maps (Davies & Smith, 1974; Smith & Davies, 1973a, b).

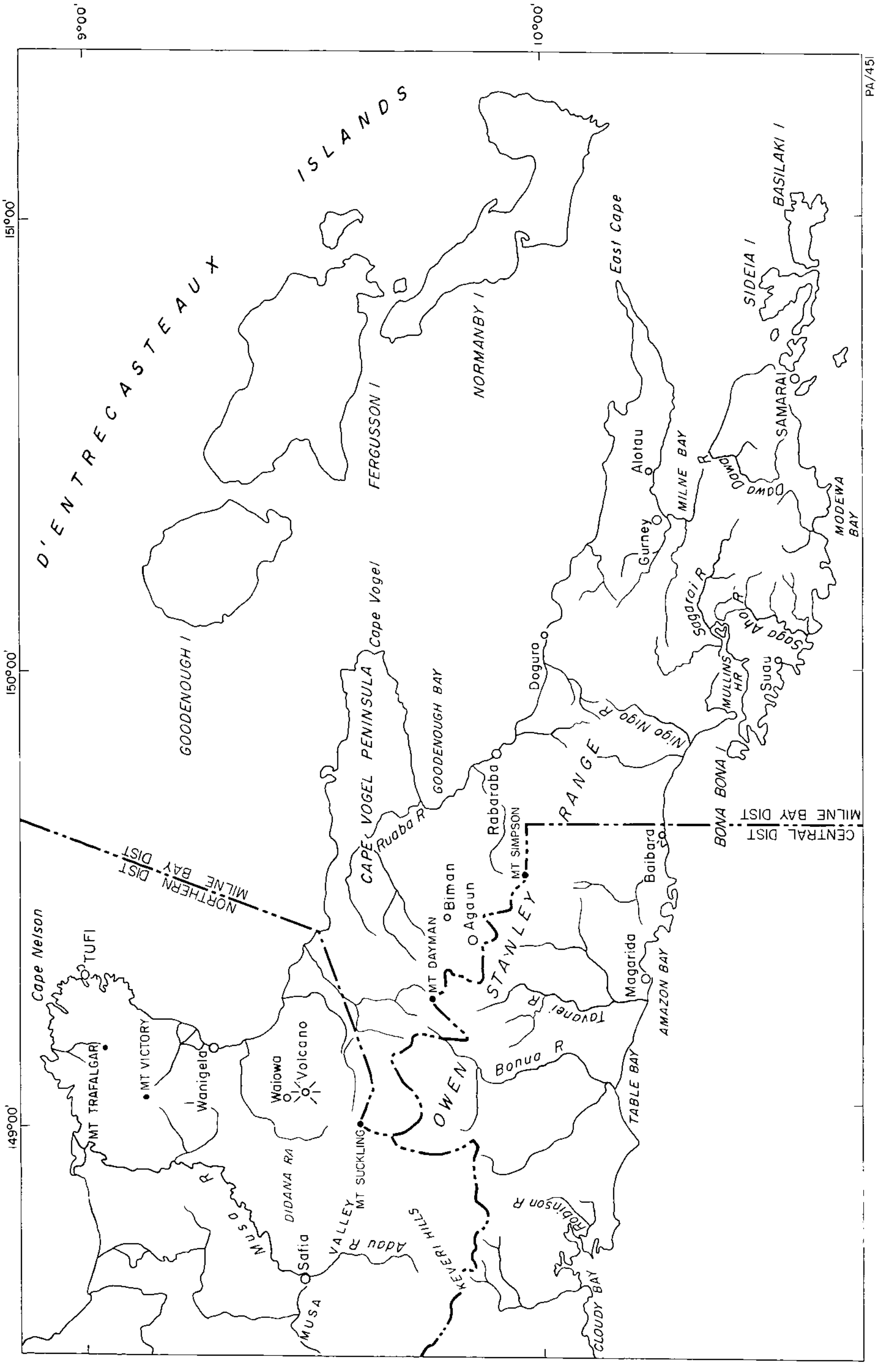

Fig. 1. Southeast Papuan mainland.

The southeast Papuan mainland (Fig. 1) is a mountainous peninsula, up to 120 km across, which is dominated by the Owen Stanley Range, whose highest peaks are Mount Suckling (3576 m), Mount Simpson (2884 m), and Mount Dayman (about 2800 m). West of Mount Suckling the main range is broken by the Musa valley, a flat-floored intermontane basin. North of Mount Suckling a separate mountain mass, the Victory-Trafalgar volcanic complex, rises from the coastal plain. The main rivers in the Owen Stanley Range are the Musa, Ruaba, Bonua, and Tavanei. Extensive coastal plains are developed only in the Tufi Sheet area, and to a lesser extent, in the Abau Sheet area. Rainforest covers most of the area, except for grass and swamp vegetation on parts of the coastal plain, and alpine scrub and grassland on some of the higher peaks.

Annual rainfall is lowest around Goodenough Bay (1000-2500 mm) and highest (up to 4500 mm) in the higher ranges and on the Suau coast between Samarai and Mullins Harbour (Hart, 1970). Rainfall is heaviest on the north coast during the season of northwest winds (December-March) and on the south coast during the season of southeast winds (May-October). Helicopter operations within the Owen Stanley Range may be hampered by high winds during these seasons.

The area includes parts of the Milne Bay, Central, and Northern Districts and is administered from centres at Alotau, Magarida, Rabaraba, Suau, and Tufi. Most of the area is accessible from the coast by foot tracks, and there are short motor roads at Milne Bay and some of the government stations and plantations. There are scheduled air services to Agaun, Baibara plantation, Dogura, Gurney (Alotau), Rabaraba, Robinson River plantation, Tufi, and Wanigela, and there are airstrips at Bimara (Biman), Cloudy Bay (at present disused), Loani (near Samarai), and Safia. Natural helicopter landing sites are plentiful.

The main local industries are the production of copra, cocoa, and coffee. Projected industries include commercial fishing, beef cattle raising, and the development of hydro-electric power on the Musa River.

The whole area is covered by 1:50 000 and 1:250 000 topographic maps and vertical aerial photographs at about 1:50 000.

History of investigation

Early reports include those of MacGillivray (1852) and Gibb-Maitland (1892). Stanley (1923) prepared the first account of the geology of Papua, drawing mainly on his own traverses and maps. Papp & Nason-Jones (1930) mapped part of the Cape Vogel peninsula. Baker (1946) described the 1943 eruption of Waiowa (Goropu) volcano and (1953) described diorite from East Cape. Paterson & Kicinski (1956) reviewed the geology of eastern Papua and discussed the petroleum prospects of the Cape Vogel Basin.

During the 1950s J. E. Thompson made a number of traverses across southeast Papua, including a reconnaissance survey of the Cape Vogel peninsula with a party from the CSIRO Division of Land Research (CSIRO, 1964), during which he collected specimens of clinoenstatite-bearing lavas (Dallwitz et al., 1966; Dallwitz, 1968). Palaeontological specimens collected by Thompson from the Nigo Nigo River and the Milne Bay area were described by Kicinski (1954) and Belford (1959). An outline of Thompson's findings in southeastern Papua appears in his synthesis of the structure of Papua New Guinea (Thompson & Fisher, 1965).

Recent work by BMR includes a survey by Smith & Green (1961) in the Musa River area, traverses by Latter (1964) in the Mount Dayman area, and Davies (1967) in the Milne Bay area, and fieldwork by Davies (1971) southwest of Mount Suckling. Jongsma (1972) has described the marine geology of the Milne Bay area. Various mining company investigations are discussed in the Explanatory Notes.

Systematic geological mapping of the area east of 149°E was carried out by the BMR in 1967-69. Fieldwork was shared with geologists from the Geological and Volcanological Branch of the Department of Lands, Surveys and Mines (now the Geological Survey of Papua New Guinea). Fieldwork was initially supervised by Davies, working with Smith and G. Cifali (BMR) and R. F. Heming, P. D. Hohnen, R. P. Macnab, P. E. Pieters, and R. J. Tingey (Geological and Volcanological Branch). An interim report was produced in 1968 (Davies et al., 1968), and the survey was completed by Cifali, Hohnen, Pieters, and Smith in 1968-69.

This Bulletin expands on the interim report and incorporates other information such as the results of fieldwork by General Exploration Co. of Australia on the Cape Vogel peninsula (Bickel, 1969). Apart from the maps and Explanatory Notes other recent work on southeast Papua includes Smith (1969) and Jakes & Smith (1970) on the Cape Nelson volcanoes, Smith (1970) and Smith & Simpson (1972)

TABLE 1. STRATIGRAPHY

	Unit (Map Symbol)	*Distribution*	*Thickness* (m)	*Lithology*	*Remarks*
HOLOCENE	Fanglomerate Qru	E end of Musa valley near Ubo village	Up to 50	Gravel, sand, and silty clay with scattered subangular boulders up to 10 m across	
	Wakioki Fanglomerate Qrx	NE of Mt Suckling where Wakioki R. flows onto alluvial plain			
PLEISTOCENE TO HOLOCENE	Alluvium and beach deposits Qa	Coastal plains and beaches, and in major river valleys; most extensive areas to NW and S of main ranges	Up to 50	Gravel, sand, silt, clay	
	Raised coral Qc	E end of Cape Vogel peninsula; isolated areas S of Goodenough Bay along N coast of W of East Cape	Up to 50	Coral reef	
	Colluvium Qs	W and SW of Mt Suckling, S of Mt Dayman, central part of Cape Vogel peninsula	Up to 100	Chaotic deposits of angular rock fragments in fine matrix; may include some alluvium	Landslide and creep deposits; ultramafic colluvial breccias mapped separately (Ubo and Wakioki Fanglomerates)
PLEISTOCENE	Agaun Conglomerate Qpa	Agaun valley and upper part of tributary to Tavanei R.	100 approx.	Conglomerate, sandstone, siltstone (former alluvium)	Terraced and partly dissected deposits on floor of Agaun valley; no definite evidence of age
	Silimidi Conglomerate Qps	NE part of Musa valley in Sivai-Darumu area, area, S part of Musa valley in Silimidi-Boroboro gorge	500 approx.	Conglomerate, sandstone, siltstone (former alluvium); tilted but not folded	Forms fault-bounded recently elevated blocks; overlies Tpd with angular unconformity; interfingers with Qpv and Qpi; no definite evidence of age
	Sivai Breccia Member Qpi	Interbedded with Silimidi Conglomerate	Individual sheets 10-20	Ultramafic breccia	Thin planar sheets within Qps
	Ibau Breccia Qpi	Upper reaches of Ibau R. and between lower reaches of Ibau and Silimidi Rs	Up to 150	Ultramafic breccia	Thick unbedded chaotic deposits

TABLE 1—(*cont.*)

	Unit (Map Symbol)	*Distribution*	*Thickness* (m)	*Lithology*	*Remarks*
PLIOCENE	Undifferentiated sediment Tpa	Small hills on alluvial plain	100	Poorly consolidated sand, silt, and gravel	More extensive W of 148°30′E
	Mailu Beds Tpm	Mailu Is., Turtle Back Is., and Laruoro Is. off central S coast	500 approx.	Lithified siltstone, sandstone, and conglomerate; folded	Conglomerate components consist mainly of 'Juliade' type limestone and chert with minor volcanic fragments of Kutu Volcanics and Fife Bay Volcanics type
	Domara River Conglomerate Tpd	Musa and Keveri valleys	1500	Conglomerate, sandstone, siltstone, some volcanic lava and agglomerate; folded	Non-marine with possible marine intercalations; deposited in intramontane basin; age based on K-Ar dates of associated volcanics
	Bonua Porphyry Tpb	Upper reaches of Bonua R., dykes within ultramafic rocks; stock in NE part of Didana Ra.; necks on Kilka Cr.		Microdiorite and micromonzonite porphyry stocks; lamprophyric dykes	Possibly related to volcanics in Tpd; age based on K-Ar date
UPPER MIOCENE TO LOWER PLIOCENE	Mau Monzonite Tpx	SE of Mt Suckling		Xenolithic granodiorite, biotite monzonite, biotite hornblendite	Covers area of 150 km^2; age based on K-Ar date
UPPER MIOCENE	Suckling Granite Tmk	Immediately S of Mt Suckling		Medium and coarse-grained granite	Age based on K-Ar date
MIDDLE MIOCENE	Shoshonitic intrusives	Refer Table 11			
MIDDLE ?MIOCENE TO HOLOCENE	Upper Cainozoic volcanics	Refer Table 6			
MIDDLE MIOCENE TO HOLOCENE	Cape Vogel Basin	Refer Table 5			
LOWER TO MIDDLE MIOCENE	Adau Limestone Tma	Upper reaches of Adau R. and E end of Keveri valley	100 approx.	Reef limestone and shelly calcarenite	Fault-bounded remnants; age based on upper Te and lower Tf foraminifera

TABLE 1—(*cont.*)

	Unit (Map Symbol)	*Distribution*	*Thickness* (m)	*Lithology*	*Remarks*
UPPER OLIGOCENE TO MIDDLE MIOCENE	Modewa River Beds Tme	SW of Milne Bay in Eabiha, Saga Aho, Sige Lele, Sige Eueu, Suwen, and Modewa R. valleys, and in Baxter Harbour area	Up to 200	Limestone, tuffaceous sandstone	Age based on middle Eocene foraminifera
	Suwen Member Tmes	Middle reaches of Sige Eueu and Suwen Rs	Not known	Graded-bedded tuffaceous sandstone and siltstone, minor limestone	
	Padowa Beds Tmp	N side of Sagari valley N to Gumini R.	Not known	Tuffaceous sandstone	Age based on Te foraminifera
	Debolina Beds Tmd	Debolina Cr. and middle reaches of Dawa Dawa R.	Not known	Tuffaceous sandstone	Age based on Te foraminifera
EOCENE	Juliade Beds Tej	Central S coast between Baibara and Onibu Pt; inland E and W of Bonua R.	At least 300	Interbedded limestone and chert	Age based on middle Eocene foraminifera
EOCENE?	Imo Tonalite Tei	Linear body in W part of area		Tonalite, granophyric tonalite, diorite	Age from tentative correlation with Eocene tonalites in N part of Papuan ultramafic belt
	East Cape Gabbro Tee	About 13 km^2 between East Cape and 150°45′E		Gabbro	Probably high-level intrusion related to Kutu Volcanics; age indefinite
UPPER CRETACEOUS TO EOCENE	Badila Beds Kub	Badila R., middle reaches of Nigo Nigo and Wegulani Rs, and in Momore Ra. SE of Mullins Harbour	Not known	Shale, argillite, calcilutite, limestone, calcareous tuff, minor basalt	Age based on Senonian and Eocene foraminifera
	Kutu Volcanics KTk_1, KTk_2	Main ranges S and SE of Musa valley/Mt Suckling area; ranges N and SE of Milne Bay	3000 approx.	Basalt (some pillows) with minor gabbro and rare ultramafics; minor calcareous and tuffaceous sediments	Age based on Late Cretaceous and Eocene foraminifera. KTk_1, Late Cretaceous; KTk_2, middle Eocene
	Godagina Beds Teg	S of Keveri valley	100 approx.	Marl, calcilutite	Probably lenticular body within Kutu Volcanics; age based on foraminifera
	Touiawaira Limestone Member Tet	Touiawaira Cr. and adjacent streams N of Milne Bay	3-7	Limestone	Lenticular interbed within Kutu Volcanics; contains benthonic foraminifera indicating relatively shallow water

TABLE 1—(*cont.*)

			Unit (Map Symbol)	*Distribution*	*Thickness* (m)	*Lithology*	*Remarks*
UPPER CRETACEOUS			Yau Gabbro Ky	Yau valley E and SE of Agaun		Altered gabbro, granophyre, tonalite	Subvolcanic pluton related to Gorupu Metabasalt; presence of prehnite and pumpellyite indicates low grade of metamorphism
UPPER CRETACEOUS			Goropu Metabasalt Kw	Mt Suckling/Mt Dayman area and SE to Kiramara R.	3000-4000	Metamorphosed basalt, dolerite, and gabbro, some altered calcareous rocks; prehnite pumpellyite-greenschist facies	Age based on foraminifera within calcareous member (Bonenao Schist Mbr)
UPPER CRETACEOUS			Bonenao Schist Member Kb	NW and SE of Mt Suckling, SE and E of Mt Dayman, and in Bailebo R.	1000	Calcareous schist and schistose limestone; metamorphosed	Contains Late Cretaceous foraminifera
JURASSIC TO CRETACEOUS	PAPUAN ULTRAMAFIC BELT	Basalt Zone	Korala Volcanics Kr	E and W of Korala R.	1000 or greater	Basalt lava (some pillow structures); some alteration	Probably lateral equivalents of Upper Cretaceous KTk_1 and Kw; age based on these correlations
JURASSIC TO CRETACEOUS	PAPUAN ULTRAMAFIC BELT	Gabbro Zone	High-level gabbro Kh	NW part of Sibium Ra., S part of Awaribo Ra; may be other areas in granular gabbro (below)	1000	Gabbro with zoned plagioclase and/or ophitic texture	Occurs at top of basalt zone, transitional to basalt zone; age from association with Kr and Kg
JURASSIC TO CRETACEOUS	PAPUAN ULTRAMAFIC BELT	Gabbro Zone	Granular gabbro Kg	Sibium, Didana, Keman, and Awariobo Ras, and Foasi R.	3000-4000	Granular gabbro; some streaky gabbro and pegmatitic gabbro	Intrudes Kc, Ku, and U, probably cogenetic with Ku, Kc, Kh, and Kr
JURASSIC TO CRETACEOUS	PAPUAN ULTRAMAFIC BELT	Gabbro Zone	Cumulate gabbro Kc	Small bodies within main mass of granular gabbro (above)	1000 approx.	Gabbro with cumulus texture	Probably subvolcanic plutons related to Kr and KTk_1; intruded by Kg, may be transitional to Ku
JURASSIC TO CRETACEOUS	PAPUAN ULTRAMAFIC BELT	Ultramafic Zone	Cumulate ultramafics Ku	SE part of Didana Ra.; SE part of Awarioba Ra.	Up to 500	Ultramafic rock with cumulus texture	Probably transitional upwards into Ku
JURASSIC TO CRETACEOUS	PAPUAN ULTRAMAFIC BELT	Ultramafic Zone	Tectonite ultramafics U	S part of Sibium-Didana Ras, E part of Didana Ra.	4000-8000	Ultramafic rock with tectonite texture; i.e. texture indicates solid state recrystallization	Probably represents upper mantle; no evidence as to age

on uplift in the Milne Bay area, Smith (1972) on the intrusives in the southeast of the area, and Davies & Smith (1971) on the geology of eastern Papua.

The rock units in eastern Papua are summarized in Table 1, and their general distribution is shown in Figure 2 (see also 1:250 000 geological maps). The rock units are described in stratigraphic sequence (oldest first), except in the descriptions of the Cape Vogel Basin, and the Upper Cainozoic volcanic rocks and the intrusive rocks.

CRETACEOUS-EOCENE

Papuan Ultramafic Belt

The Papuan ultramafic belt consists of a basal layer of peridotite overlain by gabbro which is in turn overlain by basalt volcanics. It conforms to accepted definitions of an ophiolite complex (Steinmann, 1927), although no sheeted dyke complex has been recognized between the gabbro and basalt layers. The ultramafic belt has been described by Davies (1968; 1971), and only a brief account is given here, followed by some specific details of that part of the complex which falls within the area described.

The belt is 400 km long and 25 to 40 km wide and lies on the northeastern side of the Owen Stanley Range between 7°S and 10°S and 146°50′E and 149°10′E. Only about 15 percent of the ultramafic belt, the south-easternmost part, lies within the area covered by this Bulletin. The belt consists of 4 to 8 km of ultramafic rocks overlain by about 4 km of gabbroic rocks which are overlain by 4 to 6 km of basalt volcanics. The ultramafic and gabbroic rock types and their mode of occurrence are discussed below. The basalt volcanics (Lokanu Volcanics) are described separately.

The Papuan ultramafic belt is faulted against the Owen Stanley Metamorphics, Goropu Metabasalt, and Kutu Volcanics, and is unconformably overlain in places by Eocene volcanics and Miocene and younger volcanics. It is intruded by Eocene tonalite and, in the Mount Suckling area, by Mio-Pliocene granite and monzonite.

K-Ar determinations on gabbro and basalt and rare microfossil evidence in the basalt layer indicate that all the units in the ultramafic belt, except the tectonite ultramafics at the base of the complex, are Cretaceous and possibly Jurassic. The tectonite ultramafics are clearly older than the other rocks and presumably formed at some time before the Jurassic? or Cretaceous. The ultramafic belt is thought to have been emplaced by thrusting during the Eocene (see p. 64).

Within the area described in this Bulletin, peridotite and gabbro form the Didana Range and the Keman and Awariobo Ranges on either side of the Musa valley (9°20′-57′S, 148°30′-149°10′E) and south and southeast of Mount Suckling. Basalt of the Lokanu Volcanics crops out in relatively small areas northwest and south of the Musa valley. The geology of the Didana Range and a small part of the Keman Range has been described by Smith & Green (1961).

Ultramafic rocks

The basalt layer of the Papuan ultramafic belt consists of ultramafic rocks which have a maximum exposed thickness of 8 km in the Bowutu Mountains (Salamaua Sheet area) and probably 3 km in the area covered by this Bulletin. Over 95 percent of the ultramafic rocks have a metamorphic texture and are here termed 'tectonite ultramafics'; less than 5 percent have an igneous cumulus texture and are here called 'cumulate ultramafics'. The cumulate ultramafics form a discontinuous layer up to 500 m thick at the top of the ultramafic layer, and are probably genetically related to the overlying gabbro, rather than to the tectonite ultramafics.

The tectonite ultramafics consist predominantly of harzburgite (olivine 60-80%, orthopyroxene 20-40%, accessory chromite) and some dunite (olivine, accessory chromite), with ubiquitous dykes, veins, and other irregular small bodies of coarse-grained orthopyroxenite. Serpentinization is not common, except near some of the faults, and near the contacts with the gabbro layer. Olivine and orthopyroxene are uniformly highly magnesian ($Fo_{91.6-93.6}$; $En_{92.1-93.4}$; England & Davies, 1973).

The cumulate ultramafics, which are more variable in composition, are commonly layered and contain significant amounts of clinopyroxene (which is absent from most of the tectonite ultramafics). The mineral assemblages consist of various combinations of olivine, orthopyroxene, clinopyroxene, and chromite. Most of the cumulate ultramafics contain no plagioclase, but in some outcrops they can be seen to pass up-section into plagioclase-bearing

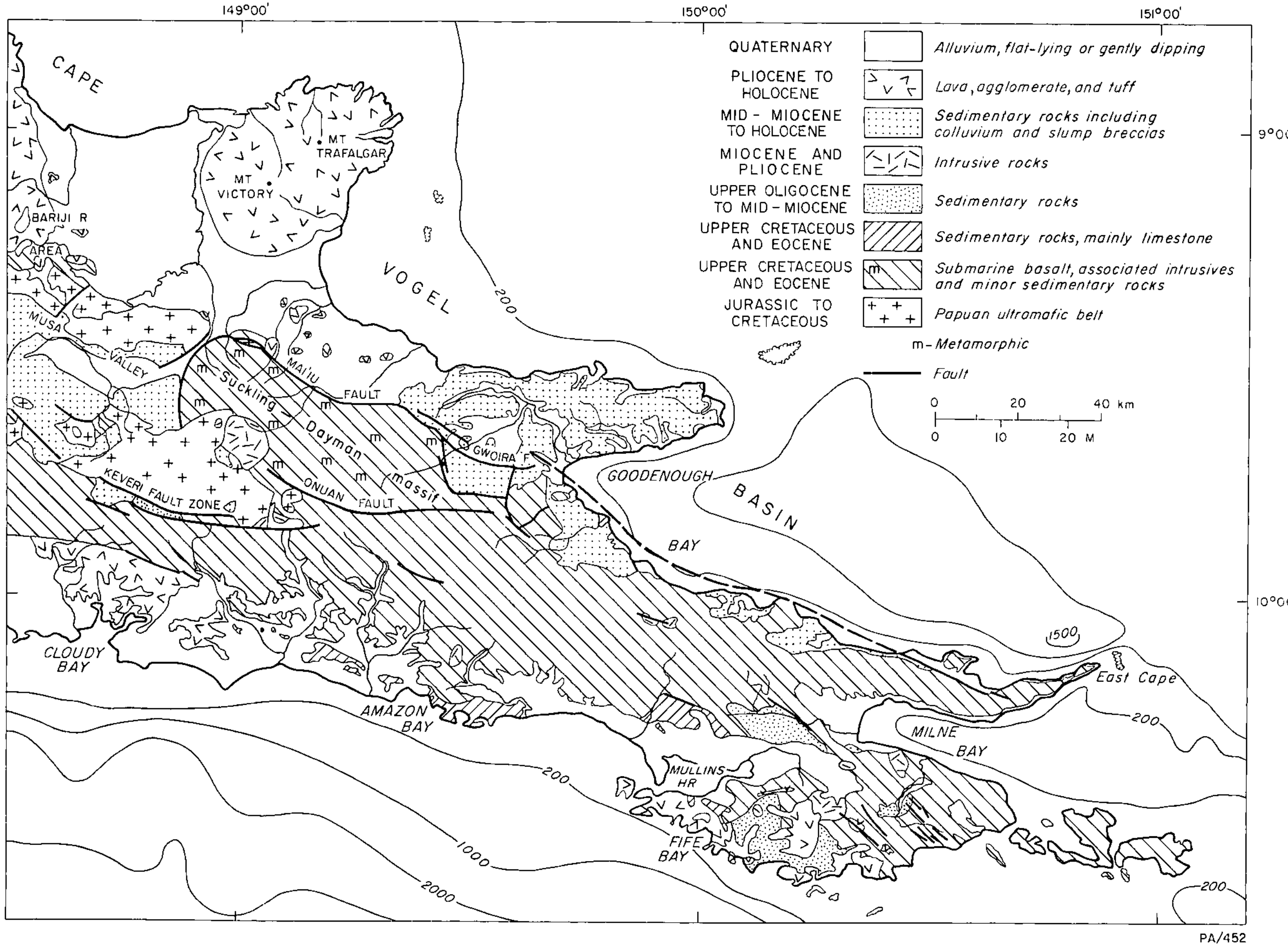

Fig. 2. Simplified geology of southeast Papuan mainland.

cumulates. Rocks with more than about 5 percent plagioclase were mapped as part of the gabbro layer. Unlike those of the tectonite ultramafics, the olivine and orthopyroxene of the cumulate ultramafics have a wide range of composition ($Fo_{78-89.6}$, $En_{81-90.5}$; England & Davies, 1973).

Ultramafic rocks within the area described. Over 95 percent of the ultramafic rocks have been mapped as tectonite ultramafics, but some areas of cumulate ultramafics may have been missed because of the reconnaissance nature of the mapping and possibly because the diagnostic cumulus textures have been obliterated by deformation. Cumulate ultramafics have been found in the eastern parts of the Didana and Awariobo Ranges, but only in the Awariobo Range is the area sufficiently large and well defined to be shown on the accompanying maps. Ultramafic rocks with possible cumulus texture are exposed in Uku Creek in the northwestern part of the Keman Range.

The tectonite ultramafics in the Keman and Awariobo Ranges cover an area of about 450 km^2, and form one of the largest contiguous outcrop areas of ultramafics in the Papuan ultramafic belt. They form a gently dipping sheet, possibly no more than 3 km thick. The sheet is bounded by normal faults, except in the headwaters of the Ibinambo River, where the thrust-faulted contact with underlying basic schist has been broken and tilted by vertical faults.

A notable feature of the tectonite ultramafics within the area described is the presence of some wehrlite (olivine, minor diopside, accessory chromite), as well as the typical harzburgite, dunite, and orthopyroxenite. The wehrlite was noted at several localities in the eastern part of the Awariobo Range, at about 9°50′S, 149°E. Massive harzburgite is predominant. In places it is cut by dykes of both pyroxenite and dunite, from 1 to 10 cm thick, and elsewhere interfingers with massive dunite. In Uku Creek and at the confluence of Duuba Creek and the Adau River (9°48′S, 148°44′E), harzburgite and dunite appear to be interlayered and are cut by pyroxenite dykes from 1 to 3 cm thick, parallel to the layering. These rocks are partly serpentinized, and the original textures are obscured. Shearing parallel to the layering is indicated by the stretched and boundinage nature of the pyroxenite dykes. In both areas the layering dips consistently at 40° to 60°S.

Gabbroic rocks

The second layer of the Papuan ultramafic belt, which is about 4 km thick, consists of gabbroic rocks. The characteristics of the three main types of gabbro distinguished as mappable units are summarized below:

High-level gabbro characterized by its ophitic or subophitic texture and zoned plagioclase, or both. The grainsize ranges from 1 to 2 mm. The plagioclase is more sodic (some labradorite) than in most of the granular gabbro. It almost invariably occurs within the top 1000 m of the gabbro layer, and is possibly transitional into the basalt layer. The maximum thickness is 1000 m.

Granular gabbro characterized by its granular allotriomorphic or hypidiomorphic texture and the absence of zoning in the plagioclase which consists mainly of bytownite. The grainsize ranges from 1 to 2 mm. The most common rock types are homogeneous intrusive (as distinct from cumulate) gabbro and gabbro pegmatite. The thickness is up to 3000 m.

Cumulate gabbro is similar to the granular gabbro in grainsize (but some is coarser), mineral assemblages, and chemistry, but can be distinguished by its cumulus texture with or without layering. The cumulate gabbro includes the layered cumulates of the 'transition group' of Smith & Green (1961). The thickness ranges up to 3000 m.

The cumulate and high-level gabbros cannot be distinguished from granular gabbro on the aerial photographs, and consequently it has been necessary to round off the boundaries of known areas of high-level and cumulate gabbros, and to show all gabbro of unknown affinity as granular gabbro on the accompanying map (Tufi Sheet). Thus the area mapped as granular gabbro includes much cumulate gabbro and probably some high-level gabbro.

The granular and cumulate gabbros consist of hypersthene (En_{70-90}), augite, bytownite and, in some rocks, olivine. Primary amphibole is rare. Opaque iron oxides and sulphides are lacking in most of the granular gabbro, but are present in the high-level gabbro.

Gabbroic rocks within the area described. High-level gabbro is exposed in a strip about 1 km wide along the southern edge of the Awariobo Range. If it is assumed that the layer dips at 45°S, then, allowing for a land surface slope of 15°S, the thickness of the high-level gabbro zone is about 0.5 km. High-level gabbro is also exposed over an area of about 10 km^2 around the Baborobo River in the northwestern part of the Didana Range (or eastern part of the Sibium Range), where it is in contact with rocks of the basalt layer to the north.

Most of the gabbroic rocks have been mapped as granular gabbro. Cumulate gabbro has been picked out only where the cumulus features are sufficiently well marked over a large area. The Didana and Keman Ranges contain some of the best examples of cumulate gabbro in the entire ultramafic belt (see Davies, 1971). A streaky type of gabbro is common in the areas mapped as granular gabbro: it generally consists entirely or almost entirely of cumulate gabbro which has been permeated and veined by a later intrusive gabbro.

Pegmatite and very fine-grained gabbro occur as rare dykes in the granular gabbro. The fine-grained dykes intruding the cumulate gabbro in Duuba Creek are notable for their granofelsic texture, and for the presence of hornblende and olivine, as well as orthopyroxene, clinopyroxene, and biotite.

Some of the gabbros show varying degrees of shearing and recrystallization, which are possibly related to their mode of emplacement as part of a subhorizontal thrust sheet. The gabbro mylonite in the northwestern headwaters of the Bonua River (9°49′S, 148°58′E) has a finely recrystallized matrix that indicates considerable heat and confining pressure at the time of shearing. The foliae within the mylonite strike 280° and dip at 40°N. A similar mylonite in the headwaters of the Duuba River includes streaks of serpentinized harzburgite. The layered fine-grained gabbro immediately southeast of Mount Avuru (at 9°47′S, 148°42′E) is an olivine-hornblende-clinopyroxene-plagioclase granofelsic gneiss which has been completely recrystallized under granulite facies conditions; the layering strikes 090° and dips at 30°S.

Owen Stanley Metamorphics

Derivation of name. Owen Stanley Range, which forms main divide in eastern Papua (from about 147°E to 150°E).

Rock type. Great variety of metamorphic rocks, which range in metamorphic grade from phyllitic subschist to greenschist facies mica schist and some glaucophane-lawsonite gniess, and in composition from quartz-feldspar-mica rocks (probably the most commom) to marble and metabasalt.

Distribution. Southeasterly trending belt, about 350 km by 70 km extending from near Lae in northwest to Musa valley in southeast.

Type section. From Kokoda southwestward to southwesterly limit of metamorphic outcrops on Brown River in which all main rock types are exposed.

Stratigraphic relationships. Probably oldest rocks in eastern Papua. Faulted against the Papuan ultramafic belt. May grade laterally to the northeast and southwest into unmetamorphosed Cretaceous sediments.

Thickness. 10 000 to 30 000 m estimated.

Age. Cretaceous and possibly older.

As mapping of the Owen Stanley Metamorphics progresses it should be possible to subdivide them into a number of formations.

Within the area described, the Owen Stanley Metamorphics occur only within a narrow west-northwesterly strip of country in the headwaters of the Ikum, Foasi, and Domara Rivers (southwestern part of the Tufi Sheet area). Metamorphics were recorded by Smith & Green (1961, p. 11) and were recognized as a mappable unit by Macnab (1967, p. 9). Most of the rocks are finely recrystallized basic schists of the greenschist and amphibolite facies, and are possibly metamorphic equivalents of the Kutu or Lokanu Volcanics.

Lokanu Volcanics

Derivation of name. Lokanu village (7°07′S, 147°03′E, Salamaua Sheet area).

Rock type. Massive basalt, basalt and spilite lava, and pillow lava; some uralite, chlorite, epidote, and silicic alteration; metamorphosed to prehnite-pumpellyite and greenschist facies near major faults; minor fine-grained calcareous sediments.

Distribution. Exposed discontinuously along entire length of Papuan ultramafic belt, especially in northwest.

Type section. Small streams south-southwest of Lokanu village.

Stratigraphic relationships. Overlies gabbro of Papuan ultramafic belt, and overlain in places by Eocene Eia Beds and Miocene Iauga Formation (Salamaua and Buna Sheet areas).

Thickness. 4000 to 6000 m, possibly thinner in places.

Age. Probably Cretaceous, based on one K-Ar age from pyroxene (116 m.y.) and some *Globotruncana* sp. in associated sediments.

The Lokanu Volcanics form the top layer of the Papuan ultramafic belt. The name is a revision of the term Lokanu Metavolcanics used by Dow & Davies (1964). Within the area described, the volcanics are exposed in only three relatively small areas: one north of the Sibium Range, another in the headwaters of the Domara River, and a third in the middle reaches of the Adau River. The rock types include moderately jointed basaltic and pillow lavas containing some epidote, uralite, and chlorite.

The Lokanu Volcanics are similar to the Kutu Volcanics, and are invariably intimately associated with peridotite and gabbro of the Papuan ultramafic belt, whereas the Kutu Volcanics are not. The Lokanu Volcanics are probaly entirely Cretaceous whereas the Kutu Volcanics range from Late Cretaceous to middle Eocene.

The Lokanu Volcanics north of the Sibium Range and in the headwaters of the Domara River were mapped by Smith & Green (1961) as the *Urere Metamorphics,* which included the limestones and conglomerates immediately to the west in the Port Moresby Sheet area. As it is now known that most of these rocks are not metamorphosed, and as they include rocks of several ages, the name Urere Metamorphics should no longer be used.

Goropu Metabasalt

Derivation of name. Goropu Mountains, around and including Mount Suckling (9°45′S, 149°E approx.).

Rock type. Metamorphosed basalt, dolerite, ophitic gabbro, some hyaloclastite, and rare interbeds of impure limestone; metamorphosed to prehnite-pumpellyite facies and greenschist with glaucophane, crossite, aragonite, and lawsonite developed locally. Pillow structure is preserved in the metabasalt in a few places.

Distribution. Suckling-Dayman massif (9°32′-58′S, 148°25′-149°28′E) and eastwards to 149° 43′E (Fig. 3); total area is about 1600 km^2.

Type section. Kovai Creek (9°33′-35′S, 149° 03′-04′E); also well exposed in eastern headwaters of Gwariu Creek between 9°47′-48′S, 149°18′E, where slightly deformed pillow lavas and schistose metabasalt crop out.

Stratigraphic relationships. To south grades into unmetamorphosed Kutu Volcanics. Probably lateral equivalent of the Owen Stanley Metamorphics and Kurada Metavolcanics (Normanby Island). Encloses lenticular? bodies of the Bonenau Schist Member.

Thickness. 3000 to 4000 m.

Age. Planktonic foraminifera in Bonenau Schist Member and hyaloclastite of Goropu Metabasalt indicate a Late Cretaceous (Maestrichtian) age. Probably metamorphosed during the Eocene.

The metamorphic rocks in the Goropu Mountains, north and west of Mount Suckling, were named the Goropu Metamorphics by Smith & Green (1961), who also included the metamorphic rocks at the northwestern end of the Musa valley (Port Moresby Sheet area). Subsequent work in the Goropu Mountains and elsewhere in the Suckling-Dayman massif has shown that the Goropu Metamorphics consist predominantly of low-grade metabasalt, with only minor metamorphosed limestone and calcareous schist. We have therefore amended the name to Goropu Metabasalt and introduced the term Bonenau Schist Member for the interbedded calcareous rocks. The metamorphics mapped by Smith & Green in the northwestern end of the Musa valley are now known to be part of the Owen Stanley Metamorphics.

The Goropu Metabasalt and Bonenau Schist Member originally consisted of a pile of submarine basalt lava, 3000 to 4000 m thick, with interbeds and lenses of pelagic limestone and rare terrigenous sediments. Some of the dolerites and ophitic gabbros are intrusive, but some represent coarser phases within the lava flows. The sequence also includes minor hyaloclastite or glassy basalt breccia. The pelagic limestones contain some planktonic foraminifera, and minor detrital quartz, silt, and carbonaceous and possibly tuffaceous material, and pyrite.

The Goropu Metabasalt is the metamorphosed equivalent of the Kutu Volcanics or, at least, of the Cretaceous part of the Kutu Volcanics. The contact at about 9°58′S is gradational, except along the Kiramara River where it may be faulted. Immediately north of the contact the Goropu Metabasalt is characterized by the presence of prehnite and pumpellyite as vein and replacement minerals; the rocks are massive and only locally schistose. Farther north and northwest, where the metabasalt is more schistose, albite, epidote, and actinolite have been developed and prehnite is absent. Close to the northern limit of outcrop the metabasalt is schistose and completely or almost completely recrystallized; neither pumpellyite nor prehnite are found and greenschist mineral assemblages prevail. Some of the central and northern schists contain minor lawsonite, aragonite, glaucophane and, in one instance, crossite.

The distribution of metamorphic mineral assemblages outlined above indicate zonation from low-grade rocks in the south (prehnite-pumpellyite facies) through intermediate (pumpellyite-bearing greenschist facies) to higher-grade metamorphics in the north (greenschist facies). The occurrence of aragonite, lawsonite, glaucophane, and crossite in some of the intermediate and higher-grade metamorphics indicates conditions of high pressure and temperature and is compatible with the concept of metamorphism by underthrusting. The grade of metamorphism within each zone is not entirely uniform, and some

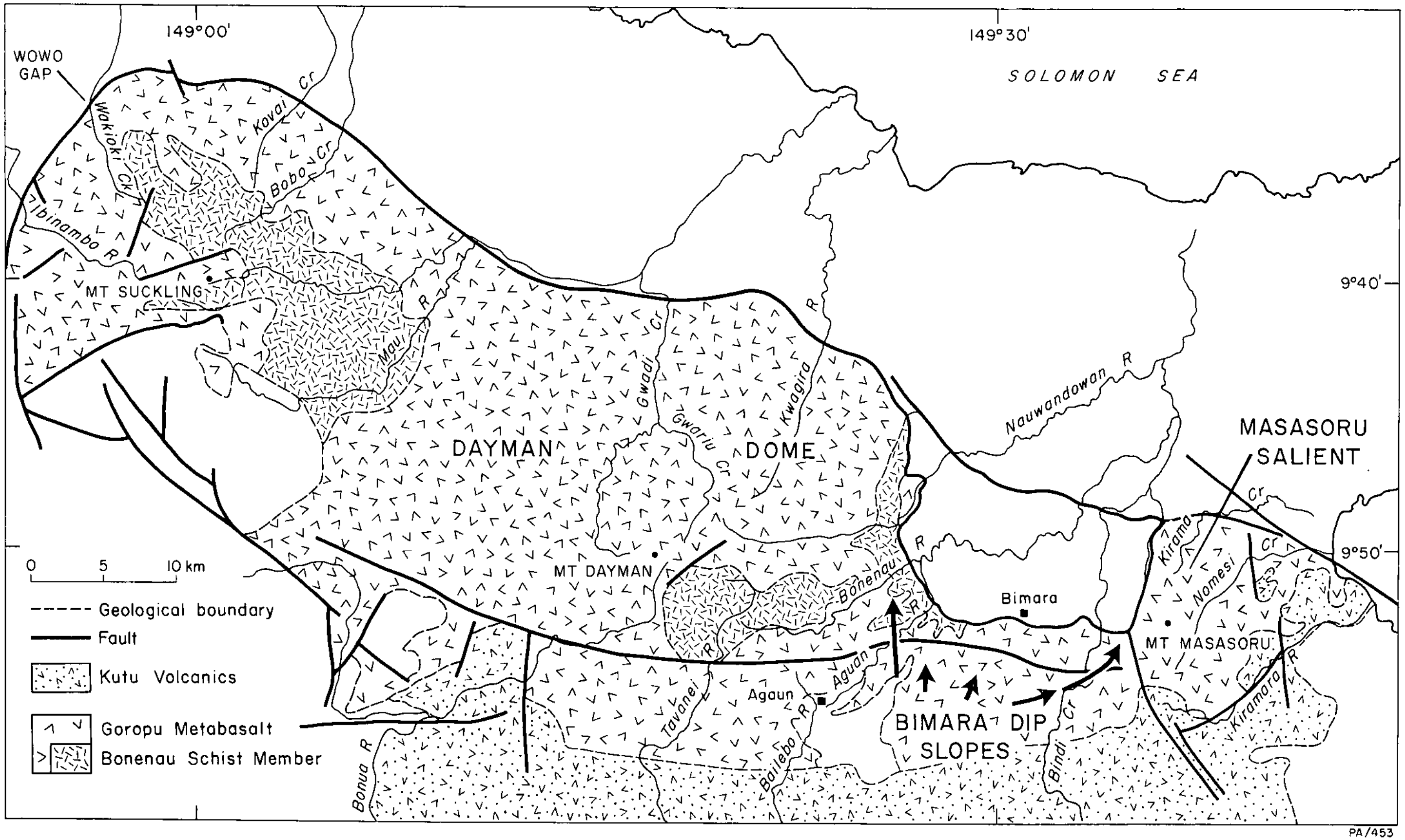

Fig. 3. Dayman Dome.

of the rocks are less schistose and lower in metamorphic grade than the surrounding rocks. These are assumed to be tectonic rafts which have been protected from shearing and recrystallization by some accident of original jointing or bedding. Davies et al. (1968) suggested that the degree of metamorphism and schistosity may decrease systematically with depth, but later work has thrown no light on the suggestion.

Bonenau Schist Member

Derivation of name. Bonenau River (9°51′-54′S, 149°22′-25′E).

Rock type. Calcareous schist and various types of schistose limestone. The typical schist consists of calcite, quartz, sericite, chlorite, and albite, with some graphite and accessory pyrite; some contain metamorphic aragonite, but dolomite and magnesite are rare. Planktonic foraminifera are preserved in some of the schists, which are hornfelsed in places.

Distribution. Suckling-Dayman massif, northeast and southeast of Mount Suckling and southeast of Mount Dayman (Fig. 3).

Type section. Headwaters of Tavanei River at 9°54′S, 149°19′E, where a sequence of schist is exposed in a gorge.

Stratigraphic relationships. Probably includes at least two large lenses completely enclosed in Goropu Metabasalt, and thinner scattered lenses and interbeds.

Thickness. Probably up to 1000 m on Mount Suckling and 600 to 1000 m near Mount Dayman.

Age. Planktonic foraminifera *Globotruncana elevata* and *G. arca* indicate a Late Cretaceous (Maestrichtian) age.

Note: Characteristically forms dip-slopes; the schistosity is generally parallel to the original bedding.

Lenses of calcareous schist are scattered throughout the Goropu Metabasalt, but only two of the larger lenses have been mapped, one near Mount Suckling (160 km^2) and the other south and east of Mount Dayman (75 km^2). Apart from the type section, there are typical exposures in the Mau River (9°44′S, 149°06′E), in the headwaters of the Bailebo River (9°53′S, 149°19′E), north and south of the Nauwandowan River (9°49′S, 149°26′E), and in the Agaun valley at 9°53′S, 149°27′E.

The Bonenau Schist Member was laid down as a pelagic limestone containing minor detrital quartz, silt, and carbonaceous and probably tuffaceous material, and pyrite. Most of the limestone has been recrystallized to schist, in which the original bedding has been obscured by a metamorphic foliation defined by discontinuous streaks and lenses of sericite and dark minerals such as chlorite, graphite, and pyrite. In places, the first metamorphic foliation has been contorted into tight minor folds and crenulations formed during a second period of deformation, which resulted in minor recrystallization of quartz, calcite and, more rarely, sericite. Most of the metamorphic minerals (including lawsonite where it occurs) were formed during the first metamorphic event.

In a few places the original bedding in the limestone has been preserved, although the rock has been finely recrystallized (0.01 mm) and slightly foliated. In other areas the limestone was hornfelsed, presumably soon after deposition, and recrystallized to assemblages containing diopside, prehnite, and garnet. The hornfelsing invariably preceded any regional metamorphism, and was presumably caused by heat from the penecontemporaneous basalts and related shallow intrusives. A spotted hornfels in the Mount Dayman area consists of dark spheroids from 1 to 3 cm across set in a lighter-coloured matrix rich in calcite. The spheroids apparently developed from crystal-growth centres during thermal metamorphism, and many of them have a pyrite grain or foraminifer at the centre which has acted as a nucleus; some of the spheroids are surrounded by a rim of magnetite.

Detailed Description of Goropu Metabasalt and Bonenau Schist Member

Mount Suckling area

Smith & Green (1961) recorded quartz-mica phyllite, quartz-mica schist, chlorite schist, sericite schist, and metaquartzite containing epidote and chlorite in the Mount Suckling area. They noted that some of the 'quartz-bearing schists' consist predominantly of calcite, and that the chlorite phyllites are strongly sheared porphyritic basalts containing metamorphic chlorite, zoisite, quartz, and glaucophane. The glaucophane was considered to be metasomatic. During a reconnaissance by helicopter in 1966 Davies and R. P. Macnab concluded that the metamorphic rocks mapped by Smith & Green consist predominantly of chloritic basic schists, probably derived from basalt, and associated minor marble.

Davies (1968) suggested that these rocks are slightly more metamorphosed equivalents of the Upper Cretaceous metabasalts that he had noted farther east near Mount Dayman. Subsequent field work in 1967 by Davies, G. Cifali, W. Manser, and R. J. Tingey, and in 1968 by P. D. Hohnen, has confirmed the predominance of basic schist derived from basalt, and the presence of lenses of calcareous schist (Bonenau Schist Member).

In the Mount Suckling area the Goropu Metabasalt has an exposed thickness of about 4000 m, assuming that there is no appreciable repetition by faulting and folding, and an area of about 180 km^2. Excellent exposures occur in the Ibinambo and Mau Rivers, in Wakioki, Kovai (Wailou), and Bobo (Ureku) Creeks, and on the grassy summit area of Mount Suckling. The dip in the northern rivers is fairly consistently to the north, but in the Ibinambo River the dip is mainly to the south. Smith & Green (1961) suggested that the metamorphic foliation was folded into a broad west-northwesterly anticline, which was subsequently disturbed by block-faulting and by the intrusion of granite and monzonite on the southern flank.

Petrography. About 60 thin sections of the basic schists from the Mount Suckling area were examined. Greenschist assemblages (actinolite, epidote, albite, chlorite, and sphene) are the most common. Many of the rocks contain relict clinopyroxene, which in some specimens has been marginally altered to glaucophane. In one specimen the blue amphibole is crossite. Veins of quartz and calcite are common, and other minerals present include pumpellyite, muscovite, stilpnomelane, and in a few specimens, lawsonite. The accessories include titaniferous magnetite, less commonly pyrite and pyrrhotite, and rarely chalcopyrite. The mineral assemblages and textures of the basic schists near the Miocene granite and monzonite intrusives indicate some degree of thermal metamorphism after the dynamic regional metamorphism; the new minerals formed include biotite, hornblende, garnet, and scapolite.

Glaucophane occurs with pumpellyite in a dynamically metamorphosed dolerite in Wowo Gap (Smith & Green specimens 211, 4316) and with pumpellyite, stilpnomelane, and albite in a metamorphosed dyke rock (2002) in Wakioki Creek. The greenschists in Bobo Creek also contain glaucophane and various combinations of quartz, chlorite, epidote, pumpellyite, actinolite, and relict clinopyroxene (1767, 1769, 1777-80); one specimen (1768) is a glaucophane-bearing mylonite with relict clinopyroxene. Glaucophane was also noted in a metadolerite schist in the Ibinambo River (1872-3). Lawsonite has been found at only two localities, one in Wakioki Creek (muscovite - lawsonite - graphite - quartz - calcite schist, 1998), and the other in the Ibinambo River immediately south of Mount Suckling, where granophyric quartz gabbro has been metamorphosed to assemblages which include lawsonite, pumpellyite, epidote, clinozoisite, and a green-brown phyllosilicate, with some magnetite, pyrite, pyrrhotite, and rare chalcopyrite (1910-35). The rocks from the metamorphic aureole around the Miocene granite and monzonite include andalusite-garnet-biotite-muscovite-quartz schist (1795), garnet-quartz-mica schist (1719), scapolite-albite-epidote-hornblende gneiss (1834), epidote-garnet-chlorite-muscovite-quartz schist (1809), and hornblende-andesine gneiss (1189).

Most of the basic metamorphic rocks in the Mount Suckling area are strongly schistose, and their textures indicate severe dynamic metamorphism. Rocks which lack a schistose texture, at least in thin section, are known from a number of localities, including the Ibinambo River immediately south of Mount Suckling and the Mau River at 9°42′S, 149°08′E. The metamorphosed ophitic gabbro (1910-35) from the Ibinambo River consists of relic phenocrysts of clinopyroxene, plagioclase laths, most of which are completely altered, some granophyric quartz and feldspar, and metamorphic minerals. Some specimens of the gabbro have an igneous texture, but the rock is generally sheared to some degree and in places has the texture of a cataclasite schist.

The *Bonenau Schist Member* in the Mount Suckling area is about 1000 m thick and covers an area of about 150 km^2. The outcrop area may coincide with the axis of a west-northwesterly anticline, which has been disrupted in the west and north by block-faulting. There are excellent exposures in the Ibinambo River, in the upper reaches of Wakioki and Bobo Creeks, and in the middle reaches of the Mau River and the parallel tributary of the Mau about 5 km to the north. Near the Mau River the schist forms dip-slopes which dip at 25° to 30° to the south and east.

Petrography. Forty specimens of calcareous schist were examined in thin section. They consist of calcite (50-90%) and quartz, with minor chlorite, sericite, albite, and graphite, and accessory pyrite. One specimen (1805) from just below the ultramafic thrust contact in the headwaters of the Ibinambo River contains dolomite rather than calcite, and the carbonate mineral in several specimens (1988, 1998) from the northwestern front of the range may be aragonite. One of the specimens (1998) contains abundant lawsonite. Some of the schists are darker or have darker bands, probably due to contamination by material from the adjacent volcanics during deposition or during metamorphism. The darker layers commonly contain epidote, actinolite, hornblende (relic), chlorite, pumpellyite, and hematite.

Although almost all the calcareous rocks are slightly schistose, they are not all uniformly recrystallized. In some the quartz and albite grains appear to be original clasts and the calcite has been only very finely recrystallized to grains averaging 0.01 mm across. More commonly, the recrystallized calcite and quartz grains are about 0.3 mm across, and are traversed by coarser veins of the same minerals. In some of the rocks quartz occurs in aggregates of very fine grains (0.1 mm), which were presumably formed by recrystallization of larger grains under stress. The calcareous schist from the northwestern front of the range is coarsely crystalline and the quartz grains show extreme strain effects. Limestone (specimen 1842) from below the basalt cliffs southeast of the Mau River is the only rock in which bedding is definitely preserved. The bedding planes are defined by layers of fine grains of quartz set in a very fine-grained carbonate matrix. A weak cleavage is oriented at 90° to the bedding.

The grade of metamorphism in the Mount Suckling area is most commonly greenschist or pumpellyite-bearing schist bordering on greenschist. The presence of lawsonite in a few specimens indicates conditions tending toward blueschist, that is, slightly higher pressure/temperature conditions. The metamorphic grade immediately below the ultramafic thrust sheet in the upper part of the Ibinambo valley is greenschist, and the assemblages are sphene-albite - epidote - actinolite and sphene - albite-chlorite-biotite.

Mount Dayman area

The Dayman Dome consists mainly of moderately metamorphosed basalt and dolerite and of green and red basic schist derived from basalt and dolerite; finely recrystallized schistose limestone and calcareous schist are interbedded with the metabasalts in places. A prominent calcareous interbed, from 500 to 1000 m thick, has been mapped as the Bonenau Schist Member in the eastern and southeastern parts of the dome.

The metabasalt and calcareous schist are folded into a broad west-northwesterly anticline 35 km long and 25 km wide. The anticline is closed at the eastern end, but open in the west where it merges with a probable anticline in the structurally more complex Mount Suckling area. The dips on limbs of the fold range from 15° to 30° and are generally conformable with the present surface of the dome. In the few areas where streams have been deeply incised in the dome, as in the Gwariu - Gwadi drainage and the Nauwandowan River, there is evidence that the structure at depth may be more complex. At two localities in the Gwadi Gorge calcareous schist dips vertically and 53°SW, whereas the overlying basic schist dips consistently at 10° to 30°N, parallel to the land surface. In the Nauwandowan River, near the eastern edge of the dome, calcareous schist dipping at 70°E is apparently faulted against the overlying basic schist which dips at 20°E parallel to the surface of the dome. The discordant attitude of calcareous schist at these localities probably reflects its incompetent behaviour under stress in contrast with the competent behaviour of the overlying basic schist and metabasalt. It is also possible, but less probable, that the broadly folded upper strata may be separated from more tightly folded lower strata by a major low-angle fault.

The margins of the dome are probably faulted and the faults may dip parallel to the metamorphic foliation. A shear zone exposed in the Kwagira (Guipa) River at 9°52′S, 149°23′E dips at 30°N.

Petrography. About 170 rocks from the Dayman Dome have been examined in thin section. They are similar to those from the Mount Suckling area, except that the metamorphic grade is slightly lower and primary igneous textures are more commonly preserved. The metamorphic grade seems to be highest (greenschist facies) around the margins of the dome and slightly lower (pumpellyite-bearing) in the higher central part of the dome. Lower-grade basalt and limestone subschist are exposed in a northerly-trending zone immediately east of Mount Dayman. These three metamorphic zones are described separately below.

The basic schists around the margin of the dome consist of typical greenschist assemblages composed of actinolite, epidote, chlorite, albite, and sphene, with or without relict clinopyroxene. Stilpnomelane, quartz, and calcite are commonly present, but glaucophane (2515 from the headwaters of Gwariu Creek, 2492A from the Gwadi Gorge, and 2635 from the Nauwandowan River) and chloritoid (3218 from the Bonua River east) are less common. Lawsonite has not been recorded. The calcareous schist around the margin of the dome consists of albite, chlorite, sericite, quartz, and calcite with accessory pyrite; aragonite is the main carbonate phase in one specimen from the lower Nauwandowan River (2539). Some of the calcareous schist is relatively enriched in chlorite and epidote.

The basic schists in the higher central part of the dome have typical greenschist assemblages, but they commonly contain some pumpellyite, which indicates a slightly lower metamorphic grade. The associated calcareous schists are similar to those on the margins of the dome, and also contain some aragonite (2538 and 5761 in the headwaters of the Nauwandowan River, and 2554, 2555, and 2592 in the Gwadi Gorge).

In the zone of lower-grade metamorphism immediately east of Mount Dayman, the rocks are notably less schistose and some primary textures are preserved in the basalts, dolerites, and limestones. Zones of weak or moderate distortion are interlayered with zones of normal schistosity. For example, in Gwariu Creek, basalt with only slightly distorted pillow structure is overlain by a subhorizontal zone of typical basic schist. The moderately distorted basalts retain between 50 and 70 percent of their primary minerals and texture. The clinopyroxene is unaltered, and in some specimens the plagioclase is preserved. More commonly, however, the plagioclase is altered to fine sericite, epidote, and pumpellyite, and pumpellyite, chlorite, epidote, calcite, and quartz form 30 to 50 percent of the rock. Amygdaloidal basalt and basalt hyaloclastite (glassy autobreccia) are common; the amygdales are up to 1 mm across. The hyaloclastite in the upper part of the Bailebo River has a limy matrix containing Late Cretaceous foraminifera. The low-grade metabasalt exposed in the Bonua River east (3217B) is veined by datolite in association with quartz and calcite.

Other lower-grade metamorphic rocks include microgabbro and ophitic gabbro (1-4 mm grainsize), limestone, calcareous schist, and calcareous hornfels. The microgabbro and ophitic gabbro typically consist of sericite, epidote, and pumpellyite (after plagioclase), skeletal titaniferous magnetite, partly altered to white sphene, and relict clinopyroxene. The rocks grade from massive microgabbro and gabbro to subschist and schist in which only fragments of relict clinopyroxene and magnetite are recognizable. The limestone is very finely recrystallized (0.01 mm) and generally shows some degree of schistosity, except for a few specimens from the headwaters of the Nauwandowan River (5760) and the upper part of the Bailebo River (2501, 2505) in which the bedding is preserved. In specimen 2501 the bedding is isoclinally folded. Foraminifera are commonly preserved even in the moderately schistose rocks and diagnostic Late Cretaceous species have been found in boulders in the upper part of the Bailebo River (2505, 2507). In specimen 5760 pyrite occurs as spheres 0.01 mm across, or as aggregates of spheres up to 0.04 mm across. The calcareous hornfels is characterized by the presence of scattered green spheroids, ranging from a few millimetres to 2 cm in diameter, composed of variolitic diopside, prehnite, and possibly other skarn minerals. Some of the spheroids have a thin shell of magnetite (2512), and some have cores of microfossils or pyrite which have acted as a nucleus for recrystallization. The calcareous hornfels in the upper part of the Nauwandowan River (5765F) and lower part of the Bonua River (278, 282, 283, 290) contain diagnostic Late Cretaceous foraminifera. Some of the other hornfels are garnetiferous. Some degree of schistosity is commonly superimposed upon the variolitic hornfels. The hornfelsing probably occurred soon after deposition and was probably caused by dolerite and ophitic gabbro intrusives, which are probably the upper part of a subvolcanic pluton related to the metabasalts. The emplacement of the dolerite and gabbro and hornfelsing of the limestone preceded regional metamorphism.

Area south and east of Dayman Dome

The areas south and southeast of the Dayman Dome consist of Upper Cretaceous basalt and limestone, metamorphosed to varying degrees. The metamorphosed rocks are included in the Goropu Metabasalt and the unmetamorphosed rocks have been mapped separately as Kutu Volcanics. The Goropu Metabasalt extends southwards to about 9°58′S, eastwards to the Kiramara River (149°41′E), and westwards to the middle part of the Bonua River (149°05′E). In the north and east the metamorphic grade is greenschist; in the south, the grade is lower and is characterized by the development of pumpellyite and prehnite as alteration and vein minerals. About 130 rocks from this area have been examined in thin section. Metamorphosed basalt predominates, with some calcareous schist in the northwest and in the Bailebo River, a stock of metamorphosed gabbro-tonalite (Yau Gabbro) near Agaun, and

Fig. 4. Bimara dip-slopes (Goropu Metabasalt) dipping at 30° to north and northwest under the Pliocene Gwoira Conglomerate and Quaternary rocks. The high peak in background is Mount Masasoru.

a body of peridotite in the headwaters of Nomesi Creek (9°54′S, 149°36′E). The description of the area has been divided into three parts: the Bimara dip-slopes, the Masasoru salient, and the area south of the Dayman Dome and Bimara dip-slopes (Fig. 3).

The basic and calcareous greenschists between 149°27′ and 149°35′E form the Bimara dip-slopes, which dip at about 20°N (Fig. 4). The name is derived from Bimara (Biman) village and airstrip (9°52′S, 149°31′E). To the west the Bimara dip-slopes merge into the Dayman Dome and to the east they are terminated against a north-south spur called the Masasoru salient. The southern margin of the Bimara dip-slopes is also probably faulted and coincides roughly with the transition from greenschist to prehnite-bearing and pumpellyite-bearing metabasalts. The Bimara dip-slopes consist of (pumpellyite-) chlorite-albite-epidote-actinolite schists, which commonly show the effects of a second metamorphic event which has deformed, and in some cases isoclinally folded, the earlier metamorphic foliation. Only 30 percent of an ophitic gabbro (2321) cropping out in Bindi Creek has been altered to chlorite, actinolite, and epidote, probably because the rock did not fail by shearing.

The Masasoru salient is named after Mount Masasoru (9°53′S, 149°36′E). It is a northerly trending spur, with a maximum elevation of about 2100 m, at the eastern end of the Bimara dip-slopes. The Goropu Metabasalt in the Masasoru salient is bounded by normal faults in the west, by unmetamorphosed basalt and Plio-Pleistocene sedimentary cover in the north and east, and by unmetamorphosed basalt in the south. The southern boundary is possibly faulted and coincides with the Kiramara River. The metamorphic grade is consistently greenschist and a typical assemblage is (quartz-chlorite-muscovite-) sphene-epidote-albite-actinolite. Most of the rocks are coarsely crystalline, but a very fine (0.005 mm) sericitic siltstone (2443) forms an isolated dip-slope in the Kiramara River. This dip-slope is inclined at 30°ENE, but the dip possibly swings to southeast and south higher in the Kiramara drainage system (photo-interpreted). An isolated dip-slope in Nomesi Creek dips at 30°NE (Fig. 5), and a remnant of a dip-slope west of Kirama Creek is subhorizontal.

Fig. 5. Isolated dip-slope of schist dipping at 30° to northeast in Nomesi Creek.

These dips and interpreted dips in schist suggest a broad fold nose with an easterly plunge. Remnants of a probable sheet of subhorizontal ultramafic fault breccia are exposed on the spur west of Kirama Creek; the breccia has been almost completely replaced by red opaline silica and magnesite (233, 2445, 2449, 2551, 5120). The ultramafic rocks cropping out high in the headwaters of Nomesi Creek are probably part of the same sheet.

To the northeast, east, and south the greenschist metabasalts of the Masasoru spur are in sharp contact with unmetamorphosed basalt. In Kirama and Nomesi Creeks the contact probably coincides with gently dipping faults parallel to the attitude of the schist, or with vertical faults. In the lower part of the Kiramara River the contact coincides with a north-south vertical fault, but farther upstream it is possible that the schist dips under the unmetamorphosed basalt. In the headwaters of Nomesi Creek the position of the contact has been located to within about 1 km, but the contact is not related to any known structural feature.

The area between the Bimara dip-slopes and 9°58′S and westwards to the Bonua River consists of slightly metamorphosed basalt characterized by the development of prehnite and pumpellyite as vein and alteration minerals. In the Bailebo River gently dipping finely recrystallized (0.01 mm) calcareous schist crops out below prehnite-bearing basalt. Some of the limestone contains diagnostic Late Cretaceous planktonic foraminifera (2580, 2584, 3233).

The contact between the prehnite-bearing and pumpellyite-bearing rocks of the Goropu Metabasalt and the unmetamorphosed basalts of the Kutu Volcanics is only approximately defined, and is possibly transitional. On the Bailebo River the contact has been placed between fossiliferous calcareous schist specimens 233 and 2584. Both are very finely recrystallized, but the basalt near 3233 is veined by chlorite and prehnite whereas only 15 percent of the basalt near specimen 2584 has been altered to chorite, epidote, and a zeolite. Similarly, south of Agaun the contact is placed between outcrops of prehnite-bearing and pumpellyite-bearing granophyric tonalite and basalt (2637, 2641) and a basalt cataclasite which contains almost no metamorphic minerals (2575A).

Kutu Volcanics

Derivation of name. Kutu River (9°50'S, 149° 37'E).

Rock type. Basalt with minor dolerite, gabbro, and rare ultramafic rocks and a few interbeds of volcanolithic sandstone, argillite, calcilutite, and limestone. Most of the basaltic rocks form massive structureless outcrops, although bedded flows and pillow lavas have been recognized in places. The sedimentary rocks generally form thin lenses or highly contorted irregular beds; more persistent and thicker calcareous beds occur in places, one of which has been mapped as the Touiawaira Member.

Distribution. In central ranges from Milne Bay northwest to about 149°41'E and along southern side of Gorupu Mountains to about 148°30'E. They probably extend southeastwards from the Milne Bay area to the adjacent islands.

Type area. Middle reaches of Kutu River beneath southern slopes of Mount Simpson. The formation is generally well exposed in streams throughout the central ranges.

Stratigraphic relationships. Forms basement in southeastern Papua. In the north faulted against the Goropu Metabasalt on the southern side of the Goropu Mountains; the contact may be gradational farther east.

Thickness. At least 3000 m in Kutu River area, but may be less to southeast.

Age. Microfossils in limestone from Kutu River indicate a Late Cretaceous (Maestrichtian) age; elsewhere microfossils in limestone interbeds are middle Eocene. The fossiliferous localities are scattered and sparse. The age of the Kutu Volcanics may range from Late Cretaceous to middle Eocene, or there may be a hiatus in the Palaeocene and early Eocene.

The Kutu Volcanics are thought to be a southeasterly continuation of the Goropu Metabasalt. The volcanics were mapped by Macnab (1967) in the headwaters of the Wavera River (9°55'S, 148°45'E) east and west of the Keveri valley, and in the main range between the Musa valley and the south coast, and by Davies (1967) in the Milne Bay area; Davies et al. (1968) have shown that these two areas are co-extensive. The Kutu Volcanics include the Wavera Volcanics of Macnab (1967) and Dawa Dawa Beds of Davies (1967) and Davies et al. (1968).

Touiawaira Limestone Member

Derviation of name. Touiawaira Creek (10°14'S, 150°25'E).

Rock type. Cream-coloured fine-graded limestone containing benthonic foraminifera.

Distribution. Discontinuous horizon, with exposed east-west strike length of no more than 5 km, centred on Touiawaira Creek (10°14'S, 150°25'E).

Type section. Touiawaira Creek, where a thickness of 5 m of limestone is exposed as an interbed within pillow lavas.

Stratigraphic relationships. Forms lenticular interbed within Eocene part of Kutu Volcanics.

Thickness. 3 to 7 m.

Age. Middle Eocene.

Touiawaira Beds was the name given by Davies et al. (1968) to the basalts and related intrusions and associated limestone and limy sediments cropping out on the northern side of East Cape peninsula. In this Bulletin the Touiawaira Beds are included in the Kutu Volcanics and the name Touiawaira is used for the limestone member exposed in Touiawaira Creek.

The microfossils in the Touiawaira Limestone Member are relatively shallow-water benthonic forms, whereas the microfossils found elsewhere in the Kutu Volcanics are all pelagic types indicating a deep oceanic environment.

The Touiawaira Limestone Member has a consistent dip of 30° to the south, which suggests that there has been little folding of the Kutu Volcanics since the middle Eocene (Fig. 6).

Petrography and Chemistry of the Kutu Volcanics

Petrography. The Kutu Volcanics consist of basalt (about 65%), dolerite (about 30%), gabbro and ultramafics (less than 1% each), interbedded with less than 5 percent of agglomerate, tuffaceous and calcareous sediments, and limestone. Spilite has been reported in the western part of the area (Macnab, 1967), but not elsewhere.

The basalt is commonly medium to dark grey and has a fine-grained equigranular, or less commonly porphyritic, texture. The dolerite and gabbro are typically mottled because of the presence of light-coloured plagioclase crystals and darker pyroxenes. The rocks are classified according to grainsize: basalt, less than 1 mm; dolerite, from 1 to 5 mm; and gabbro, over 5 mm. Subophitic and ophitic intergrowths of plagioclase and clinopyroxene are common in the coarser-grained basalts, and in the dolerites.

The basaltic rocks consist mainly of clinopyroxene (20-30%), labradorite, or more rarely calcic andesine (40-60%), and opaque oxides (5%). Olivine or quartz (less than 5%) and various secondary minerals may be present. A fine-grained interstitial green mesostasis is common in many specimens (up to 20%). The groundmass in the porphyritic basalts consists

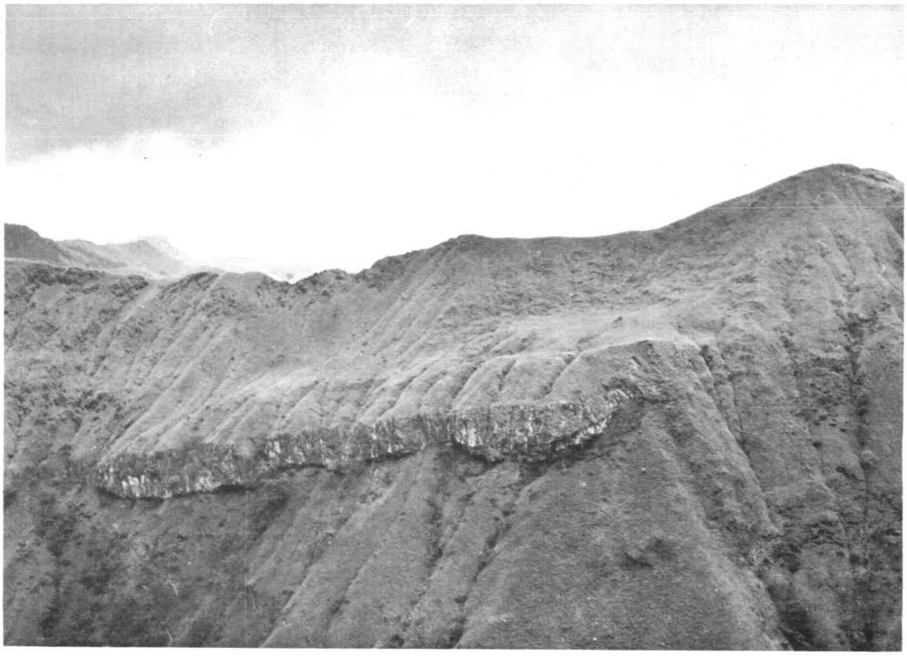

Fig. 6. Touiawaira Limestone Member, dipping to south, interbedded with basalts of the Kutu Volcanics.

of altered glass or finely crystalline material. The devitrified glass is difficult to distinguish from the fine-grained partly altered crystalline groundmass.

The olivine is almost invariably altered to bowlingite, iddingsite, or serpentine, and sericite and chlorite are present as alteration products of feldspar in some specimens. Brown amphibole has been observed as an alteration product on the margins of clinopyroxene crystals, but this is rare. Prehnite, potash feldspar, and calcite are locally abundant as secondary and vein minerals.

The spilites described from the Keveri area by Macnab (1967) are considerably altered; they contain sodic plagioclase in the groundmass and some of them are vesicular. It is possible that the rocks described as spilites represent intensely altered basalts.

Most of the ultramafic rocks occur in the north, but small bodies are known in the Milne Bay area. The ultramafic rocks in the north are probably tectonic inclusions associated with faults, but those in the southeast may be accumulative. The ultramafics are highly serpentinized peridotites, and are composed of relic pyroxene set in a matrix of mesh-textured serpentinite.

Calcilutite and limestone generally occurs as thin lenses and beds, but also as relatively thick sequences in places. Most of the irregular thin beds and lenses are highly contorted. They are typically very fine-grained, and range from cream to red or purple in colour. The limestones are composed of microcrystalline calcite with minor detrital material; the larger grains of calcite found in some specimens are the result of recrystallization. Microfossils are common in some of the limestones, and some of them are sufficiently well preserved to be identified. With an increase in the content of detrital material the limestones grade into calcilutites.

Volcanolithic sandstone and argillite are fairly common. They are fine to very fine-grained, dark grey or reddish purple, and cannot be readily distinguished from the basic volcanics with which they are associated, although they are usually better bedded. The sandstone consists of poorly sorted subangular grains of plagioclase, augite, opaque iron oxides, quartz, and basaltic rock fragments set in a fine-grained green-brown matrix. The mineral grains range up to 0.5 mm across, and the rock fragments up to 3 mm. The fine-grained argillite consists of feldspar, opaque

TABLE 2. CHEMICAL ANALYSES, KUTU VOLCANICS AND EAST CAPE GABBRO

	1	2	3	4	5	6	7	8	9	10
SiO_2	38.9	44.1	45.2	45.8	47.3	47.5	47.6	47.6	48.0	48.0
TiO_2	0.3	0.99	1.85	2.30	1.47	1.57	1.39	1.1	1.49	1.29
Al_2O_3	5.95	15.8	12.5	14.0	13.9	13.9	14.6	13.5	12.4	14.5
Fe_2O_3	4.8	4.05	6.8	4.75	4.15	4.9	4.2	2.85	4.3	4.3
FeO	5.8	6.15	8.0	6.90	7.15	6.2	6.9	7.75	8.3	6.55
MnO	0.16	0.15	0.22	0.19	0.18	0.23	0.15	0.19	0.23	0.18
MgO	30.9	10.5	5.7	6.55	7.95	6.85	7.5	8.85	7.25	7.75
CaO	3.9	7.70	9.2	10.3	11.5	11.8	12.4	12.1	10.1	11.1
Na_2O	0.2	3.30	1.79	2.30	2.05	2.3	2.3	2.0	2.35	2.1
K_2O	0.06	0.90	0.16	0.19	0.19	0.15	0.12	0.08	0.1	0.14
P_2O_5	0.04	0.15	0.15	0.18	0.12	0.13	0.11	0.08	0.11	0.07
H_2O+	7.9	4.05	5.3	2.95	2.35	2.05	1.47	2.70	3.6	1.85
H_2O-	0.78	0.44	2.9	3.30	1.83	2.2	1.43	0.98	1.56	1.61
CO_2	0.1	1.70	0.08	0.10	0.05	0.1	0.05	0.07	0.14	0.2
Total	99.79	99.98	99.85	99.81	100.19	99.88	100.22	99.85	99.93	99.64

1 Serpentinized peridotite, above Rodeki Creek (9°50′S, 149°37′E). Analyst, A. Jorgensen, AMDL (Australian Mineral Development Laboratories). (2479).
2 Basalt, Bindi Creek (10°59′S, 149°32′E). Analyst, A. Jorgensen, AMDL. (3137).
3 Basalt, boulder, Origuina River, (10°13′S, 149°37′E). Analyst, A. Jorgensen, AMDL. (2288).
4 Basalt, Kiramara River, (10°53′S, 149°41′E). Analyst, A. Jorgensen, AMDL. (2327).
5 Basalt, north of Guaugurina Bay, (10°37′S, 150°28′E). Analyst, A. Jorgensen, AMDL. (3016).
6 Basalt, Wamira River, (10°15′S, 150°04′E). Analyst, A. Jorgensen, AMDL. (3045).
7 Gabbro, Touiawaira Creek, (10°15′S, 150°24′E). Analyst, A. Jorgensen, AMDL. (2044).
8 Gabbro, boulder, Lagatina River, (10°16′S, 149°43′E). Analyst, A. Jorgensen, AMDL. (2276).
9 Basalt, Kutu River, (10°07′S, 149°40′E). Analyst, A. Jorgensen, AMDL. (2251).
10 Basalt, Dawa Dawa River, (10°34′S, 150°23′E). Analyst, A. Jorgensen, AMDL. (3011).

	11	12	13	14	15	16	17	18	19	20
SiO_2	48.0	48.1	48.1	48.3	48.4	48.5	48.6	48.6	48.8	48.9
TiO_2	1.09	1.29	1.6	1.39	1.61	1.41	1.32	1.44	1.48	1.18
Al_2O_3	14.8	14.5	13.3	13.0	13.5	13.4	13.9	14.8	13.8	13.2
Fe_2O_3	2.75	4.2	6.1	4.75	4.25	4.45	4.6	4.35	5.05	3.3
FeO	6.6	6.2	7.0	8.9	8.7	8.1	7.85	6.55	8.10	8.05
MnO	0.17	0.16	0.17	0.26	0.18	0.17	0.21	0.17	0.21	0.19
MgO	9.0	8.0	6.9	9.45	6.95	7.35	7.3	12.1	6.50	8.55
CaO	11.4	11.8	10.0	6.65	11.1	11.5	11.3	6.45	10.2	11.6
Na_2O	2.4	2.75	2.8	3.5	2.6	2.25	2.5	2.55	2.75	2.2
K_2O	0.09	0.07	0.15	0.08	0.11	0.07	0.07	0.13	0.19	0.24
P_2O_5	0.09	0.11	0.13	0.13	0.13	0.11	0.1	0.13	0.13	0.06
H_2O+	2.1	1.47	2.15	2.4	1.65	1.74	1.51	1.08	1.78	1.75
H_2O-	1.12	1.47	1.38	1.0	1.0	1.16	0.63	1.44	1.17	0.57
CO_2	0.05	0.08	0.01	0.2	0.02	0.3	0.04	0.4	0.05	0.3
Total	99.66	100.20	99.79	100.01	100.20	100.24	99.93	100.19	100.21	100.09

11 Basalt, Wamira River, (10°14′S, 150°03′E). Analyst, A. Jorgensen, AMDL. (3052).
12 Pillow basalt, Touirawaira Creek, (10°15′S, 150°25′E). Analyst, A. Jorgensen, AMDL. (2041).
13 Basalt, near summit Mt Simpson, (10°02′S, 149°34′E). Analyst, A. Jorgensen, AMDL. (2314).
14 Dolerite, Nigo Nigo River, (10°15′S, 149°56′E). Analyst, A. Jorgensen, AMDL. (3116).
15 Basalt, boulder, Lavora Bay, (10°08′S, 150°12′E). Analyst, A. Jorgensen, AMDL. (2206).
16 Basalt, boulder, Lavora Bay, (10°08′S, 150°12′E). Analyst, A. Jorgensen, AMDL. (2207).
17 Basalt, Nomesi Creek, (9°50′S, 149°38′E). Analyst, A. Jorgensen, AMDL. (2457).
18 Basalt, boulder, Sige Lele River, (10°34′S, 150°38′E). Analyst, A. Jorgensen, AMDL. (4095).
19 Basalt, Bindi Creek, (9°59′S, 149°33′E). Analyst, A. Jorgensen, AMDL. (2430).
20 Basalt, Wamira River, (10°11′S, 150°01′E). Analyst, A. Jorgensen, AMDL. (3112).

TABLE 2. (CONT.)

	21	22	23	24	25	26	27	28	29
SiO_2	49.0	49.1	49.1	50.0	50.4	53.0	53.6	47.7	49.5
TiO_2	1.49	1.16	1.16	0.80	1.28	0.78	0.76	2.60	2.90
Al_2O_3	13.8	14.1	13.4	12.60	13.6	13.4	12.9	12.4	11.4
Fe_2O_3	8.50	4.5	2.8	1.44	4.4	3.45	4.05	4.90	3.75
FeO	4.10	7.0	8.0	6.20	7.4	7.45	7.2	12.6	16.0
MnO	0.20	0.19	0.16	0.14	0.19	0.21	0.15	0.25	0.31
MgO	9.35	12.2	7.55	7.4	7.85	4.05	6.4	5.45	2.70
CaO	6.90	7.65	12.2	11.2	9.65	7.9	3.25	9.05	6.80
Na_2O	2.95	2.1	2.15	3.0	3.2	1.62	1.93	2.50	3.15
K_2O	1.37	0.07	0.08	0.06	0.39	0.15	0.52	0.09	0.12
P_2O_5	0.15	0.1	0.09	0.08	0.06	0.07	0.08	0.08	0.30
H_2O+	1.50	1.25	2.9	5.5	1.33	5.95	5.95	1.83	2.32
H_2O-	0.66	0.63	0.39	1.38	0.09	1.71	2.65	0.35	0.54
CO_2	0.05	0.03	0.2	0.21	0.2	0.16	0.4	0.05	0.05
Total	100.02	100.08	100.18	100.01	100.04	99.90	99.84	99.85	99.84

21 Basalt, boulder, Dawa Dawa River, (10°28′S, 150°29′E). Analyst, A. Jorgensen, AMDL. (4020).
22 Dolerite, boulder, Kiramara River, (10°54′S, 149°41′E). Analyst, A. Jorgensen, AMDL. (3177).
23 Basalt, Uga River, (10°59′S, 149°37′E). Analyst. A. Jorgensen, AMDL. (5073).
24 Basalt, Laimodo River, (10°18′S, 149°47′E). Analyst, A. Jorgensen, AMDL. (2270).
25 Basalt, Wamira River, (10°11′S, 150°01′E). Analyst, A. Jorgensen, AMDL. (3091).
26 Glassy basalt, boulder, Kutu River, (10°06′S, 149°37′E). Analyst, A. Jorgensen, AMDL. (2250).
27 Glassy basalt, boulder, Origuina River, (10°13′S, 149°41′E). Analyst, A. Jorgensen, AMDL. (3127).
28 Gabbro, East Cape, (10°14′S, 150°52′E). Analyst, A. Jorgensen, AMDL. (4333B).
29 Gabbro, East Cape, (10°14′S, 150°52′E). Analyst, A. Jorgensen, AMDL. (4330A).

TABLE 3. COMPARISON OF BASALTIC ROCKS FROM THE KUTU VOLCANICS WITH OCEANIC AND CONTINENTAL THOLEIITES

	1	2	3	4	5	6	7
SiO_2	51.5	49.3	48.7	49.6	49.4	49.94	49.84
TiO_2	1.2	2.4	1.4	1.4	1.6	1.51	2.52
Al_2O_3	16.3	14.6	13.5	13.7	15.5	17.25	14.09
Fe_2O_3	2.8	3.2	4.2	4.3	*	2.01	3.06
FeO	7.9	8.5	8.2	8.4	10.4	6.9	8.61
MnO	0.17	0.17	0.19	0.19	—	0.17	0.16
MgO	5.9	7.4	7.5	7.6	7.2	7.28	8.52
CaO	9.8	10.6	9.9	10.10	11.1	11.86	10.41
Na_2O	2.5	2.2	2.4	2.4	2.7	2.76	2.15
K_2O	0.86	0.53	0.14	0.14	0.2	0.16	0.38
P_2O_5	0.21	0.26	0.12	0.12	—	0.16	1.26
H_2O+	0.81	0.79	2.6	0.80	—	—	—

1 Average continental tholeiite (from Manson, 1968).
2 Average oceanic tholeiite (from Manson, 1968).
3 East Papuan tholeiites, average of 24 analyses, water as determinated.
4 East Papuan tholeiites, average of 24 analyses, recalculated to H_2O+ value of 0.80 (average of columns 1 and 2).
5 Average of 32 analyses of basaltic rocks from oceanic ridge systems (from Kay et al., 1970). (*total iron determinated as FeO).
6 Average of 10 oceanic tholeiites (Engel et al., 1965, table 3).
7 Average of 180 Hawaiian tholeiites (Engel et al., 1965, table 3).

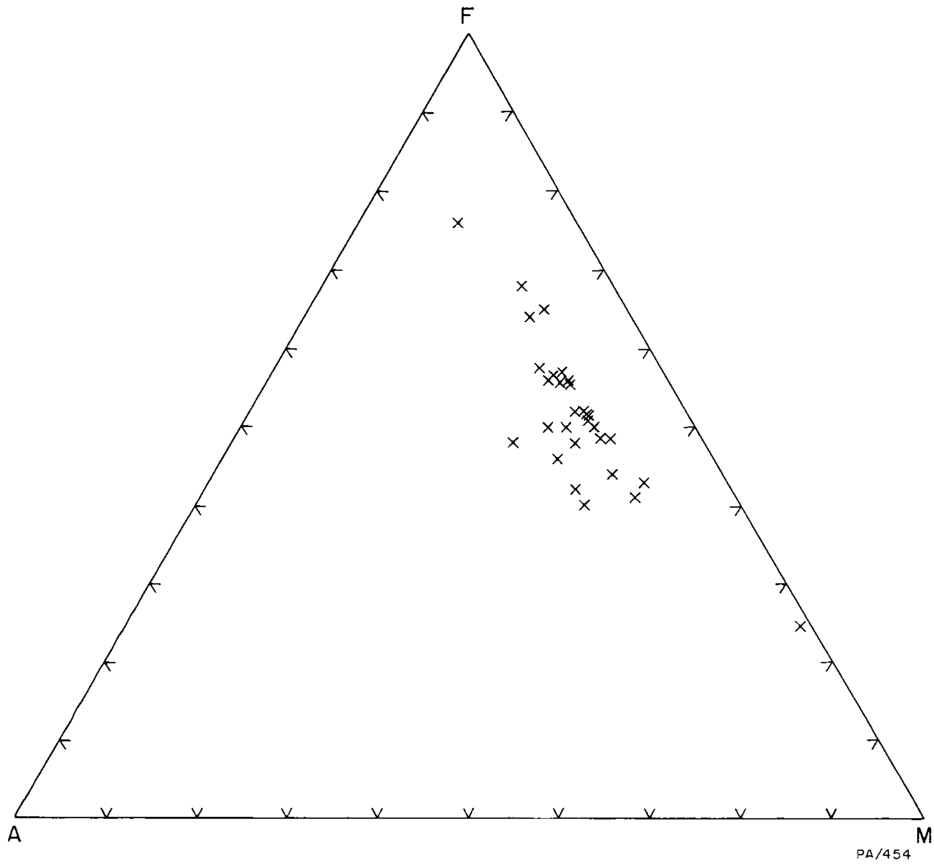

Fig. 7. FMA ($FeO+0.9Fe_2O_3$, MgO, Na_2O+K_2O) diagram for the Kutu Volcanics, including two analyses of the East Cape Gabbro.

oxides, epidote, zeolite, and calcite. Some of the sandstones and argillites contain microfossil tests.

Chemistry

Twenty-six analyses of the basaltic rocks and one of a partly serpentinized peridotite from the Kutu Volcanics are presented with two analyses from the East Cape Gabbro in Table 2. The East Cape Gabbro (p. 53) is considered to be a differentiated member of the Kutu Volcanic series. The analyses are remarkably uniform despite the fact that the specimens analysed were collected over a wide area. Thus although the SiO_2 content of the basaltic rocks ranges from 45 to 53 percent only four of the analyses lie outside the range 47 to 50 percent SiO_2. The basalts have a low K_2O content, moderate to low Al_2O_3 and TiO_2, and a high proportion of total iron (but low Fe_2O_3/FeO ratio) MgO, and CaO. On an FMA diagram (Fig. 7) they display a strong trend of iron enrichment and a high ferro-femic index (Coates, 1968) of 92.

The chemistry of the basaltic rocks, particularly their enrichment in iron and low K_2O content, is characteristic of tholeiitic basalts. In Table 3 the east Papuan rocks are compared with average continental and oceanic tholeiites of Engel et al. (1965) and with the average Hawaiian tholeiite (Engel et al., 1965). The east Papuan basalts are most comparable with the mid-ocean ridge basalts and the oceanic tholeiites (columns 5 and 6, Table 3), although the Al_2O_3 content is lower and total iron and MnO are higher in the Papuan rocks.

Badila Beds

Derivation of name. Badila River (149°57'E).

Rock type. Shale, argillite, calcilutite, limestone, calcareous tuff, and minor basalt.

Distribution. Badila River and middle reaches of Nigo Nigo and Wegulani Rivers, and in Momore Range to southeast of Mullins Harbour.

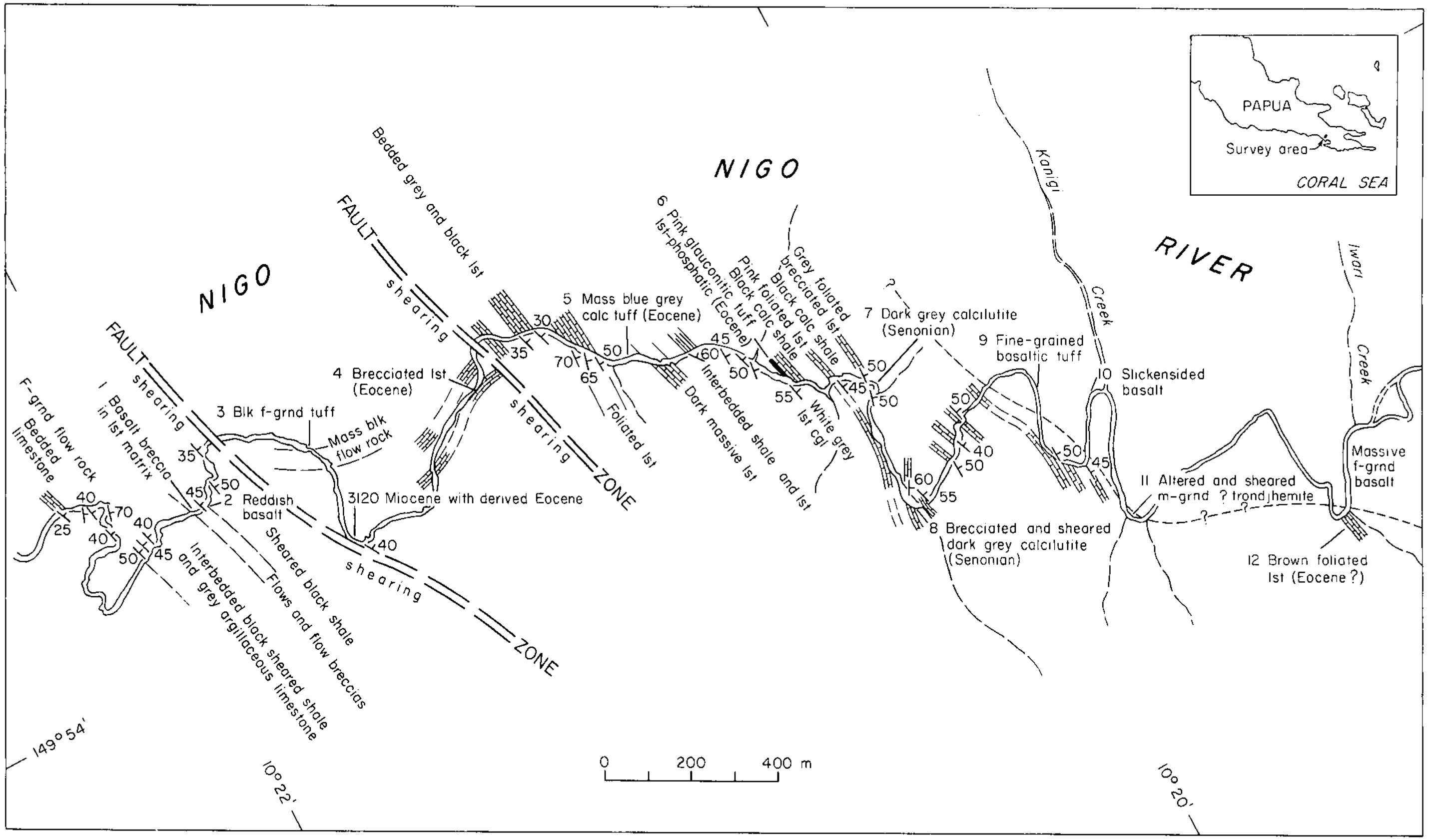

Fig. 8. Section through the Badila Beds in the Nigo Nigo River (mapped by J. E. Thompson in 1965).

Type section. Middle reaches of Nigo Nigo River between 10°19'S and 10°21'S.

Stratigraphic relationships. Not known.

Age. Microfossils indicate range from Late Cretaceous (Senonian) to Eocene.

The Badila Beds were mapped as part of the Suen Beds by Davies et al. (1968), but re-assessment of available fossil ages has shown that the Badila Beds are a separate unit. The beds form southeasterly trending strike ridges northwest and southeast of Mullins Harbour and are apparently bounded by faults.

In 1965 J. E. Thompson mapped a section through the Badila Beds in the middle reaches of the Nigo Nigo River (Fig. 8), where the beds generally dip to the north at between 25° and 70° and appear to have been gently folded. The beds are sheared by two northeast-trending fault zones in the lower part of the section.

Thompson collected specimens of limestone, calcilutite, and tuff containing Eocene (specs MH-5, MH-6, MH-12) and Late Cretaceous (Senonian) (specs MH-7, MH-8) faunas from the Nigo Nigo River and a specimen (MH-64) containing a Late Cretaceous fauna from Wegulani River. Later sampling (Davies et al., 1968) yielded a specimen (3120) containing apparently derived Eocene (b Stage) and fragments of early Miocene (e Stage) foraminifera. This apparent discrepancy in fossil ages has not been resolved.

Godaguina Beds

Derivation of name. Godaguina River (9°57'S, 148°47'E).

Rock type. Laminated red, red-brown, and white calcilutite and limestone.

Distribution. Headwaters of Godaguina River (9°57'S, 148°47'E) and area immediately to northwest, and headwaters of Domara River on northwest slope of Mount Clarence (9°52'S, 149°35'E).

Type area. Headwaters of Godaguina River.

Stratigraphic relationships. Probably a lenticular body or bodies within Kutu Volcanics, but mapped only by reconnaissance traverses and photo geological interpretation.

Thickness. Estimated at 100 m.

Age. Middle Eocene, based on foraminifera.

The Godaguina Beds were originally mapped as the Mount Clarence Calcilutite Member of the Wavera Volcanics (now included in the Kutu Volcanics) by Macnab (1967). The name Godaguina refers more accurately to the known area of outcrop.

There are good exposures of the Godaguina Beds in the headwaters of the Godaguina River and in Urua Creek; boulders of laminated calcareous rocks have been observed in several other rivers on the northern fall of the main range. The rocks are generally contorted and locally sheared and folded, and in places are partly recrystallized.

Juliade Limestone

Derivation of name. Juliade Island (10°18'S, 149°35'E).

Rock type. Limestone and chert.

Distribution. Juliade and Emhoro Islands, along south coast between Baibara and Amazon Bay, and as isolated hills and headlands as far west as Bonau River.

Type area. Juliade Island (10°18'S, 149°35'E),

Stratigraphic relationships. Not known.

Thickness. At least 300 m.

Age. Middle Eocene, based on foraminifera.

Limestone and chert along the south coast were first noted by Gibb-Maitland (1892) and were later briefly described and named the Juliade Beds by Davies et al. (1968). The limestone is creamy to white and fine-grained. Criss-cross veins of calcite are so common that the limestone takes on the appearance of a breccia in places. Much of the formation consists of massive jointed limestone containing nodules of flint; on Juliade Island it is well bedded with thin-bedded limestone alternating with thicker beds of chert.

The formation is folded into anticlines and synclines trending roughly parallel to the coast. Dips are generally moderate to steep; on Juliade Island, however, a well bedded gently dipping sequence gives way to an intensely deformed chaotic outcrop over a distance of a few centimetres (Fig. 9). The intense folding is probably due to post-depositional slumping.

OLIGOCENE-MIOCENE

Dabi Volcanics

Derivation of name. Dabi Creek (9°39'S, 149°31'E).

Rock type. Submarine basalt lava and pillow lava with minor interbeds of tuff.

Distribution. North side of Cape Vogel peninsula (9°38'S, 149°42'-53'E), and in Umurumuru Hills (9°47'S, 149°44'E) on south side of peninsula.

Type section. Creek (name not known) flowing north at 9°39'S, 149°44'E, where 500 m of basaltic lava (predominantly pillow lava) and minor tuff is exposed.

Stratigraphic relationships. Probably forms basement in Cape Vogel Basin; unconformably over-

Fig. 9. Gently dipping finely bedded limestone and chert of the Juliade Limestone giving way to an intensely deformed chaotic sequence. Juliade Island.

lain by Woruka Siltstone, Castle Hill Limestone, Tapio Marl, and Ruaba Sandstone.

Thickness. Over 500 m.

Age. K-Ar age is 28 ± 1 m.y. (middle Oligocene). A tuff (spec. 3154), which probably forms part of the sequence, contains late Oligocene (lower Te Stage) microfossils. The tuff occurs as angular blocks which have probably been shed from an outcrop about 50 m above the type section.

The basalt flows and the tuffs are generally well bedded. Most of the volcanics cropping out at Cape Vogel peninsula are bounded by faults and apparently represent upfaulted basement ridges.

Petrography. The basaltic rocks are generally fine to very fine-grained; some contain rare small (0.5 mm) phenocrysts. They consist of labradorite and pyroxene with subordinate opaque oxides; olivine or, more commonly, quartz is present in some specimens. Interstitial glass is common in some specimens, in others it has been replaced by spherulitic aggregates of zeolites. Zeolites are also present as cavity fillings. Calcite and, less commonly, epidote occur as secondary minerals.

Most of the rocks contain calcic clinopyroxene, but some of the specimens from near Dabi Creek and from the Castle Hill area contain orthopyroxene or clinoenstatite, or both. A more detailed account of the clinoenstatite-bearing lavas is given by Dallwitz et al. (1966).

Dallwitz et al. (1966) and Dallwitz (1968) have discussed the chemistry of the clinoenstatite-bearing lavas from the Dabi Volcanics, but these are not typical of the formation as a whole. New analyses of rocks from several localities are presented in Table 4. They form a heterogeneous group, but their tholeiitic affinities suggest that they may be related to the Kutu Volcanics.

Padowa Beds

Derivation of name. Padowa village (10°24′S, 150°01′E).

Rock type. Tuffaceous sandstone.

Distribution. Northern side of Sagarai valley northwards to Gumini River.

Type area. Small creek 1 km east of Padowa village, which drains southwards to Sagarai River (10°21′S, 150°13′E).

Stratigraphic relationships. Probably overlie Kutu Volcanics unconformably.

Thickness. Not known.

Age. Late Oligocene to early Miocene (Te Stage), based on microfossils.

TABLE 4. CHEMICAL ANALYSES, DABI VOLCANICS

	1	2	3	4	5	6	7	8	9	10
SiO_2	46.66	49.2	49.8	50.0	50.1	50.8	52.1	52.20	52.5	52.7
TiO_2	1.18	0.71	0.65	0.66	1.08	0.75	0.67	0.76	0.28	0.59
Al_2O_3	11.81	15.6	15.3	14.7	14.2	14.9	16.1	10.43	15.8	14.4
Fe_2O_3	5.23	6.15	5.05	5.45	7.85	4.05	6.05	5.24	2.05	5.25
FeO	7.73	3.15	4.65	4.80	6.05	5.70	4.20	8.19	5.00	3.85
MnO	0.17	0.13	0.11	0.11	0.14	0.15	0.12	0.18	0.13	0.15
MgO	7.88	6.40	7.40	7.35	5.40	7.10	5.00	7.31	6.90	5.10
CaO	11.00	9.70	9.70	9.30	7.75	8.40	10.0	9.48	10.2	9.75
Na_2O	2.14	1.83	1.81	1.78	2.30	4.20	2.50	2.02	1.83	1.86
K_2O	0.34	1.66	0.04	0.04	0.16	0.07	1.06	0.29	0.34	1.78
P_2O_5	0.15	0.06	0.06	0.05	0.06	0.05	0.06	0.14	0.03	0.05
H_2O+	4.73	1.86	1.39	1.43	1.37	2.27	1.07	2.86	3.70	1.40
H_2O-	0.98	2.60	3.85	3.95	3.45	1.57	0.91	0.39	1.17	1.51
CO_2	n.d.	0.54	0.02	0.29	0.13	0.06	0.15	n.d.	0.05	1.27
Total	100.00	99.59	99.83	99.91	100.04	100.07	99.99	99.49	99.98	99.66

1 Basalt, Cape Vogel Peninsula. Analyst, A. McClure, Bureau of Mineral Resources (BMR). (LB51).
2 Basalt, Cape Vogel Peninsula, (10°39'S, 149°43'E). Analyst, L. W. Castanelli, AMDL. (3560C).
3 Basalt, Cape Vogel Peninsula, (10°39'S, 149°43'E). Analyst, L. W. Castanelli, AMDL. (3560A).
4 Basalt, Cape Vogel Peninsula, (10°39'S, 149°43'E). Analyst, L. W. Castanelli, AMDL. (3560B).
5 Basalt, Cape Vogel Peninsula, (10°39'S, 149°47'E). Analyst, L. W. Castanelli, AMDL. (2483).
6 Basalt, Cape Vogel Peninsula, (10°39'S, 149°46'E). Analyst, L. W. Castanelli, AMDL. (6042).
7 Basalt, Cape Vogel Peninsula, (10°39'S, 149°44'E). Analyst, L. W. Castanelli, AMDL. (3156).
8 Basalt, Cape Vogel Peninsula, Analyst, A. McClure, BMR. (LB47).
9 Basalt, Cape Vogel Peninsula, (10°39'S, 149°44'E). Analyst, L. W. Castanelli, AMDL. (3157).
10 Basalt, Cape Vogel Peninsula, (10°39'S, 149°44'E). Analyst, L. W. Castanelli, AMDL. (3155).

	11	12	13	14	15	16	17	18	19	20
SiO_2	53.2	53.51	59.4	60.1	62.22	64.6	66.3	66.6	66.6	67.1
TiO_2	0.24	0.98	0.81	0.65	0.69	0.82	0.86	0.85	0.86	0.88
Al_2O_3	11.0	12.11	15.5	14.5	15.01	13.3	12.8	12.6	12.8	12.8
Fe_2O_3	2.15	8.78	5.10	3.60	5.94	3.95	3.10	2.80	3.05	2.85
FeO	6.70	4.18	3.70	4.05	1.69	3.45	3.95	4.10	4.10	4.10
MnO	0.15	0.20	0.13	0.10	0.08	0.09	0.10	0.10	0.09	0.09
MgO	11.1	5.44	2.50	3.85	1.79	2.50	2.15	2.05	2.05	1.92
CaO	7.45	4.66	7.50	8.90	6.89	7.30	6.65	6.55	6.75	6.50
Na_2O	1.01	2.33	2.55	1.87	1.97	2.20	2.20	2.15	2.30	2.35
K_2O	0.55	1.85	0.55	0.13	0.71	0.26	0.34	0.17	0.21	0.22
P_2O_5	0.03	0.10	0.09	0.07	0.10	0.08	0.09	0.09	0.09	0.75
H_2O+	4.00	2.28	0.88	0.83	2.38	0.85	0.73	0.65	0.69	0.75
H_2O-	2.60	3.73	0.91	1.11	1.36	0.82	0.58	1.13	0.66	0.49
CO_2	0.08	n.d.	0.02	0.06	n.d	0.09	0.06	0.05	0.09	0.08
Total	100.26	100.15	99.64	99.82	100.83	100.31	99.91	99.89	100.34	100.22

11 Tholeiitic andesite, Cape Vogel Peninsula, (10°40'S, 149°49'E). Analyst, L. W. Castanelli, AMDL. (4228C).
12 Tholeiitic andesite, Cape Vogel Peninsula, Analyst, A. McClure, BMR. (LB86).
13 Tholeiitic andesite, Cape Vogel Peninsula, Analyst, L. W. Castanelli, AMDL. (32).
14 Tholeiitic andesite, Cape Vogel Peninsula, Analyst, L. W. Castanelli, AMDL. (22).
15 Tholeiitic andesite, Cape Vogel Peninsula, Analyst, A. McClure, BMR. (LB93).
16 Tholeiitic dacite, Cape Vogel Peninsula, (10°39'S, 149°44'E) Analyst, L. W. Castanelli, AMDL. (3150).
17 Tholeiitic dacite, Cape Vogel Peninsula, (10°39'S, 149°44'E). Analyst, L. W. Castanelli, AMDL. (2409).
18 Tholeiitic dacite, Cape Vogel Peninsula, Analyst, L. W. Castanelli, AMDL. (34).
19 Tholeiitic dacite, Cape Vogel Peninsula, (10°39'S, 149°44'E). Analyst, L. W. Castanelli, AMDL. (2407).
20 Tholeiitic dacite, Cape Vogel Peninsula, (10°39'S, 149°44'E). Analyst, L. W. Castanelli, AMDL. (2408).

Fig. 10. Graded bedding in tuffaceous sandstone of the Modewa River Beds. Sige Eueu River.

DEBOLINA BEDS

Derivation of name. Debolina Creek (10°33′S, 150°25′E).

Rock type. Tuffaceous sandstone.

Distribution. Debolina Creek and middle reaches of Dawa Dawa River.

Type area. Debolina Creek (10°32′-33′S, 150° 23′-25′E).

Stratigraphic relationships. Unconformably overlie Kutu Volcanics.

Thickness. Unkown.

Age. Late Oligocene to early Miocene (Te Stage), based on microfossils.

MODEWA RIVER BEDS

Derivation of name. Modewa River (10°39′S, 150°19′E).

Rock type. Limestone and minor tuffaceous sandstone; in some areas graded-bedded tuffaceous sandstone (Fig. 10) and siltstone predominate.

Distribution. Eabiha, Saga Aho, Sige Lele, Sige Eueu, Suwen, and Modewa Rivers and Baxter Harbour area.

Type area. Middle reaches of Modewa River (10°39′S, 150°19′E), where bedded limestone and minor tuffaceous sandstone are exposed.

Stratigraphic relationships. Probably overlie Kutu Volcanics unconformably; overlain, probably unconformably, by Fife Bay Volcanics.

Thickness. Not known.

Age. Late Oligocene to middle Miocene (Te to lower Tf), based on foraminifera.

The Modewa River, Padowa, and Debolina Beds probably represent a period of localized volcanic activity accompanied by limestone accumulation in a shallow sea. The sediments are typically regularly bedded and are gently folded with dips up to 30°.

Adau Limestone

Derivation of name. Adau River (9°53'S, 148° 48'E).

Rock type. Massive light-coloured with some darker impure limestone and subordinate silty limestone and calcareous mudstone with limestone lenses.

Distribution. Adau River at east end of Keveri valley.

Type section. Outcrops extending for several kilometres along Adau River at east end of Keveri valley.

Stratigraphic relationships. Probably overlies Kutu Volcanics unconformably; unconformably overlain by Domara River Conglomerate.

Thickness. Not known.

Age. Early and middle Miocene (upper Te and lower Tf Stages), based on foraminifera.

The Adau Limestone (Adau Limestone Member of Macnab, 1967) is a fault-bounded lenticular body of bioclastic limestone and associated calcareous sediments which forms low pinnacles along the Adau River. It represents a localized area of shallow-water reef shoal sedimentation. The limestone locally contains a rich fauna of algae, bryozoans, some brachiopods, and foraminifera (Macnab, 1967).

MIOCENE-RECENT

CAPE VOGEL BASIN

(Mio-Pliocene)

The Cape Vogel Basin extends along the north coast of eastern Papua between Cape Ward Hunt (148°10'E) and East Cape (151°E); it is named from Cape Vogel peninsula, where a thick sedimentary sequence is exposed. Much of the basin lies offshore: in the southeast it occupies a trough between the mainland and the D'Entrecasteaux Islands; north of the islands and westwards to Cape Ward Hunt the basin is a broad shallow shelf area, and farther north the shelf plunges rapidly into the Solomon Basin. The present width of the basin including the onshore deposits ranges from 90 to 220 km.

The sediments of Cape Vogel peninsula were mentioned by Stanley in his account of the geology of Papua (Stanley, 1923). In 1929, geologists of the Anglo-Persian Oil Co. mapped over 4500 m of Miocene to Holocene sediments on Cape Vogel peninsula (Papp & Nason-Jones, 1930). Paterson & Kicinski (1956) have summarized the stratigraphy in the northwestern part of the basin in addition to the stratigraphy in the Cape Vogel area. The sediments on the southern margin of the basin were described briefly by Davies et al. (1968). Bickell (1969) has re-examined the area and much of the following account is taken from his review.

Only the onshore part of the Cape Vogel Basin east of 148°30'E is discussed here. Its stratigraphy is summarized in Table 5.

The oldest recorded sedimentary rock is a specimen of limestone collected by Thompson (1967) from Castle Hill (9°25'S, 149°51'E) in which Belford (1968) found Palaeocene foraminifera. Thompson refers to a veneer of Palaeocene limestone, marl, and conglomerate overlying submarine volcanics in the Castle Hill area. A single K-Ar age on the basement submarine lavas (Dabi Volcanics) and the planktonic and larger foraminifera in the sediments overlying the basement indicate that the age of the basement is late Oligocene. Thompson's locality has not been resampled and the problem remains unsolved.

Woruka Siltstone

Derivaiton of name. Woruka village (9°38'S, 149°53'E).

Rock type. Grey laminated siliceous siltstone and light brown claystone with minor thin beds of glauconitic clayey siltstone containing rare foraminifera.

Distribution. Immediately west of Castle Hill on Cape Vogel peninsula (9°39'30"S, 149°51'E).

Type section. Immediately west of Castle Hill.

Stratigraphic relationships. Laps unconformably on to Dabi Volcanics and probably unconformably overlain by Castle Hill Limestone.

Thickness. About 45 m are exposed.

Age. Probably early Miocene. The foraminifera indicate that the age is no older than early Miocene (upper Te stage), and the overlying Castle Hill Limestone is of middle Miocene age.

Castle Hill Limestone

Derivation of name. Castle Hill (9°39'S, 149° 52'E).

Rock type. Cream-coloured moderate to thick-bedded reefal limestone and calcarenite with a basal conglomerate consisting of poorly sorted basaltic pebbles and coralline material set in a coarse to medium-grained limy matrix.

Distribution. Castle Hill.

Type section. Cliff face on north side of Castle Hill.

TABLE 5. STRATIGRAPHY OF THE CAPE VOGEL BASIN

	Unit (Map symbol)	*Distribution*	*Thickness* (m)	*Lithology*
PLEISTOCENE TO HOLOCENE	Alluvium Qa	Coastal areas and larger river valleys	Less than 50	Gravel, sand, silt, clay
	Coral limestone Qc	E end of Cape Vogel peninsula; small isolated areas S of Goodenough Bay	Up to 50	Coral reef
PLEISTOCENE	Kwagira Beds Qpk	Inland from Moi Biri Bay	200 approx.	Conglomerate, sandstone, siltstone, marl; poorly sorted, mostly non-marine
PLIOCENE	Kwinimaga Sandstone Tpk	NW part of Cape Vogel peninsula	200	Sandstone, conglomerate, siltstone, claystone
	Uga Sandstone Tpu	Along coast S of Goodenough Bay	500	Sandstone, siltstone, minor conglomerate; folded
	Awaitapu Claystone Tpw	SW and N parts of Cape Vogel peninsula	350	Claystone, laminated marl; some sandstone, siltstone, and conglomerate; folded
	Gwoira Congolmerate	Embayment in main range E of Mt Dayman	1000	Conglomerate, sandstone, siltstone; poorly sorted; tilted
UPPER MIOCENE	Tapio Marl Tmt	N central part of Cape Vogel peninsula; hill S of Tapio village	60	Marl and shale interbedded with limestone and thin lenses of sandstone and conglomerate
MIDDLE MIOCENE TO PLIOCENE	Ruaba Sandstone Tmr	Central and N parts of Cape Vogel peninsula	3500	Sandstone, conglomerate, siltstone; some silty claystone and tuff; plant remains and marine microfossils
MIDDLE MIOCENE	Castle Hill Limestone Tmh	Castle Hill on Cape Vogel peninsula	120	Reef limestone and calcarenite with basal conglomerate
LOWER MIOCENE	Woruka Siltstone Tmz	Small exposure below Castle Hill on Cape Vogel peninsula	45	Siliceous siltstone, claystone, minor thin beds of glauconitic silty sandstone
UPPER OLIGOCENE	Dabi Volcanics Tod	Cape Vogel peninsula; prominent ridges near N and S coasts	(based not exposed)	Basalt lava (some pillows), minor tuff
PALEOCENE (not mapped)		Reported from Castle Hill area, Cape Vogel peninsula	1-2	Interbedded limestone and conglomerate

Stratigraphic relationships. Laps unconformably on to Woruka Siltstone and Dabi Volcanics; unconformably overlain by Tapio Marl and Ruaba Sandstone.

Thickness. 120 m.

Age. Middle Miocene (lower Tf), based on foraminifera.

The Castle Hill Limestone has been correlated with the Robinson Bay Limestone 250 km to the northwest (Bickell, 1969).

Tapio Marl

Derivation of name. Tapio village (9°38'S, 149° 53'E).

Rock type. Dark grey marl and shale with interbeds of limestone and thin lenses of sandstone and conglomerate.

Distribution. Hill immediately south of Tapio village on Cape Vogel peninsula.

Type section. Kwapu Kwapu Creek south of Tapio village (9°39'S, 149°53'E).

Stratigraphic relationships. Overlies Castle Hill Limestone conformably or with minor disconformity, and overlapped unconformably by Ruaba Sandstone.

Thickness. About 60 m.

Age. Late Miocene, based on foraminifera.

Ruaba Sandstone

Derivation of name. Ruaba River, which flows into Goodenough Bay at base of Cape Vogel peninsula.

Rock type. Cyclic interbeds of conglomerate, sandstone, siltstone, and claystone; sandstone and siltstone predominate to east.

Distribution. Covers most of northern part of Cape Vogel peninsula.

Type section. An approximately north-south line from 9°39'S, 149°48'E to 9°44'S, 149°48'E, where a southerly dipping sequence composed mainly of sandstone, siltstone, and minor conglomerate is exposed.

Stratigraphic relationships. Laps unconformably on to Dabi Volcanics, Castle Hill Limestone, and Tapio Marl; overlain with angular unconformity by Awaitapu Claystone and a raised coral reef.

Thickness. 3500 m, of which about 1400 m is late Miocene and 2100 m is Pliocene?

Age. Middle Miocene (lower Tf Stage) at base, overlain by 1400 m of late Miocene and 2100 m of Pliocene? Middle and late Miocene ages based on foraminifera.

In the central part of Cape Vogel peninsula the Ruaba Sandstone dips southward in an almost continuous monocline. To the west, near the Ruaba River, the pattern is complicated by sharp folds and faults as the structural trends swing north into an anticline near Collingwood Bay.

The name Ruaba Sandstone replaces the Cape Vogel Group of Bickel (1969) and the Lower Arenaceous Series and part of the Upper Arenaceous Series of Papp & Nason-Jones (1928) (summarized in Paterson & Kicinski, 1956). The definition of the unit follows Bickel (1969), but the name Ruaba is preferred to Cape Vogel because it is more specific. The Ruaba Sandstone is exposed in the Ruaba River in the Cape Vogel Basin.

The Ruaba series of Stanley (1923) probably included several units now known as the Uga Sandstone, Gwoira Conglomerate, and Kwinimage Beds, and probably included part of the Ruaba Sandstone.

Awaitapu Claystone

Derivation of name. Awaitapu Creek on Cape Vogel peninsula (about 9°44'S, 149°48'E).

Rock types. Yellow-grey to yellow-brown laminated blocky to platy and in part highly calcareous (marly) claystone; northern part is more calcareous and contains sparse macrofossils.

Distribution. Southern part of Cape Vogel peninsula and northern part of peninsula between Dabi Creek and Posa Posa Harbour.

Type section. Southern tributary of Awaitapu Creek (9°44'S, 149°47'30"E).

Stratigraphic relationships. Overlies Ruaba Sandstone with angular unconformity.

Thickness. 350 m.

Age. In north contains Pliocene foraminifera; in south inferred to be Pliocene.

The name Awaitapu Claystone replaces the Upper Arenaceous Series of Papp & Nason-Jones (1930). The Awaitapu Claystone between Dabi Creek and Posa Posa Harbour was originally mapped as middle Miocene by Papp & Nason-Jones, but recent work by Bickel (1969) has shown that the formation is Pliocene.

Kwinimage Sandstone

Derivation of name. Kwinimage River.

Rock type. Conglomerate, sandstone, siltstone, and claystone in cyclic units; some plant remains.

Distribution. Western end of Cape Vogel peninsula, where formation forms a low gently sloping plateau bounded by cliffs on north coast.

Type section. Coastal cliffs at 9°37'S, 149°35'E.

Stratigraphic relationships. Laps on to Ruaba Sandstone with angular unconformity; probably unconformably overlain by Kwagira Beds to west.

Thickness. About 200 m.

Age. Plant fossils tentatively ascribed an Eocene age by White (1970), but stratigraphic relationships indicate a Pliocene age.

Kwagira Beds

Derivation of name. Kwagira River.

Rock type. Poorly consolidated conglomerate, sandstone, and siltstone; probably terrestrial.

Fig. 11. Poorly sorted conglomerate and sandstone of the Gwoira Conglomerate. Ruaba River.

Fig. 12. Gwoira Range. Beds of Gwoira Conglomerate dipping south from Mount Gwoira (left centre). Masasoru salient in right background, and eastern end of Dayman Dome in foreground. (Photograph by J. S. Milson).

Distribution. Low hills immediately north of Suckling-Dayman mountian block between 149° 15′E and 149°39′E.

Type section. Kwagira River between 9°41′S and 9°42′S.

Stratigraphic relationships. Unconformable on Goropu Metabasalt and probably also on Kwinimage Sandstone.

Thickness. About 100 m.

Age. Inferred to be Pleistocene.

The boundary between the Kwinimaga Sandstone and the Kwagira Beds is taken where the subdued topography of the former gives way to the steep dissected badlands type of topography found on the Kwagira Beds.

SEDIMENTS SOUTH OF CAPE VOGEL PENINSULA

A narrow coastal strip of sediments overlies the Cretaceous and Eocene volcanics (Kutu Volcanics) along the southern shore of Goodenough Bay and to the southwest of Cape Vogel peninsula in the Gwoira Range. They are considered to be a paralic facies of the sediments exposed on, and to the west of, Cape Vogel peninsula.

Gwoira Conglomerate

Derivation of name. Gwoira Range and Mount Gwoira (9°50′S, 149°30′E).

Rock type. Poorly sorted conglomerate, sandstone, and siltstone composed of clasts derived from Kutu Volcanics and Goropu Metabasalt.

Distribution. Gwoira Range (9°43′-45′S, 149° 25′-36′E).

Type section. Ruaba River between 9°52′S, 149°30′E and 9°48′S, 149°34′E.

Stratigraphic relationships. Unconformably overlies Goropu Metabasalt and Kutu Volcanics; faulted to north.

Thickness. 1050 m.

Age. Inferred to be Pliocene.

The Gwoira Conglomerate consists mainly of strongly lithified massive conglomerate, in beds from 5 to 8 m thick, alternating with thinner beds of sandstone and siltstone (Fig. 11). The sequence was probably laid down by rhythmic deposition in a paralic environment. Unlithified sandstone predominates at the top of the sequence.

The strata dip consistently at 30° to the south, except at the western and southern contacts. In the west, the dip ranges from 20° to 50° at the southern contact; in the upper part of the section the beds are nearly horizontal and overlie the Goropu Metabasalt unconformably at an angle of about 30° (Fig. 4).

The Gwoira Conglomerate has been uplifted along a major west-northwest-trending fault (Gwoira Fault) forming the northern boundary of the formation. During uplift the beds were presumably tilted to the south (Figs 12, 13).

Uga Sandstone

Derivation of name. Uga River, which enters Goodenough Bay at Uga Point (9°55′S, 149° 49′E).

Rock type. Unlithified sandstone, siltstone, and minor conglomerate.

Distribution. Coastal strip up to 10 km wide on southern side of Goodenough Bay between Kiramara River and Dogura Bay, lower reaches of Wamira River, middle part of Tameo valley, and eastward along coast to Bently Bay (10°16′S, 150°36′E).

Type section. Middle reaches of Uga River between 149°45′E and 149°47′E.

Stratigraphic relationships. Unconformably overlies Cretaceous and Eocene basalts (Kutu Volcanics).

Thickness. Up to 300 m.

Age. Probably late Pliocene.

A notable feature of the Uga Sandstone is the large-scale cross-bedding exposed in the hills behind Raba Raba. Foreset beds up to 20 m thick and dips as high as 25° have been observed in cliff sections; in places the hills are capped by a thin cover of horizontal sediments (Fig. 14). These features suggest that the Uga Sandstone was deposited close to a shoreline as a series of river deltas which coalesced to form a coastal plain (Fig. 15).

The sediments have been eroded into steep badlands, which are well developed in the hills behind Raba Raba. They are being rapidly eroded at the present time and owe their present relief of up to 300 m in the western part of the outcrop area to rapid Quaternary uplift.

Agaun Conglomerate

Derivation of name. Agaun airstrip and mission (9°55′S, 149°23′E).

Rock type. Poorly consolidated alluvial and partly colluvial sediments (conglomerate, sandstone, and siltstone).

Distribution. Agaun valley and upper reaches of a tributary of Tavanei River immediately to southeast.

Type area. Cliff below southwestern end of Agaun airstrip, where a sequence about 50 m thick is exposed.

Stratigraphic relationships. Unconformably overlies Goropu Metabasalt and Yau Gabbro.

Thickness. About 100 m.

Age. Inferred to be Pleistocene.

The Agaun valley is a broad open valley which forms a low pass in the main ranges

Fig. 13. Gwoira Fault forming the northern boundary of the Gwoira Conglomerate. Mount Gwoira in centre; Kwagira Beds in foreground.

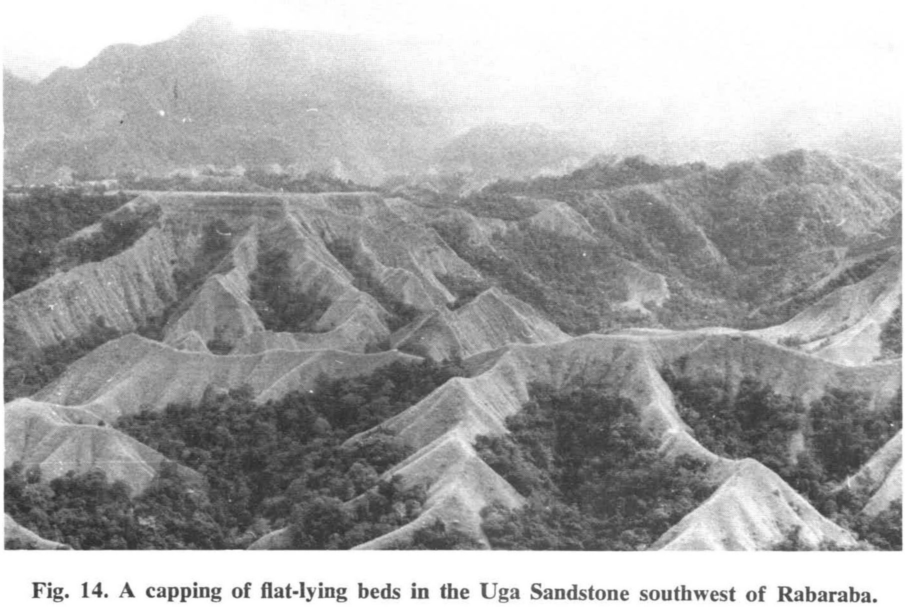

Fig. 14. A capping of flat-lying beds in the Uga Sandstone southwest of Rabaraba.

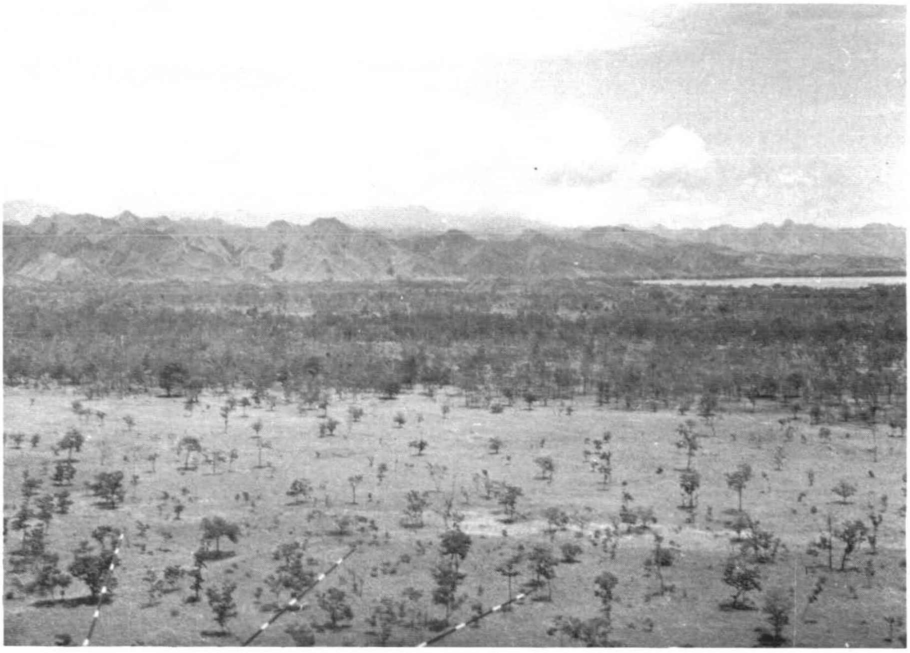

Fig. 15. Flat-lying deltaic beds at the mouth of the Kutu River, Goodenough Bay. The hills in the background (Uga Sandstone) are uplifted deltaic deposits.

Fig. 16. Uplifted alluvial terraces (Agaun Conglomerate) in the upper reaches of the Tavanei River. View southeast from Agaun Mission.

south of Dayman Dome. The valley floor reaches a maximum elevation of 900 m above sea level at Agaun Mission on the watershed between the Agaun River flowing north-northeast and a tributary of the Tavanei River flowing south-southwest. The mountains on either side of the valley rise to 1700 m above sea level.

The Agaun Conglomerate forms a well developed series of flat-lying or gently sloping terraces in the Agaun valley; the terraces continue for about 2 km on the western side of the Tavanei River tributary, but here they are perched on the valley side well above the river which flows in a steep-sided gorge (Fig. 16). The sediments were presumably laid down in an intermontane basin, and the terraces have been formed as a result of Holocene uplift in the Agaun area.

MUSA VALLEY

(Pliocene-Holocene)

Domara River Conglomerate

The Domara River Conglomerate, which crops out in the western part of the Tufi Sheet area, consists of Pleistocene sediments and minor interbedded volcanics. The volcanics are described separately as the Musa Volcanic Member (see p. 44).

The Domara River Beds of Smith & Green (1961) were re-examined by Macnab (1967). Our account is taken mainly from these two sources.

Derivation of name. Domara River (9°32′S, 148°40′E).

Rock type. Conglomerate, sandstone, siltstone, mudstone, and rare fossiliferous calcareous mudstone.

Distribution. Entirely within Musa valley, except for outlier in Keveri valley (9°53′S, 148°45′E) and possible outlier capping a hill between Keveri valley and south coast.

Type area. Middle and middle-upper reaches of Domara River.

Stratigraphic relationships. Unconformably overlies Papuan ultramafic belt and Goropu Metabasalt; unconformably overlain by Silimidi Conglomerate and associated ultramafic breccia.

Thickness. About 1500 m.

Age. Pliocene, based on a K-Ar age of interbedded volcanics.

Smith & Green (1961) noted that the Domara River Conglomerate is generally poorly sorted and was apparently laid down very rapidly. The grainsize varies laterally; the finer conglomerates are cross-bedded, and scour-and-fill structures were noted in places. In places the conglomerate contains carbonized wood fragments up to 1 m long. Macnab (1967) noted that the conglomerate consists of a series of cylic sequences ranging from coarse to fine-grained. He recorded beds of lignitic coal up to 1 cm thick, cross-bedded carbonaceous sandstone and shale with slump structures, and some intercalated fossiliferous limestone. Both Smith & Green and Macnab reported the presence of planispiral and conispiral gastropods of probable freshwater origin. The beds are characteristically gently folded or tilted by block faults.

The Domara River Conglomerate is probably terrestrial and was localized in a tectonic basin between rising mountain ranges. The cyclic deposition noted by Macnab (1967) can be explained by periodic uplift and rejuvenation of the surrounding mountain blocks. The sediment was derived from the adjacent peridotites, gabbros, and basalts of the Papuan ultramafic belt, the metamorphic rocks of the Goropu Metabasalt, and from contemporary volcanic activity.

The age of the formation is important because it marks the beginning of a period of uplift, and defines the older age limit of the vigorous block-faulting which resulted in the rupturing and tilting of the Domara River Conglomerate and the elevation and tilting of the Didana, Keman, and Awariobo Ranges and Mount Avuru. The field relationships and a tentative opinion on the freshwater molluscan fauna by N. H. Ludbrook (Smith & Green, 1961) suggest that the Domara River Conglomerate is Pleistocene, but recent K-Ar ages on specimens from the Musa Volcanic Member indicate a Pliocene age.

Silimidi Conglomerate

The Silimidi Conglomerate was originally mapped as the Silimidi Beds by Smith & Green (1961) and much of the following description is taken from their work. The formation consists of a sedimentary sequence containing sheets of ultramafic breccia known as the Sivai Breccia Member.

Derivation of name. Silimidi village (9°40′S, 148°46′E).

Rock type. Conglomerate, sandstone, and siltstone (formerly alluvium).

Distribution. Eastern end of Musa valley, particularly in Sivai and Darumu Creeks area (9°35'S, 148°47'E) and Silimidi and Ibau Rivers area (9°42'S, 148°46'E).

Type area. Creek section in small stream southeast of Silimidi village.

Stratigraphic relationships. Overlies Domara River Conglomerate unconformably; includes horizons of Sivai Breccia Member.

Thickness. About 500 m.

Age. Inferred to be Pleistocene.

The Silimidi Conglomerate probably originally covered the whole of the eastern part of the Musa valley, but has been partly eroded away by the Ibinambo River. The sediments have been tilted but not folded, and crop out in recently elevated fault-bounded blocks.

Sivai Breccia Member

Derivation of name. Sivai Creek (9°34'S, 148° 47'E).

Rock type. Ultramafic breccia composed of rock fragments of strained harzburgite set in matrix of fine rock fragments and rock flour cemented by opaline silica, magnesite, and serpentinite. Some of the rock fragments range up to 2 m across, but most of them are 10 to 30 cm in diameter. The smaller fragments are angular and the larger subrounded. The rock fragments may be unaltered, or partly or completely serpentinized.

Distribution. Thin planar sheets within Silimidi Conglomerate in Sivai Creek and Darumu Creek areas.

Type area. South bank of Sivai Creek about 6 km northeast of junction of Darumu and Sivai Creeks.

Stratigraphic relationships. Interbedded with sediments of Silimidi Conglomerate.

Thickness. Individual sheets range from 10 to 20 m thick.

Age. Quaternary.

Ibau Breccia

Derivation of name. Ibau River (9°45'S, 148° 55'E).

Rock type. Massive ultramafic breccia consisting of rock fragments of strained harzburgite set in matrix of fine rock fragments and rock flour cemented by opaline silica, magnesite, and serpentinite. Some rock fragments are unaltered, others are partly or completely serpentinized.

Distribution. In two bodies, one between Ibau and Silimidi Rivers in southeastern part of Musa valley (9°42'S, 148°50'E), and the other in upper reaches of Ibau River (9°45'S, 148°55'E).

Type area. Cliff section on Ibau River (9°39'S, 148°51'E).

Stratigraphic relationships. Overlies Domara River Conglomerate and basement formations unconformably; may grade laterally into Sivai Breccia.

Thickness. About 150 m.

Age. Pleistocene.

The Ibau Breccia in the southeastern part of the Musa valley forms a body about 12 km across characterized by an irregular surface, hummocky on a broad scale, which slopes from an elevation of about 1200 m in the southeast to the level of the Musa valley floor (about 200 m) in the northwest. The surface is tilted and fractured by normal faults in places. In the upper reaches of the Ibau River the formation forms the flat central part of the upper Ibau drainage basin and is almost certainly a colluvial valley-fill deposit formed by mass wasting from the surrounding slopes. The top of the breccia is 1950 m above sea level, and a thickness of 150 m of unstratified breccia is exposed in gorges eroded by the Ibau River. The breccias were examined during a helicopter reconnaissance, and were later visited by Thompson (1968).

The ultramafic breccias in the Musa valley have two modes of occurrence: thin planar sheets within the Silimidi Conglomerate (the Sivai Breccia Member) and thick chaotic deposits (the Ibau Breccia). The rock types within each unit are essentially the same.

Green (1961) studied the ultramafic breccia in the Sivai Creek-Darumu Creek area (9°35'S, 148°50'E) and near Silimidi (9°41'S, 148°47'E), but did not see the massive Ibau Breccia. Apart from ultramafic breccia, he found gabbro breccia (exclusively gabbro) and basalt-peridotite breccia. The latter occurs only in Wowo Gap (9°35'S, 148°55'E) and consists of clasts of basalt, peridotite, and some quartz microdiorite and Goropu Metabasalt set in a matrix of basaltic crystal tuff. Green also recorded transgressive ultramafic breccia completely enclosed in otherwise massive peridotite. One of us (H.L.D.) has revisited a transgressive breccia mapped by Green's co-worker (J. W. Smith) in Darumu Creek. This particular example is sheared and is probably a fault breccia. However, it may not be typical, for Green has stated that the transgressive breccias do not show slickensides or other evidence of shearing.

Green concluded that the ultramafic breccias are 'vent and extrusive breccias resulting from the penetration, brecciation and local entrainment (fluidization) of peridotitic country rock by volcanic gases' and that the source of the volcanic gases was a subjacent body of basalt

Fig. 17. Coarse unsorted alluvial deposits in the Wakioki River. The Wakioki Fan-conglomerate is comprised of similar material.

magma, as evidenced by the basalt fragments and basaltic crystal tuff matrix in the basalt-peridotite breccia. He supported the hypothesis with analyses which show that the matrix of the ultramafic breccia is richer in alumina than the clasts, and with the observation that antigorite (high-temperature serpentine polymorph) has developed on the margins of some clasts. Other chemical and mineralogical changes reported by Green could be attributed to post-depositional groundwater leaching and precipitation.

We conclude that the Ibau Breccia is simply a product of mass wasting, presumably in a succession of rock slides, but that volcanic fluidization is a valid alternative hypothesis for the Sivai Breccia Member. The development of colluvial breccias was probably facilitated by fracturing of the ultramafic source rock, probably due to faulting. In this context, we have noted that, in comparison with typical peridotite of the Papuan ultramafic belt, the peridotite clasts in the Sivai and Ibau breccias show an unusually high degree of strain, to the point where some are finely recrystallized.

Ubo Fanglomerate

Derivation of name. Named by Smith & Green (1961) after Ubo village (9°30′S, 148°48′E).

Rock type. Poorly sorted unconsolidated very coarse boulder conglomerate. Most of the boulders are 1 to 2 m across, but some are larger; they consist of rocks from the Goropu Metabasalt.

Distribution. Eastern end of Musa valley near Ubo village (9°37′S, 148°47′E).

Type area. Ibinambo River near Ubo village.

Stratigraphic relationships. Unconformably overlies Goropu Metabasalt. To the west fanglomerate almost certainly passes transitionally into Holocene bedded conglomerates and sandstones on the floor of the valley near the Adau and Domara Rivers.

Thickness. Probably from 50 to 100 m.

Age. Pleistocene to Holocene.

Wakioki Fanglomerate

Derivation of name. Wakioki River, which flows northwest and north from Mount Suckling.

Rock type. Poorly sorted unconsolidated very coarse boulder conglomerate (Fig. 17). The boulders were derived mainly from the Goropu Metabasalt.

Distribution. North of Mount Suckling along Wakioki River (9°19′-35′S, 148°-149°E).

Type area. East and west of Wakioki River at 9°30′S.

Stratigraphic relationships. Unconformably overlies Goropu Metabasalt and almost certainly grades laterally into Holocene alluvial deposits.

Thickness. Up to 50 m.

Age. Holocene.

The fanglomerate deposits form gently sloping boulder strewn areas which are fan-shaped in plan. They consist of poorly sorted gravel, sand, and silty clay containing subangular boulders up to 10 m in diameter. The larger boulders may have been transported by catastrophic floods after the upper reaches of rivers were temporarily dammed by landslides.

RAISED CORAL REEFS

Raised coral reefs of probable Pleistocene or Pliocene age form discontinuous coastal benches, small limestone plateaux, and remnant cappings (Fig. 18) on the coastal hills along the north coast in the southeastern part of the area. The discontinuous form of the reefs is probably due to a combination of rapidly shelving coast, rapid sedimentation (at the time of reef growth), and subsequent rapid erosion. The largest areas of raised coral are at the eastern end of Cape Vogel peninsula and in the Tameo valley. Narrow coastal benches are present along the north coast of East Cape peninsula and small reef remnants cap basalt ridges at the head of Milne Bay and at isolated localities from Cape Frere westwards to the head of Goodenough Bay.

The fossil coral reefs have been uplifted to various levels. On East Cape peninsula the coral benches occur at elevations between 50 and 180 m, at the head of Milne Bay the small coral plateaux are up to 60 m above sea level, in the Tameo valley fossil reefs occur at 480 m, and on the western side of Cape Frere there are small reef remnants at 275 and 610 m. Other small reef remnants at elevations between 260 and 470 m occur as far west as the head of Goodenough Bay.

The raised reefs on Cape Vogel are probably Plio-Pleistocene, and fossil evidence suggests that those in the Tameo valley are Pliocene (D. H. Blake, pers. comm.). Elsewhere they are probably Plio-Pleistocene.

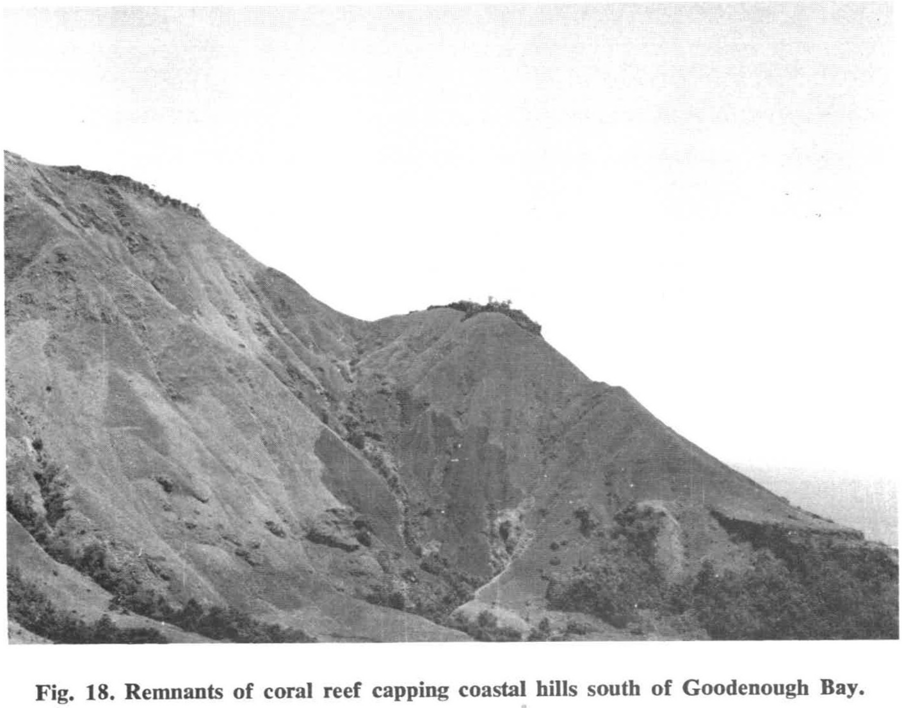

Fig. 18. Remnants of coral reef capping coastal hills south of Goodenough Bay.

TABLE 6. STRATIGRAPHY OF THE UPPER CAINOZOIC VOLCANICS

	Unit (Map symbol)	*Distribution*	*Thickness* (m)	*Lithology*	*Remarks*
HOLOCENE	Waiowa Volcanics Qrw	Waiowa (Goropu) volcano on N margin of Goropu Mts	25	Unconsolidated basic to intermediate ash and agglomerate; shoshonitic	Small explosion crater active in 1943-44
PLEISTOCENE TO HOLOCENE	Victory Volcanics Qv	Mt Victory volcano on NW coast	2500	Andesite, basaltic andesite, minor basalt and dacite; unconsolidated tuff and ash; calc-alkaline	Stratovolcano with some small subsidiary centres; active in 1890s
	Sesagara Volcanics Qz	Small hills on coastal plain N and NE of Goropu Mts	Up to 300	Intermediate pyroclastic deposits and lava; shoshonitic	One or two small volcanic cones
	Manna Volcanics Qm	Bariji area	750	Acid lavas and much ash-flow tuff; calc-alkaline	Small volcanic cones and tholoids, larger dissected ash cones. K-Ar dates on ash layers of 10 000 to 80 000 yrs
	Uoivi Volcanics Qu	Bariji R. area	600	Basic lavas; shoshonitic	Lava flows, flow domes, scoria mounds, cinder cones, explosion craters. K-Ar ages of 80 000-560 000 yrs
PLEISTOCENE	Cape Nelson Volcanics Qpn	Mt Trafalgar volcano, S of Cape Nelson on N coast	Up to 2500	Andesite, basaltic andesite, minor basalt, dacite, and unconsolidated tuff and ash;	Age estimated from degree of dissection
	Hydrographers Volcanics Qph	Hydrographers Ra., N of Bariji R. in extreme NW part of area	Up to 2500	Andesite, basaltic andesite, basalt, dacite; agglomerate, ash; calc-alkaline	K-Ar ages of 670 000-1 450 000 yrs

TABLE 6—*(cont.)*

	Unit (Map symbol)	*Distribution*	*Thickness* (m)	*Lithology*	*Remarks*
PLIOCENE	Musa Volcanic Member (Domara River Conglomerate) Tpz	Interbedded with Tpd; S side of Sibium-Didana Ras, N and SE sides of High Didana Ra.	At least 3 beds, each 5-10 m thick	Basic agglomerate; shoshonitic	
UPPER MIDDLE TO UPPER MIOCENE	Cloudy Bay Volcanics Tpc	SW coast inland from Cloudy Bay	300 approx.	Basic and intermediate agglomerate and lava; shoshonitic	No definite evidence of age, possibly correlative of Tpf
	Fife Bay Volcanics (Tpf) (Tpfs)	Between Guaugurina Bay and Bona Bona Is., SE coast, and in immediate hinterland	At least 500	Basic and intermediate agglomerate and lava; minor tuff and tuffaceous sediment; shoshonitic	Includes Mt Suau Mbr; mapped as Pliocene, possibly middle Miocene on basis of 12.6 m.y. K-Ar date on underlying dyke
UPPER MIOCENE TO LOWER PLIOCENE	Sesara Volcanics Tps	N and S of Bariji R. in NW part of area	550	Basic lava and agglomerate, tuff; minor sediment; shoshonitic	K-Ar ages of 5.4, 5.5, 5.6, and 5.7 m.y.

ALLUVIUM

Unconsolidated gravel, sand, and silt occur in the lower reaches of most of the larger river valleys. The most extensive outcrops are in the Musa valley, north of the main ranges as far east as Goodenough Bay, and south of the ranges eastwards to Mullins Harbour. Alluvium is being deposited rapidly at the present day, especially in the vicinity of the ranges in the west, where the rate of erosion is extremely high. The thickness of the deposits is unknown, but is probably greatest at the foot of Mount Suckling, where the alluvial plain rises to an altitude of over 500 m above sea level.

UPPER CAINOZOIC VOLCANICS

Eleven Upper Cainozoic volcanic units, ranging in age from Miocene to Holocene, have been mapped in southeastern Papua (Table 6). The volcanic rocks are divided into two petrographically and geochemically distinct groups: (i) the shoshonitic rocks of the Fife Bay, Cloudy Bay, Sesara, and Uoivi Volcanics, the Musa Volcanic Member of the Domara River Conglomerate, and the Sesagara and Waiowa Volcanics, and (ii) the potassium-rich calc-alkaline rocks of the Hydrographers Range, Cape Nelson, Manna, and Victory Volcanics.

The Fife Bay and Cloudy Bay Volcanics crop out on the southern side of the main ranges; all the other volcanic formations crop out to the north in the Bariji River area (9°13′S, 148°32′E), the Musa River valley, and north of the Goropu Mountains. Except for some overlap in the Bariji River area, the rocks of the shoshonite association are spatially distinct from the calc-alkaline volcanics.

Nomenclature

The term calc-alkaline association, originally proposed by Peacock (1931), has become well established as the name for the mainly andesitic suite of rocks found in circum-Pacific areas. Recent workers (e.g. Taylor et al., 1969) have distinguished high-potassium calc-alkaline and low-potassium calc-alkaline rocks in some circum-Pacific areas. Taylor & White (1966) and Taylor et al. (1969) subdivided the calc-alkaline suite into basalts, low-silica andesites, andesites, and dacites on the basis of their SiO_2 content, and this scheme of nomenclature is adopted here.

The nomenclature of the shoshonitic rocks is less well defined and is still somewhat controversial. Joplin (1965, 1968) proposed the term shoshonite association for potassium-rich rocks of the absarokite-shoshonite-banakite series of Iddings (1895) and the latites of Ransome (1898). Recent workers (e.g. Jakes & White, 1969; Gill, 1970) have suggested that the shoshonitic rocks form an integral part of the circum-Pacific island arc volcanic association (see also Jakes & Gill, 1970). In this account we follow a classification suggested by A. J. R. White (pers. comm.; see also Jakes & White, 1972) in which shoshonitic rocks are classified according to their SiO_2 content, using the same subdivisions as used to subdivide the calc-alkaline rocks. This scheme of nomenclature is given in Table 7.

FIFE BAY VOLCANICS

The Fife Bay Volcanics comprise the former Fife Bay and Mount Nelson Beds of Davies et al. (1968). The Mount Nelson Beds have been renamed the Mount Suau Member of the Fife Bay Volcanics. The rocks were first noted by Macgillivray (1852) and Gibb Maitland (1892), and have been briefly described by Davies (1967) and Davies et al. (1968).

Derivation of name. Fife Bay on south coast (150°E).

Rock type. Lava, agglomerate, tuff, and minor tuffaceous sediments. The rocks belong to the shoshonite association and consist mainly of porphyritic absarokites and minor non-porphyritic absarokites, shoshonites, and banakites. A characteristic feature is the presence of well formed phenocrysts of green clinopyroxene.

Distribution. Crops out along south coast between Bona Bona Island and Guauguina Bay, on adjacent offshore islands, and in higher ranges south of Sagarai valley.

Type area. Coastal outcrops between Fife Bay and Gabusumrea Bay (149°47′E).

Stratigraphic relationships. Overlie Kutu Volcanics and Modewa Beds unconformably.

Thickness. Exposed thickness probably at least 500 m.

Age. The absence of volcanic landforms indicates that the volcanics are older than Quaternary; they are younger than the late Oligocene to middle Miocene sediments which they overlie. K-Ar dating* of a dyke in the underlying sedi-

* Australian Mineral Development Laboratories determination.

TABLE 7. NOMENCLATURE OF THE CALC-ALKALINE AND SHOSHONITIC VOLCANIC ROCKS

SiO_2 (wt %) (arbitrary)	*Calc-alkaline Association* (After Taylor & White, 1966; Taylor et al., 1969)	*Shoshonite Association* (A. J. R. White, pers. comm; Jakes & White, 1972)
53	basalt	absarokite
57	low-Si andesite	shoshonite
63	andesite	banakite
67	dacite	
	rhyolite	

ments yielded an age of 12.6 ± 0.4 m.y., which suggests a late middle to late Miocene age for the formation.

The Fife Bay Volcanics are gently folded, with an overall southerly dip. They are not sheared, but are commonly jointed with some well developed columnar jointing.

Pillow lavas have been observed in some of the coastal outcrops, and most of the lavas were probably erupted in a shallow sea. The benthonic foraminifera in the underlying sediments indicate a relatively shallow sea, and evidence from elsewhere in eastern Papua shows that a period of late Cainozoic uplift began in Miocene times.

Mount Suau Member

Derivation of name. Mount Suau (10°33′S, 150°15′E), also known as Mount Nelson and Cloudy Mountain.

Rock type. Well indurated agglomerate composed of subangular to subrounded components up to 30 cm across of green, red, or grey porphyritic absarokite set in a hard red fine-grained matrix containing prominent pyroxene crystals.

Distribution. Forms a sheet 100 to 300 m thick, which dips at 30° in the ranges south of Sagarai valley, and is exposed on coast east of Baxter Harbour. It probably also occurs on some of the offshore islands. The member has been observed in situ at Baxter Harbour and in the upper reaches of the Suen River, and as large angular tumbled blocks in the upper reaches of the Sigc Lele, Sige Eueu, and Modewa Rivers.

Type area. Coastal outcrops on southwestern side of Baxter Harbour.

Stratigraphic relationships. Overlies Kutu Volcanics and Modewa Beds unconformably.

Thickness. About 100 to 300 m.

Age. Late middle to late Miocene.

The Mount Suau agglomerate is probably comagmatic with the numerous dykes in the underlying sediments. It probably represents a type of autobrecciated lava flow formed in a submarine environment when a swarm of dykes broke through into the sea. The distribution of the Mount Suau Member suggests that it is the oldest part of the Fife Bay Volcanics.

CLOUDY BAY VOLCANICS

Derivation of name. Named after Cloudy Bay (148°43′E) on south coast.

Rock type. Agglomerate, lava, and volcanic boulder conglomerate. The formation consists mainly of absarokite with subordinate shoshonite and banakite. The rocks are typically porphyritic and vesicular, and generally form massive outcrops.

Distribution. Around Cloudy Bay and in hills to north.

Type area. Outcrops on north shore of Aivaguina River estuary (10°10′S, 148°45′E).

Stratigraphic relationships. Faulted against Kutu Volcanics.

Thickness. At least 200 to 300 m.

Age. Considered to be Quaternary or possibly Holocene by Macnab (1967), but because of their similarity to the Fife Bay Volcanics they are now considered to be late Miocene.

SESARA VOLCANICS

The Sesara Volcanics have been described by Smith & Green (1961) and Ruxton (1966) on which the following account is based.

Derivation of name. Named by Smith & Green (1961) after Sesara village (9°12′S, 148°37′E).

Rock type. Agglomerate, with subordinate lava and tuff, and minor sediments. The formation consists mainly of fine-grained or porphyritic, vesicular to scoriaceous, absarokites and minor shoshonites.

Distribution. South of Bariji River in northwestern corner of the Tufi Sheet area; sedimentary rocks mainly on eastern side of outcrop area.

Type area. Along track between Sesara and Korala, about 6 km east-southeast of Sesara.

Stratigraphic relationships. Overlie basic and ultrabasic rocks of Papuan ultramafic belt.

Thickness. Ruxton (1966) reported exposed thickness of 550 m in Bariji River gorge.

Age. Determined by K-Ar methods as mid-Pliocene (Ruxton, 1966).

Smith & Green (1961) considered the Sesara Volcanics to be remnants of a large central type volcano, but more recent mapping has shown that they were probably erupted from several adjacent centres.

Musa Volcanic Member of Domara River Conglomerate

Musa Volcanic Member is the name given to the volcanic rocks interbedded with the Domara River Conglomerate (see p. 36). The member includes the Musa, Awala, and Imuru Volcanics Members of Smith & Green (1961).

Derivation of name. Musa valley area.

Rock type. Lava and agglomerate, including both absarokites and shoshonites.

Distribution. Beds of agglomerate, 5 to 10 m thick, crop out on northern margin of Didana Range to east of Musa River. Lava flows are exposed west of the junction between the Awala and Musa Rivers, and tuff, lava, and agglomerate crop out nearby in the Urere River. Agglomerate and some tuff are exposed in the Imuru Creek gorge east of Bubudi. North of Bubudi, Buri Creek cuts through a large area of volcanics. Volcanic rocks have also been observed at several localities in the Domara and Foasi Rivers, and Macnab (1967) has recorded interbedded volcanics in the headwaters of the Domara River and in the Keveri valley.

Type area. Buri Creek, north of Bubudi (9°38'S, 148°21'E, Port Moresby Sheet area).

Stratigraphic relationships. Lower part of formation is interbedded with Domara River Conglomerate.

Thickness. Individual beds are generally from 5 to 10 m thick, but range up to about 100 m.

Age. Whole rock K-Ar determination (R. W. Page, pers. comm.) of a lava fragment (spec. 0772; 9°46'S, 148°40'E) from an agglomerate south of Mount Avuru gave an age of 2.36 ± 0.05 m.y. Page notes that although the rock appears to be fresh, the plagioclase phenocrysts gave an age of 22.0 ± 0.5 m.y. This large discrepancy may be due to the presence of excess radiogenic argon in the plagioclase; alternatively the plagioclase may have crystallized about 22 m.y. ago, but the whole rock did not become a closed system to argon until it was extruded 2 to 3 m.y. ago. The presence of partly eroded clusters and embayed grains of plagioclase lend support to the latter hypothesis.

Biotite from a dyke in Dimidi Creek (spec. 0670; 9°45'S, 148°51'E) has a K-Ar age of 5.3 ± 0.2 m.y. (also determined by R. W. Page in 1968). The dyke intrudes ultramafic rocks and is thought to be related to the volcanic rocks found in the Domara River Conglomerate.

Uoivi Volcanics

The Uoivi Volcanics comprise lava flows, lava cones, flow domes, scoria mounds, cinder cones, and explosion craters. The following description is taken from Ruxton (1966).

Derivation of name. Named by Ruxton (1966) after Uoivi village (9°8'S, 148°28'E, Port Moresby Sheet area).

Rock type. Lava and scoria, composed mainly of absarokite with subordinate shoshonite and banakite.

Distribution. North and south of Bariji River at eastern edge of Managalase Plateau in north-western corner of Tufi Sheet area.

Type area. Bariji River south of Kururi village (9°9'S. 148°28'E, Port Moresby Sheet area).

Stratigraphic relationships. Overlie Sesara Volcanics, possibly unconformably; interbedded with Manna Volcanics.

Thickness. Up to 600 m.

Age. Late Pleistocene to Holocene (Ruxton 1966).

Sesagara Volcanics

Derivation of name. Sesagara Hills (9°33'S, 148°08'E).

Rock type. Lava, agglomerate, and ash, composed of absarokite and shoshonite.

Distribution. Sesagara Hills, north of Goropu Mountains.

Type area. Lower reaches of Uiaku River (9°29'S, 149°08'E).

Stratigraphic relationships. Overlie and probably partly interbedded with Quaternary alluvium.

Thickness. Up to 200 m.

Age. Quaternary. The remnants of small summit craters which were probably active in Holocene time are found on two of the hills north of the Goropu Mountains; the other hills show no obvious volcanic landforms and may be as old as Pleistocene.

Waiowa Volcanics

Derivation of name. Waiowa (Goropu) Volcano. Named Waiowa Volcanics by Smith & Green (1961).

Rock type. Unconsolidated agglomerate and tuff composed of fragments of shoshonite.

Distribution. Around Waiowa Volcano (9°28'S, 149°58'E) up to a maximum distance of about 5 km from crater.

Type area. Bobo Creek (9°33'S, 149°05'E), where it dissects outer slopes of volcano.

Stratigraphic relationships. Overlie Holocene alluvium.

Thickness. About 25 m.

Age. Holocene. The rocks were erupted during the volcanic activity of 1943-44.

Waiowa Volcano erupted in 1943 and 1944 (Baker, 1946). No lava was extruded, but pyroclastic material, including lava blocks up to 0.5 m in diameter, was distributed over an area within a radius of 4 km of the crater. Much of the material was rapidly reworked before a cover of vegetation was established,

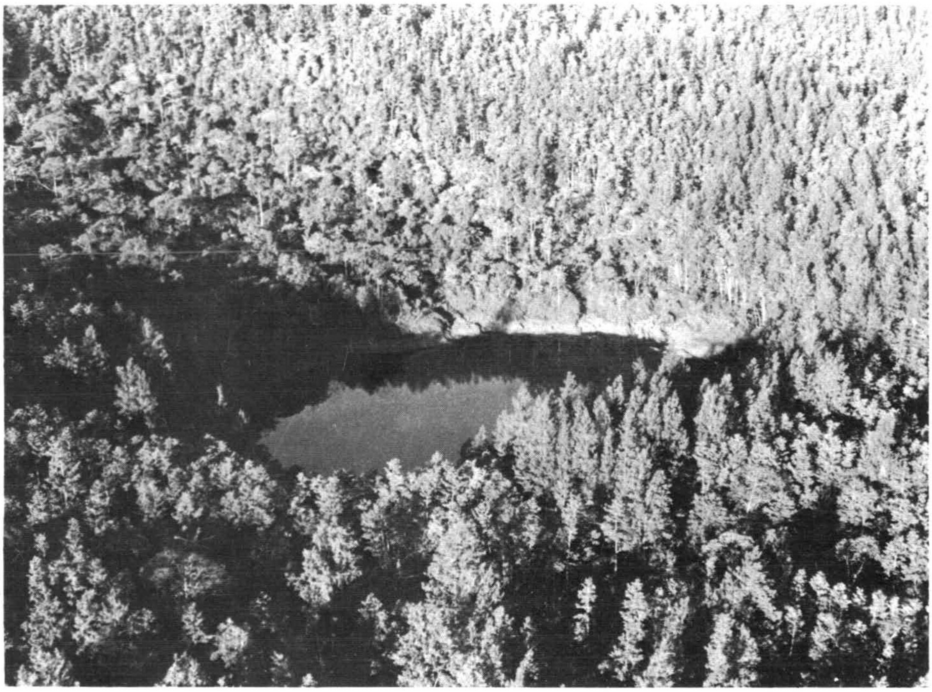

Fig. 19. The crater of Waiowa volcano.

but the record of the 1943-44 eruptions is still preserved in some sections along the rivers adjacent to the volcano.

The cone was formed during a series of eruptions (Baker, 1946) when well bedded agglomerate and ash were laid down. These beds are now exposed in nearby rivers. According to Baker there were at least four eruptions from as many as four vents between 27 December and 31 August 1944. No trace remains of three of the vents, which were presumably buried in a final eruption from the present crater.

There has been no further volcanic activity since 1943-44 and the cone is now heavily timbered. The crater (Fig. 19) contains a lake 200 m in diameter; the crater rim is 25 m above the lake, but the cone itself only rises slightly above the surrounding countryside.

Petrography of the Shoshonitic Volcanic Rocks

The shoshonitic Upper Cainozoic volcanic rocks of eastern Papua include absarokite, shoshonite, and banakite.

The absarokites in the Fife Bay and Cloudy Bay Volcanics generally contain numerous phenocrysts up to 4 mm across set in a fine-grained groundmass. The phenocrysts include pale green clinopyroxene (10-20%) associated with smaller crystals of opaque oxides (0.5 mm), and in most cases olivine (up to 15%) or plagioclase (up to 30%), or both. Most of the clinopyroxene crystals are zoned; their margins are more deeply coloured than the cores and fine inclusions of opaque oxides commonly mark zone boundaries. In a few specimens the clinopyroxene phenocrysts are intergrown with olivine, or contain inclusions of olivine.

The olivine has commonly been replaced by iddingsite, bowlingite, serpentine, or chlorite. Most of the plagioclase phenocrysts consist of labradorite (An_{55-70}), but a few consist of bytownite (An_{75-80}); normal and oscillatory zoning over a narrow compositional range is common.

The groundmass in the porphyritic absarokites consists of labradorite microlites, interstital potash feldspar, opaque oxides, minor augite and olivine, and accessory apatite. In some specimens the groundmass contains small crystals of biotite; in others a medium to dark brown glass is common. One porphyritic specimen (3401) from near Cloudy Bay contains 20 percent of small rounded crystals of sodalite.

The secondary minerals include chlorite, calcite, and minor prehnite and epidote. Some of the absarokites contain irregular and spherical vesicles and amygdales up to 5 mm across. The vesicles are commonly lined with fine-grained chlorite, and some are filled with intergrowths of fibrous zeolite and analcite, and in some specimens colourless to green chlorite.

The 'welded' basaltic agglomerate which forms the Mount Suau Member of the Fife Bay Volcanics consists mainly of absarokite. The interstitial matrix is fine-grained or glassy, but is essentially similar to the absarokite fragments, except that secondary minerals are more common. The matrix contains large crystals of augite and, less commonly, plagioclase.

The absarokites in the Bariji River area and in the Musa Volcanic Member contain phenocrysts of biotite and more rarely hornblende. Leucite has been recorded in the groundmass of one of the rocks from the Domara River Beds (Macnab, 1967). Non-porphyritic absarokites are associated with the porphryritic absarokites in some areas.

Shoshonite occurs in the Bariji River area, and in the Musa Volcanic Member, the Sesagara and Waiowa Volcanics, and as a minor component of the Cloudy Bay and Fife Bay Volcanics. It is massive or vesicular, and typically porphyritic, with phenocrysts of andesine, biotite, hornblende, augite, opaque oxides, and rarely olivine. The groundmass is composed of andesine, potash feldspar, augite, opaque oxides, sphene, apatite, and secondary chlorite, zeolite, and calcite. Minor analcite has been observed in a shoshonite from the Cloudy Bay Volcanics.

Banakite occurs as a minor component of the Fife Bay, Cloudy Bay, and Waiowa Volcanics. It generally consists of numerous phenocrysts of andesine, less commonly biotite, and rare clinopyroxene set in a groundmass of plagioclase, potash feldspar, and subordinate clinopyroxene and opaque oxides, and less commonly biotite.

HYDROGRAPHERS VOLCANICS

The Hydrographers Volcanics crop out mainly in the Buna Sheet area, but small outcrops are present north of the Bariji River in the extreme northwestern part of Tufi Sheet area.

Derivation of name. Hydrographers Range (8° 58'S, 148°22'E, Buna Sheet area). The formation was called the Hydrographer Range Volcanics by Paterson & Kicinski (1956), but the name was amended by Ruxton (1966).

Rock type. Lava and agglomerate with minor tuff. The main rock types are andesite and subordinate low-silica andesite with minor basalt and dacite of the high-potassium calc-alkaline association.

Distribution. Hydrographers Range (8°58'S, 148°22'E).

Type area. Coastal exposures on western side of Dyke Ackland Bay (8°58'S, 148°31'E).

Stratigraphic relationships. Probably interbedded with Uoivi and Manna Volcanics on northern margin of Managalase Plateau.

Thickness. Up to 2500 m.

Age. 0.67 to 1.45 m.y. (based on K-Ar dates by I. McDougall).

The Hydrographers Range, which is one of four large volcanoes on the north coast of Papua, is a deeply dissected Pleistocene strato-volcano north of the Managalase Plateau. Mount Lamington (Taylor, 1958) lies to the west of the area covered by this Bulletin, and Mount Victory and Mount Trafalgar (Fig. 20) to the east.

CAPE NELSON VOLCANICS

The volcanics forming Mount Trafalgar (9°09'S, 149°10'E), a deeply dissected strato-volcano on the northeast Papuan coast, are called the Cape Nelson Volcanics.

Derivation of name. Cape Nelson (9°09'S, 149°15'E).

Rock type. Lava, agglomerate, and unconsolidated ash. The main rock types are andesite and subordinate low-silica andesite with minor basalt and dacite of the high-potassium calc-alkaline association.

Distribution. Cape Nelson peninsula.

Type area. Stream draining south from summit area of Mount Trafalgar (9°10'S, 149°09'E).

Stratigraphic relationships. Overlain by Mount Victory Volcanics. The upper part of the Cape Nelson Volcanics is probably interbedded with the lower part of the Mount Victory Volcanics.

Thickness. Up to 2500 m. The estimate is based on the elevation of the present summit and evidence of recent subsidence (Branch, 1965).

Age. Pleistocene; degree of dissection is comparable to that of Hydrographers Range where volcanism has been dated at 500 000 to 600 000 years.

No trace of volcanic landforms remain around the summit area of Mount Trafalgar, but the lower slopes in the north and northeast consist of a series of lava flows. Recent subsidence of the volcano, probably as a result of volcanic loading (Branch, 1965), has resulted in the drowning of the valleys between the flows and the formation of a deeply indented coastline.

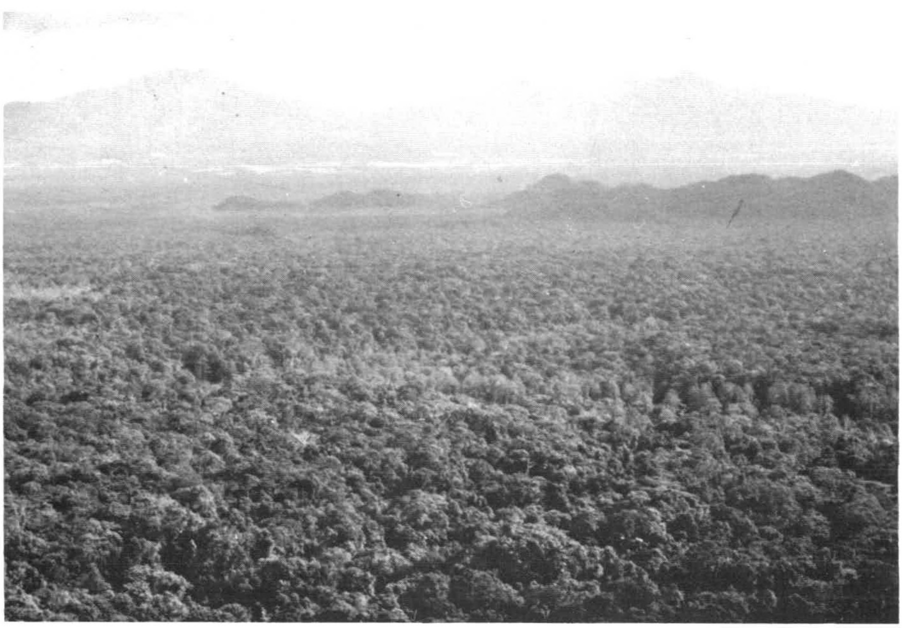

Fig. 20. Mount Victory (left) and Mount Trafalgar, with the Sesagara Hills in the foreground.

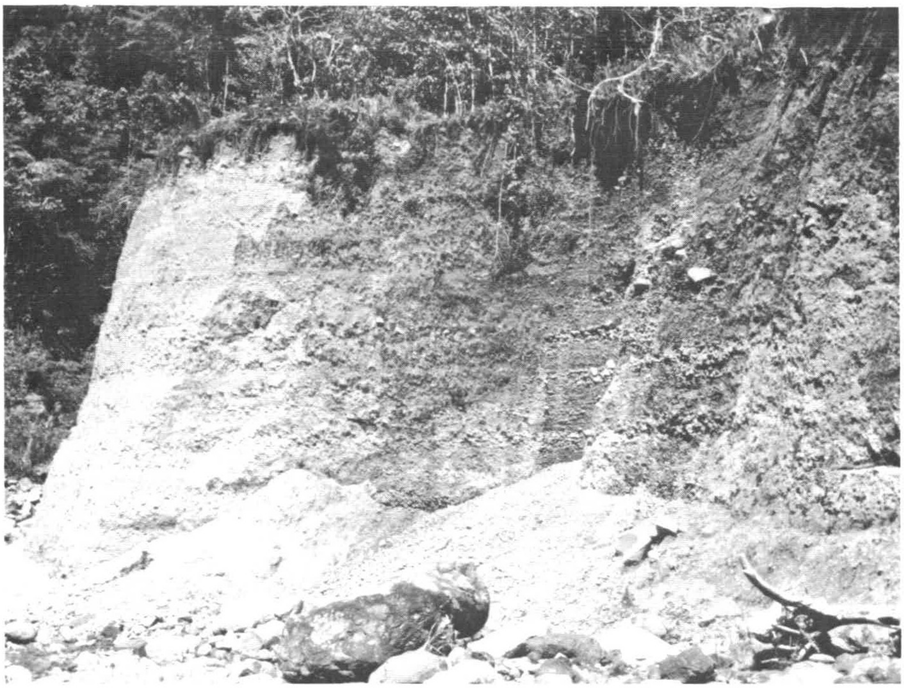

Fig. 21. Unconsolidated volcanic ash in the Kopwei River on the northeast slopes of Mount Victory. Probably deposited during recent activity of the volcano.

Mount Victory Volcanics

Mount Victory (2500 m) is a large stratovolcano on the southwestern side of Mount Trafalgar.

Derivation of name. Mount Victory (9°13'S, 149°05'E).

Rock type. Lava with subordinate agglomerate and unconsolidated ash. The main rock types are andesite and subordinate low-silica andesite with minor basalt and dacite of the high-potassium calc-alkaline association.

Distribution. Mount Victory Volcano at base of Cape Nelson peninsula.

Type area. Iu-ai-iu River near summit of volcano, where a sequence of ash and unconsolidated agglomerate is exposed in river banks.

Stratigraphic relationships. Overlie Cape Nelson Volcanics. The lower part of the Mount Victory Volcanics is probably interbedded with the upper part of the Cape Nelson Volcanics where the two volcanoes abut against each other.

Thickness. Up to 2500 m, the present height of the volcano.

Age. Pleistocene and Holocene.

Mount Victory is dormant and was last active in the late 19th and early 20th centuries (Smith, 1969). The lower slopes of the volcano rise gently from alluvial plains on three sides; to the northeast Mount Victory and Mount Trafalgar are separated by a saddle about 300 m above sea level. The upper 500 m of the volcano rise relatively steeply to an irregular summit area, which includes a fairly well preserved crater, remnants of earlier craters, and lava domes (Smith, 1969).

There are four small flank cones on the southwestern slopes of Mount Victory and two small cones in the saddle between Mount Victory and Mount Trafalgar to the north. Two of the cones in the southwest are well formed and are relatively recent, two are older. A series of lava flows from these flank cones, now heavily forested, were probably erupted in comparatively recent times. The cones in the saddle between Mount Victory and Mount Trafalgar are well formed, and one contains a small crater lake (Lake Ridubidubina).

The most recent activity from Mount Victory was the eruption of nueé ardentes in the 1890s, followed by a period of dome building which continued into the 1930s. The thick unconsolidated ash deposits in the Kopwei River on the northeast side of the cone (Fig. 21) were probably erupted in the 1930s. At present there is only minor solfataric activity in the crater area.

Manna Volcanics

The Manna Volcanics form a series of ash cones and tholoids north of the Bariji River near the eastern margin of Managalase Plateau.

Derivation of name. Named by Ruxton (1966) from Mount Manna (9°08'S, 148°30'E).

Rock type. Dacite and rhyolite ash-flow deposits with subordinate lava. The rocks belong to the high-potassium calc-alkaline association.

Distribution. Eastern margin of Managalase Plateau.

Type area. Mount Manna (9°08'S, 148°30'E).

Stratigraphic relationships. Interbedded with Uoivi Volcanics.

Thickness. Up to 760 m.

Age. Holocene.

Petrography of the High-Potassium Calc-Alkaline Volcanic Rocks

The calc-alkaline basalts are composed of phenocrysts of plagioclase (up to 3.5 mm), clinopyroxene, and olivine set in a fine-grained groundmass of plagioclase, clinopyroxene, minor olivine, opaque oxides, and a small amount of glass. The plagioclase phenocrysts (An_{65-75}) show normal zoning and, to a lesser extent, oscillatory zoning with a narrow range of composition. The cores and margins are commonly defined by zones of fine inclusions. The olivine phenocrysts (2 mm) are rounded with wide iddingsite rims. The clinopyroxene (less than 2 mm) commonly shows simple twinning and is subhedral; the larger crystals contain inclusions of olivine and plagioclase.

The low-silica andesites are either moderately porphyritic or fine even-grained rocks. In the porphyritic varieties, plagioclase phenocrysts (3.0 mm) are predominant, but smaller phenocrysts of clinopyroxene, orthopyroxene, opaque oxides, olivine, and rarely amphibole and biotite may be present. The groundmass consists of devitrified glass with plagioclase, clinopyroxene, orthopyroxene, and opaque oxides. The plagioclase phenocrysts (An_{35-65}) display normal and oscillatory zoning. Amphibole and biotite, where present, are surrounded by rims of opaque oxides. The non-porphyritic varieties consist of clinopyroxene, altered olivine, flow-oriented plagioclase, opaque oxides, and rare orthopyroxene.

The andesites and dacites contain numerous phenocrysts of plagioclase and amphibole, and less commonly biotite, clinopyroxene, opaque oxides, and rarely potash feldspar. The fine-grained groundmass consists of abundant glass with crystals of plagioclase, amphibole, biotite, opaque oxides, and minor clinopyroxene. The zoned plagioclase phenocrysts (up to 5 mm) range from andesine to labradorite. The hornblende is generally the common brown variety, but deep red-brown oxyhornblende or green hornblende occur in some specimens; opaque oxide rims are common, and in some crystals several opaque zones alternate with zones of unaltered hornblende. Clinopyroxene forms aggregates, which are commonly surrounded by rims of fine-grained amphibole or, less commonly, biotite. Potash feldspar occurs as small (0.5 mm) phenocrysts in some specimens.

Ruxton (1966) states that the rhyolites of the Manna Volcanics are typical of the calc-alkaline suite. They are light grey, and consist of phenocrysts of zoned plagioclase, brown biotite, brown hornblende, augite, and rarely apatite set in a groundmass of pink glass with perlitic cracks and microlites. Tridymite occurs in cavities, and is common in the ash-flow tuffs. Quartz and, to a lesser extent olivine and feldspar, occur as xenocrysts.

Geochemistry of the Upper Cainozoic Volcanic Rocks

Fifty-six major element analyses have been made of the Upper Cainozoic volcanics in southeastern Papua; many of these have been published (Ruxton, 1966; Jakes & Smith, 1970). Table 8 presents 25 new analyses of the shoshonitic volcanics and Table 9 is a compilation of representative calc-alkaline analyses from the literature.

The high-potassium calc-alkaline volcanics and the shoshonitic volcanics have many chemical similarities. TiO_2 is low in both groups, a feature typical of rocks in orogenic areas (Jakes & White, 1972). In both groups TiO_2, CaO, MgO, and FeO + Fe_2O_3 show a negative correlation with SiO_2. The Al_2O_3 content varies widely, as does the FeO/Fe_2O_3 ratio.

TABLE 8. CHEMICAL ANALYSES, SHOSHONITIC VOLCANICS

	1	2	3	4	5	6	7	8	9	10
SiO_2	47.2	47.3	47.9	47.9	48.1	48.1	48.2	48.3	48.5	48.6
TiO_2	1.01	0.78	0.73	0.62	1.06	0.92	0.75	0.60	0.80	0.88
Al_2O_3	13.2	11.30	13.6	10.2	14.10	15.30	17.20	13.4	15.4	17.4
Fe_2O_3	4.60	7.05	5.55	5.85	7.85	7.00	7.15	2.85	3.55	5.80
FeO	4.65	5.90	5.05	4.55	2.10	4.65	1.81	6.15	6.00	4.10
MnO	0.16	0.20	0.18	0.16	0.15	0.16	0.17	0.14	0.15	0.18
MgO	8.15	11.80	7.15	10.6	5.90	5.05	9.35	13.1	7.15	3.80
CaO	10.10	8.00	11.80	12.5	9.75	8.65	3.95	9.35	11.1	9.35
Na_2O	2.10	1.50	2.05	1.40	4.25	2.95	2.45	1.30	2.10	3.05
K_2O	3.85	4.05	3.15	2.25	1.29	2.10	2.60	2.50	3.00	2.55
P_2O_5	0.82	0.68	0.31	0.46	0.95	0.30	0.49	0.39	0.46	0.32
H_2O+	2.75	1.05	1.88	2.10	2.70	2.80	4.05	1.51	1.34	2.30
H_2O-	1.13	0.25	0.20	1.09	1.40	0.83	1.71	0.29	0.40	0.73
CO_2	0.11	0.05	0.60	0.47	0.10	1.40	0.40	0.08	0.07	1.20
Total	99.83	99.91	100.15	100.15	99.70	100.21	100.28	99.96	99.82	100.26

1 Absarokite, agglomerate, Aivaguina River, 10°08'S, 148°48'E). Analysts, R. J. Buckley and A. Jorgensen, AMDL. (3401).

2 Absarokite, boulder, Watuti River, (10°31'S, 150°16'E). Analyst, A. Jorgensen, AMDL. (4296A).

3 Absarokite, agglomerate boulder, Saragai River, (10°28'S, 150°14'E). Analyst, A. Jorgensen, AMDL. (2155).

4 Absarokite, Gara River, (10°36'S, 150°22'E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (6057).

5 Absarokite, agglomerate, Aivaguina River, (10°08'S, 148°47'E). Analysts, R. J. Buckley and A. Jorgensen, AMDL. (3402A).

6 Absarokite, agglomerate boulder, Sige Lele River, (10°31'S, 150°08'E). Analyst, A. Jorgensen, AMDL. (2100).

7 Absarokite, agglomerate boulder, Modewa River, (10°38'S, 150°16'E). Analyst, A. Jorgensen, AMDL. (4258).

8 Absarokite, Gabugoghi Bay, (10°35'S, 149°58'E). Analyst, A. Jorgensen, AMDL. (4268).

9 Absarokite, Mullins Harbour, (10°31'S, 149°57'E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (3298).

10 Absarokite, agglomerate boulder, Modewa River, (10°36'S, 150°16'E). Analyst, A. Jorgensen, AMDL. (2133).

TABLE 8 (CONT.)

	11	12	13	14	15	16	17	18	19	20
SiO_2	48.7	49.0	49.1	49.3	50.2	50.3	50.9	51.5	53.6	54.2
TiO_2	1.03	0.54	1.08	0.61	0.97	1.17	0.97	0.65	0.72	1.03
Al_2O_3	13.7	15.9	13.7	14.6	19.1	17.8	19.9	16.00	17.3	15.2
Fe_2O_3	7.00	3.15	7.10	3.00	4.20	7.95	3.90	4.10	4.60	2.05
FeO	2.90	4.30	2.85	5.45	2.85	1.33	2.30	4.50	3.05	5.50
MnO	0.13	0.14	0.11	0.14	0.13	0.15	0.13	0.16	0.15	0.13
MgO	6.00	8.95	5.90	8.65	3.95	3.70	2.55	5.55	3.10	9.10
CaO	9.90	6.45	9.95	11.2	7.20	8.35	6.20	7.45	7.30	7.00
Na_2O	3.75	3.05	3.45	2.05	2.85	3.65	4.20	4.05	2.85	2.65
K_2O	1.35	3.05	1.70	2.60	3.75	2.70	4.00	3.15	3.10	1.60
P_2O_5	0.87	0.40	0.87	0.40	0.69	0.60	0.55	0.52	0.56	0.32
H_2O+	3.40	1.92	2.55	1.27	1.45	0.97	2.50	2.00	1.82	0.78
H_2O-	1.05	2.90	1.21	0.65	1.59	0.95	1.07	0.28	1.52	0.26
CO_2	0.03	0.40	0.08	0.12	0.69	0.13	0.52	0.20	0.08	0.05
Total	99.81	100.15	99.65	100.04	99.62	99.75	99.69	100.11	99.75	99.87

11 Absarokite, agglomerate, Aivaguina River, (10°08′S, 148°47′E). Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3402B).
12 Absarokite, Gabugoghi Bay, (10°35′S, 149°58′E). Analyst, A. Jorgensen, AMDL. (4276)
13 Absarokite, agglomerate, Aivaguina River, (10°08′S, 148°47′E). Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3402C).
14 Absarokite, Mullins Harbour, (10°32′S, 149°58′E). Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3300).
15 Absarokite, boulder, Liba River, (10°03′S, 148°50′E). Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3406A).
16 Absarokite, agglomerate, Aivaguina River, (10°10′S, 148°44′E). Analysts, R. J. Buckley and A. Jorgensen, AMDL. (3403A).
17 Absarokite, boulder, Liba River, (10°03′S, 148°50′E). Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3406B).
18 Absarokite, boulder, Watuti River, (10°31′S, 150°16′E). Analysts, A. Jorgensen, AMDL. (4323).
19 Shoshonite, agglomerate, Suwen River, (10°37′S, 150°12′E. Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3335).
20 Shoshonite, Uiaku River, (9°30′S, 149°09′E). Analysts, R. W. Bruce and L. W. Castanelli, AMDL. (3557A).

TABLE 8 (CONT.)

	21	22	23	24	25
SiO_2	56.5	57.0	57.0	57.1	57.1
TiO_2	1.17	1.04	0.76	0.80	1.08
Al_2O_3	13.3	13.8	19.5	19.6	13.6
Fe_2O_3	3.10	1.45	3.85	5.90	2.25
FeO	3.65	4.15	1.85	0.20	3.70
MnO	0.09	0.09	0.11	0.55	0.09
MgO	7.90	7.60	1.60	1.70	7.75
CaO	6.45	6.50	5.15	3.00	6.40
Na_2O	2.35	2.60	4.15	4.05	2.65
K_2O	4.15	4.30	3.40	3.10	4.05
P_2O_5	0.05	0.53	0.46	0.50	0.40
H_2O+	0.26	0.62	0.89	2.00	0.43
H_2O-	0.44	0.02	0.35	1.15	0.05
CO_2	0.04	0.03	0.53	0.05	0.05
Total	99.90	99.73	99.60	99.70	99.60

21 Shoshonite, Waiowa Volcano, (9°32′S, 149°06′E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (3553).
22 Banakite, Waiowa Volcano (9°34′S, 149°05′E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (3445).
23 Banakite, agglomerate, Aivaguina River, (10°10′S, 148°44′E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (3403D).
24 Banakite, agglomerate, Aivaguina River, (10°10′S, 148°44′E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (3403C).
25 Banakite, Waiowa Volcano, (9°34′S, 149°05′E). Analysts, R. L. Bruce and L. W. Castanelli, AMDL. (3446).

TABLE 9. REPRESENTATIVE CHEMICAL ANALYSES, CALC-ALKALINE VOLCANICS

	1	2	3	4	5	6	7	8	9	10
SiO_2	50.59	53.85	55.97	58.52	59.69	61.8	62.64	64.12	67.50	68.90
TiO_2	1.05	1.51	0.93	0.76	0.67	0.70	0.67	0.61	0.56	0.29
Al_2O_3	16.29	15.60	16.20	16.20	16.01	16.4	16.48	16.80	15.20	15.60
Fe_2O_3	3.66	4.02	4.37	2.93	4.47	2.70	1.68	1.61	1.50	1.20
FeO	5.08	3.66	2.21	3.28	0.47	1.90	2.64	2.18	1.20	0.90
MnO	0.17	0.12	0.12	0.09	0.08	0.09	0.08	0.07	0.05	0.05
MgO	8.96	6.80	4.62	4.14	5.28	3.20	3.91	2.96	1.20	0.82
CaO	9.50	7.17	6.50	5.59	5.98	4.95	5.10	4.44	3.05	2.25
Na_2O	2.89	3.64	3.70	3.64	4.16	4.25	4.25	4.38	4.20	4.40
K_2O	1.07	1.56	2.15	2.67	2.00	2.60	1.06	2.41	3.40	3.75
P_2O_5	0.21	0.43	0.28	0.25	0.24	0.27	0.26	0.41	0.16	0.08
Loss	0.81	1.66	2.52	1.47	0.76	0.96	1.05	0.32	1.65	1.93
Total	100.28	100.02	99.57	99.54	99.81	99.82	99.82	100.14	99.67	110.17

1 Basalt, northern slope Mt Trafalgar, (9°03'S, 149°09'E). Jakes & Smith (1970). (3544).
2 Basaltic andesite, upper northeast slope Mt Victory, (9°11'S, 149°06'E). Jakes & Smith (1970). (6516).
3 Basaltic andesite, lower north slope Mt Trafalgar, (9°01'S, 149°08'E. Jakes & Smith (1970). (3545).
4 Basaltic andesite, lower northwest slope Mt Trafalgar, (9°03'S, 149°04'E). Jakes & Smith (1970). (3548).
5 Andesite, upper southwest slope Mt Victory, (9°13'S, 149°04'E). Jakes & Smith (1970). (3500B).
6 Andesite, upper southwest slope Mt Victory, (9°13'S, 149°04'E). Jakes & Smith (1970). (3500A).
7 Andesite, northeast slope Mt Victory, (9°11'S, 149°06'E). Jakes & Smith (1970). (6518).
8 Dacite, lower southwest slope Mt Trafalgar, (9°10'S, 149°06'E). Jakes & Smith (1970). (3526B).
9 Rhyolite, Manna Volcanics, Ruxton (1966, table 2, analysis 41). (G138).
10 Rhyolite ash flow, Manna Volcanics. Ruxton (1966, table 2, analysis 43). (G13).

The SiO_2 content of the shoshonitic rocks (44-63%) is lower than in the calc-alkaline lavas (50-69%). On the FMA diagram (Fig. 22) the calc-alkaline analyses plot in a flat trend with no suggestion of the iron enrichment characteristic of tholeiitic rocks. The shoshonitic analyses plot in a diffuse area across the base of the calc-alkaline trend on the FMA diagram.

The most significant differences between the shoshonitic and calc-alkaline rocks are the alkali content and alkali ratios. The shoshonitic rocks are higher in total alkalis than the calc-alkaline rocks and comparison of total alkali/SiO_2 (Fig. 23) and K_2O/SiO_2 (Fig. 24) plots shows that this differences lies in the K_2O content. The K_2O/Na_2O ratios for equivalent SiO_2 contents are higher in the shoshonitic rocks and show a greater scatter than in the calc-alkaline rocks.

INTRUSIVE ROCKS

Numerous small intrusive bodies are associated with the Upper Cretaceous and Eocene submarine basalts in southeastern Papua. The Yau and East Cape Gabbros and the Imo Tonalite have been mapped separately. The Yau and East Cape Gabbros are considered to be co-magmatic with the associated volcanic rocks on the basis of petrographic and chemical similarities.

YAU GABBRO

Derivation of name. Yau River.

Rock type. Gabbro and granophyric tonalite.

Distribution. Stock intruding contact between Goropu Metabasalt and Kutu Volcanics; it has a mean diameter of 5 km centred on Mount Mura (10°57'S, 149°25'E).

Type area. Middle and upper reaches of Yau River.

Relationships. Intrudes Goropu Metabasalt and Kutu Volcanics.

Age. Inferred to be genetically related to Kutu Volcanics and therefore probably of Late Cretaceous age.

Petrography. The gabbro is typically medium to coarse-grained, and is composed of clinopyroxene or its alteration products (30-40%), plagioclase (30-50%), opaque oxides, and an interstitial mesostasis. The clinopyroxene is generally altered to tremolite-actinolite or less commonly hornblende, and in some specimens alteration is 80 to 90 percent complete. Alteration of plagioclase to fine-grained sericite is common.

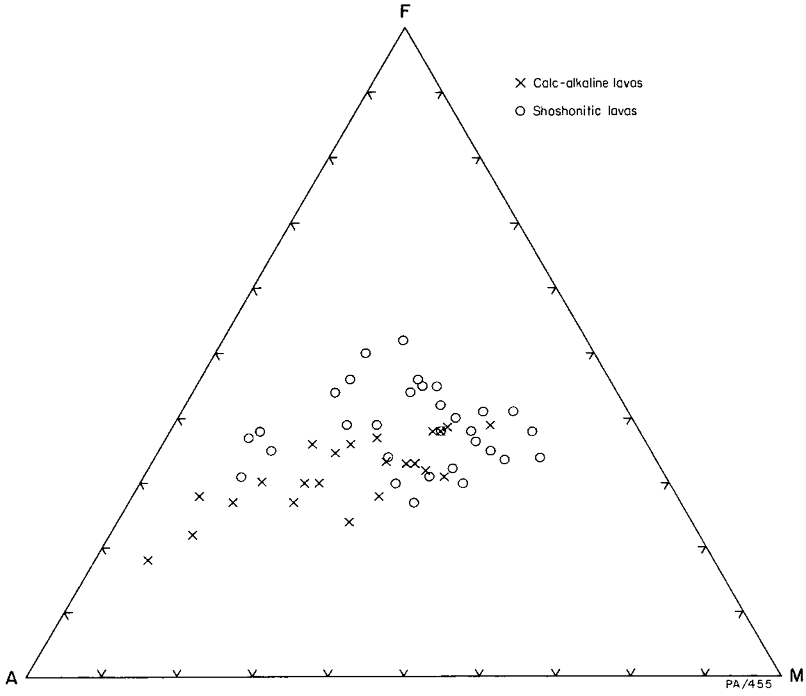

Fig. 22. FMA (FeO+0.9Fe_2O_3, MgO, Na_2O+K_2O) diagram for the Upper Cainozoic lavas. Data from Ruxton (1966), Jakes & Smith (1970), and Table 8.

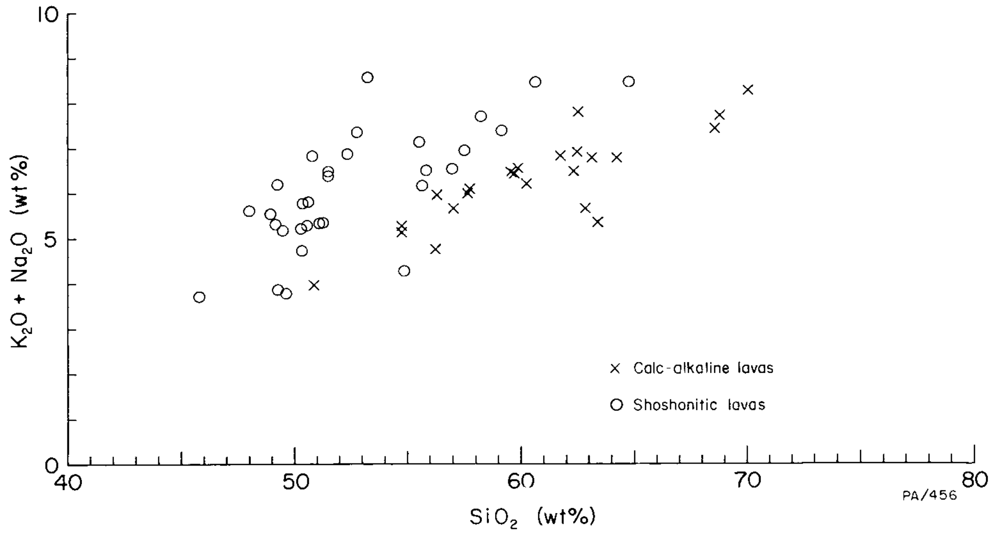

Fig. 23. Total alkali/silica plot for the Upper Cainozoic lavas. Data from Ruxton (1966), Jakes & Smith (1970), and Table 8.

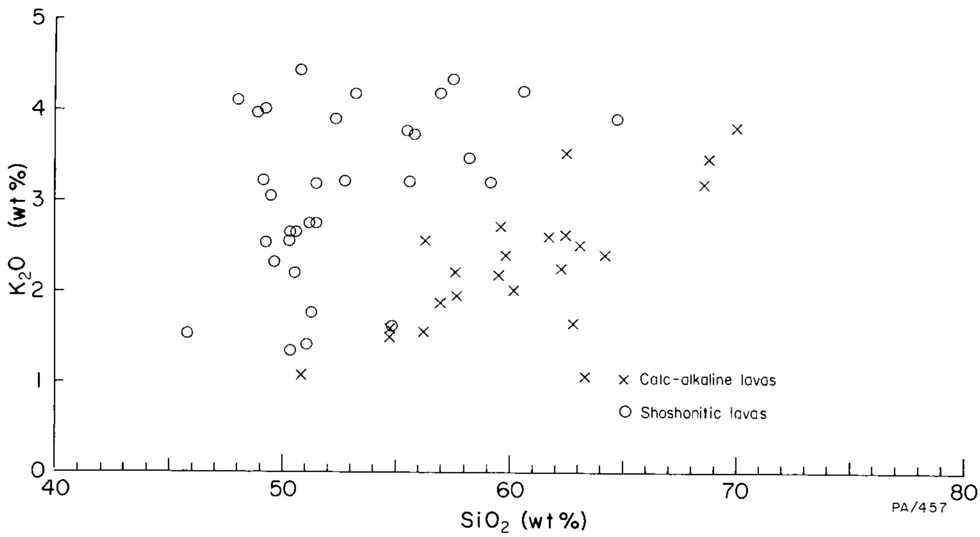

Fig. 24. K_2O/SiO_2 plot for the Upper Cainozoic lavas.

The granophyric tonalite is medium to coarse-grained, and consists of altered plagioclase, clinopyroxene, which is commonly altered to tremolite-actinolite, quartz (up to 20%), skeletal opaque oxides, and minor interstitial mesostasis. Quartz-feldspar intergrowths are common in many specimens, and chlorite, pumpellyite, and prehnite are found in places.

The Yau Gabbro is probably a subvolcanic stock related to the Upper Cretaceous basalts. The mineral assemblages are consistent with late magmatic differentiation of a tholeiitic magma such as that from which the volcanics were derived.

Similar rocks are found in the Ruaba River and Bindi Creek to the east, and on the Dayman Dome to the north.

EAST CAPE GABBRO

Derivation of name. East Cape (10°13'S, 150°51'E).

Rock type. Gabbro.

Distribution. About 13km² between East Cape and 150°45'E.

Type area. From East Cape (10°13'S, 150° 51'E) westwards to Kape Point (10°13'S, 150° 48'E).

Relationships. Intrudes Kutu Volcanics.

Age. Inferred to be Eocene.

Petrography. The gabbro is typically medium-grained, and consists of subhedral clinopyroxene (20%), intergrown with elongate laths of labradorite (An_{60-65}; 50-60%), subordinate orthopyroxene (5-10%), opaque oxides (5%), and a fine-grained green interstitial mesostasis (5-10%).

Baker (1953) described specimens of 'micropegmatitic quartz diorite' collected from the coastal platform on the northern side of East Cape and on Meimeiara Island. The diorite is probably part of the same intrusive body as the gabbro.

The two analysed specimens of the East Cape Gabbro (Table 2, analyses 28-29) are similar in composition to the Kutu Volcanics with which they are thought to be co-magmatic. The relatively higher total iron content (17.5-19.75%) is consistent with differentiates of a tholeiitic magma.

IMO TONALITE

Derivation of name. Imo River (9°14'S, 148° 28'E, Port Moresby Sheet area).

Rock type. Tonalite and diorite.

Distribution. Imo River (9°14'S, 148°28'E).

Relationships. Intrudes Cretaceous? basalt and gabbro of Papuan ultramafic belt; probably equivalent to Kui Tonalite in Salamaua Sheet area.

Age. Eocene, from inferred correlation with Kui Tonalite.

Petrography. Nine specimens of the Imo Tonalite from the Port Moresby Sheet area have been examined in thin section. Six are tonalites with 30 to 45 percent quartz and granophyric quartz-feldspar intergrowths; the other constituents are andesine or less commonly oligoclase, hornblende, magnetite, rare opaque oxides, and very rare zircon. The secondary minerals are epidote, uralite, chlorite, and less commonly prehnite.

The other three rocks examined are diorites composed of hornblende (40%) intergrown with plagioclase, which ranges from andesine to labradorite.

INTRUSIVES IN MOUNT SUCKLING AREA

The intermediate and acid dykes and small stocks in the Mount Suckling area (Davies, 1971) have been named the Mau Monzonite, Suckling Granite, and Bonua Porphry. The small outcrops of biotite-bearing pyroxenite to the south and southeast of Mount Suckling are probably separate bodies related to the shoshonitic intrusives to the southeast.

Mau Monzonite

Derivation of name. Mau River on southeast side of Mount Suckling.

Rock type. Granodiorite, adamellite, monzonite, and hornblendite.

Distribution. 150 km^2 to southeast of Mount Suckling.

Type area. Mau River between 9°43'S, 149°02'E and 9°45'S, 149°04'E.

Relationships. Intrudes Goropu Metabasalt and may intrude Suckling Granite.

Age. Late Miocene to early Pliocene, based on hornblende K-Ar ages of 4.37, 6.03, and 6.26 m.y. (Davies & Smith, 1974).

Petrography. The monzonite, adamellite, and granodiorite are composed of grains of zoned plagioclase (andesine to oligoclase) up to 1 mm in diameter, green-brown hornblende, brown biotite, and interstitial orthoclase, with or without accessory quartz. The accessories are sphene, apatite, zircon, and in one specimen xenotime.

The hornblendite consists predominantly of hornblende and biotite (50-90%) with subordinate feldspars. The presence in some of the rocks of aggregates of hornblende containing scattered fine-grained magnetite suggests that the hornblende was formed by the alteration of pyroxene.

The association of monzonite and granitic rocks with biotite-rich and hornblende-rich rocks in the Mau Monzonite requires some explanation. It is possible that the rocks represent mafic accumulative fractions complementary to the more siliceous members of the intrusive body. Alternatively, the mafic rocks are xenoliths, possibly related to the biotite pyroxenites in the Mount Suckling area which have undergone reaction with the monzonitic magma.

The chemical analyses of four specimens from the Mau Monzonite (Table 10, analyses 1-4) suggest that the rocks are calc-alkaline.

Suckling Granite

Derivation of name. Mount Suckling (9°40'S, 149°00'E).

Rock type. Medium and coarse-grained granite and adamellite.

Distribution. Two stocks 5 to 10 km south and southwest of Mount Suckling. Total area of outcrop about 20 km^2.

Type area. Stocks south of Mount Suckling.

Relationships. Intrudes ultramafic rocks of Papuan ultramafic belt and Goropu Metabasalt.

Age. Late Miocene. Hornblende from two samples (2577, 2578) yielded K-Ar ages of 9.43 and 10.8 m.y., whereas biotite from two samples (2576, 2577) gave K-Ar ages of 3.24 and 3.32 m.y. (Davies & Smith, 1974). The hornblende ages (early late Miocene) are probably a minimum estimate of the age of emplacement. The biotite ages (Pliocene) possibly reflect the time of cooling and commencement of argon accumulation caused by uplift of the Suckling-Dayman mountain block.

Petrography. The Suckling Granite commonly consists of zoned oligoclase (20-60%), perthitic potash feldspar (10-50%), quartz (10-20%), hornblende, biotite, and accessory sphene, apatite, and opaque oxides. The grain-size averages from 1 to 2 mm with some plagioclase grains up to 3 mm.

The westernmost stock of Suckling Granite intrudes ultramafic rocks; the eastern stock was emplaced between ultramafic rocks and the Mau Monzonite. The Suckling Granite and Mau Monzonite are probably related, but it is possible to map a boundary between the two.

A chemical analysis of the Suckling Granite is given in Table 10 (analysis 5). The analysis is typical of a calc-alkaline granite.

Bonua Porphyry

Derivation of name. Bonua River, which rises south of Mount Suckling and flows south.

Rock type. Porphyritic micromonzonite and microdiorite.

Distribution. East and west of Bonua River (9°55'S, 149°05'E). Other intrusive bodies tentatively correlated with the Bonua Porphyry are two necks in the headwaters of the Domara River (Kiliki Creek) and a small body northeast of the Kidana Range.

Type area. Bonua River (9°55'S, 149°05'E).

Relationships. Intrudes rocks of Papuan ultramafic belt and Kutu Volcanics.

Age. Inferred to be late Miocene.

TABLE 10. CHEMICAL ANALYSES, INTRUSIVE ROCKS IN MOUNT SUCKLING AREA

	1	2	3	4	5
SiO_2	50.9	67.5	67.7	69.4	69.2
TiO_2	1.06	0.39	0.43	0.36	0.31
Al_2O_3	12.8	15.2	15.2	15.0	15.4
Fe_2O_3	4.30	0.65	0.63	0.67	0.69
FeO	3.55	1.81	1.74	1.43	1.26
MnO	0.14	0.04	0.04	0.04	0.04
MgO	6.85	2.15	1.88	1.11	1.00
CaO	8.20	2.65	2.75	1.83	2.20
Na_2O	2.95	4.80	4.95	4.75	5.20
K_2O	4.05	3.25	3.15	3.60	3.65
P_2O_5	0.85	0.16	0.16	0.13	0.07
H_2O+	2.85	0.85	0.88	1.38	0.30
H_2O-	1.18	0.15	0.09	0.12	0.02
CO_2	0.18	0.05	0.09	0.07	0.30
Total	99.86	99.65	99.69	99.89	99.64

1 Basic Instrusive, boulder, Mau Monzonite, (9°41'S, 149°21'E). Analyst, A. Jorgensen, AMDL (1853B).

2 Granodiorite, boulder, Mau Monzonite, (9°41'S, 149°02'E). Analyst, A. Jorgensen, AMDL (1787).

3 Granodiorite, boulder, Mau Monzonite, (9°41'S, 149°02'E). Analyst, A. Jorgensen, AMDL (1786).

4 Granite porphyry, boulder, Mau Monzonite, (9°41'S, 149°02'E). Analyst, A. Jorgensen, AMDL (1790).

5 Granite, Suckling Granite, (9°43'S, 148°58'E). Analyst, A. Jorgensen, AMDL (2576).

TABLE 11. SHOSHONITIC INTRUSIVES

Name	*Locality*	*Field Occurrence*	*Rock Types*
Gabahusuhusu Syenite	Gabahusuhusu Cr. (10°25'S, 150°25'E)	Stock (24 km^2)	Syenite; subordinate monzonite and diorite, minor gabbro
Imudat Monzonite	Middle reaches of Imudat R. (10°14'S, 149°22'E)	Stock (15 km^2)	Monzonite; minor banakite dykes
Magavara Syenite	Middle reaches of Mase, Magavara, (10°08'S, 149°53'E) and Wamira Rs; isolated outcrops, N. coast; boulders in adjacent streams	Dykes and stocks	Biotite gabbro, monzonite, syenite, absarokite, banakite, sanidine-melanite porphyry
Sige Lele Gabbro	Lower reaches of Sige Lele R. (10°33'S, 150° 07'E)	Stock (15 km^2)	Biotite gabbro
Ulo Ulo Gabbro	Ulo Ulo mine (10°27'S, 150°19'E)	Stock (12 km^2)	Gabbro; subordinate monzonite
Watuti Gabbro	Watuti R. (10°33'S, 150°07'E)	Stock (12 km^2)	Biotite gabbro

Petrography. The Bonua Porphyry generally contains phenocrysts of andesine up to 3 mm across set in a finer (average grainsize 1 mm or less) groundmass of potash feldspar, hornblende (with relic cores of pyroxene in some cases), and biotite. Accessory quartz is present in some specimens.

The Bonua Porphyry is probably related to the Mau Monzonite and Suckling Granite which crop out immediately to the north.

SHOSHONITIC INTRUSIVE ROCKS SOUTHEAST OF MOUNT SUCKLING

Intrusive rocks crop out in the main ranges south of Goodenough Bay and in the southwest of Milne Bay. Dyke swarms of undersaturated porphyries were first noted in the mountains south of Goodenough Bay by Thompson & Fisher (1965), and syenite was recorded on the southern shore of Milne Bay by Davies (1967). During the regional mapping further outcrops were discovered; all are now recognized as members of the shoshonite association (Smith, 1972).

Most of the individual intrusives have been mapped and named separately, except in the Magavara River area. In the following account, descriptions of the individual intrusives (summarized in Table 11) precede the general account of the petrography and geochemistry of the shoshonitic intrusive rocks.

GABAHUSUHUSU SYENITE

Derivation of name. Gabahusuhusu Creek (10°25′S, 150°25′E).

Rock type. Mainly syenite with some monzonite, diorite, and minor gabbro.

Distribution. Forms a stock of about 24 km^2 centred on Gabahusuhusu Creek.

Type area. Gabahusuhusu Creek between 10°25′S, 150°25′E and 10°28′S, 150°25′E.

Relationships. Intrudes Kutu Volcanics.

Age. Middle Miocene, based on biotite and hornblende K-Ar dates of 11.1 and 16.0 m.y. respectively (Smith, 1972).

A small body of dunite is intruded by syenite in the lower part of Gabahusuhusu Creek at 10°11′S, 150°21′E (Davies, 1967). The dunite is probably related to the basalts of the Kutu Volcanics.

IMUDAT MONZONITE

Derivation of name. Imudat River (149°22′E).

Rock type. Monzonite with minor banakite.

Distribution. Stock about 15 km^2 in area in middle reaches of Imudat River.

Type area. Middle reaches of Imudat River (10°14′S, 149°28′E).

Relationships. Intrudes Kutu Volcanics.

Age. Middle Miocene, based on biotite K-Ar date of 12.5 m.y. (Smith, 1972).

MAGAVARA SYENITE

Derivation of name. Magavara River (10°00′S, 149°59′E).

Rock type. Dykes of absarokite, banakite, and sanidine-melanite porphyry; large dykes and small stocks of biotite gabbro, porphyritic syenite, and monzonite; and small stocks of syenite. Syenite is predominant.

Distribution. Middle reaches of Mase, Magavara, and Wamira Rivers, and isolated outcrops on coast between Bartle and Dogura Bays.

Type area. Middle reaches of Magavara River and eastern tributaries of Mase River between 149°50′E and 150°00′E.

Relationships. Intrudes Kutu Volcanics.

Age. Middle Miocene, based on hornblende K-Ar date of 16.5 m.y. (Smith, 1972).

SIGE LELE GABBRO

Derivation of name. Sige Lele River (10°33′S, 150°07′E).

Rock type. Gabbro.

Distribution. Small stock, about 15 km^2, in lower reaches of Sige Lele River.

Type area. Lower reaches of Sige Lele River upstream from junction with Sige Eueu River between 10°33′S, 150°07′E and 10°34′S, 150°07′E.

Relationships. Intrudes Kutu Volcanics and Modewa Beds.

Age. Middle Miocene, based on inferred relationship with other shoshonitic intrusives.

ULO ULO GABBRO

Derivation of name. Ulo Ulo mine (10°27′S, 150°19′E).

Rock type. Gabbro and subordinate monzonite.

Distribution. Small stock, about 12 km^2, centred on Ulo Ulo mine.

Type area. Ulo Ulo mine (10°27′S, 150°19′E).

Relationships. Intrudes Kutu Volcanics.

Age. Middle Miocene, based on inferred relationship with other shoshonitic intrusives in area.

WATUTI GABBRO

Derivation of name. Watuti River (10°33′S, 150°18′E).

Rock type. Gabbro and biotite pyroxenite.

Distribution. Stock, about 12 km^2 in area, in middle reaches of Watuti and Basadidi Rivers.

Type area. Watuti River, upstream from Mila village.

Relationships. Intrudes Kutu Volcanics.

Age. Middle Miocene, based on inferred relationship with other shoshonitic intrusives in area.

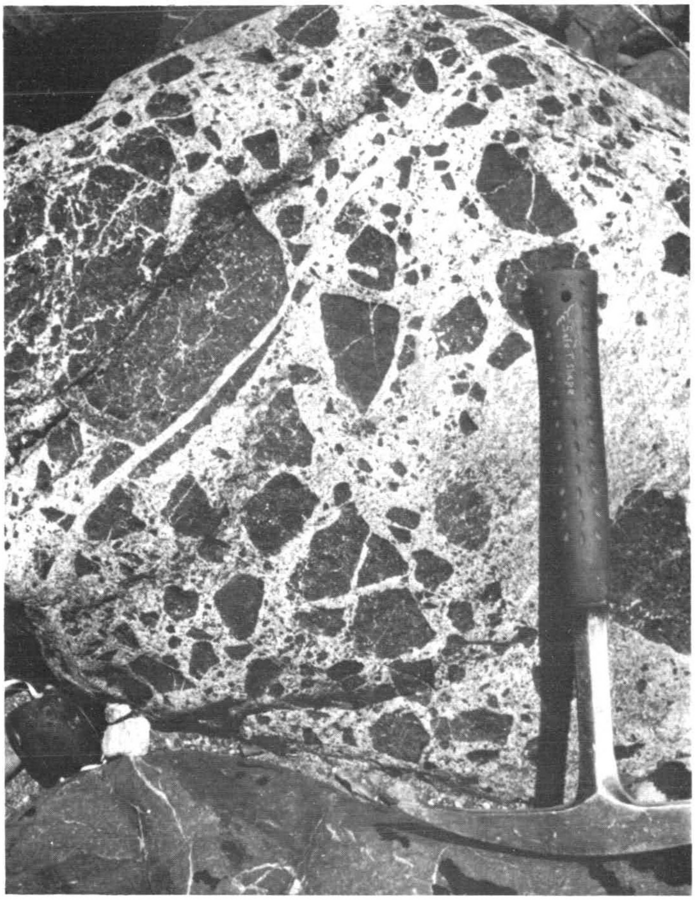

Fig. 25. Boulder of syenite containing inclusions of pyroxenite. Wamira River.

PETROGRAPHY AND CHEMISTRY OF THE SHOSHONITIC INTRUSIVES

Petrography

The shoshonitic intrusives in southeastern Papua have been divided into two petrographically and chemically distinct groups referred to as the near-saturated and the undersaturated groups (Smith, 1972). The Gabahusuhusu Creek, Imudat River, Sige Lele River, Ulo Ulo mine, and Watuti River stocks are near-saturated, and rare boulders are found in the Mase-Magavara-Wamira River south of Goodenough Bay. The undersaturated rocks occur mainly in this last area (Magavara Syenite), but are also minor associates of the near-saturated rocks southwest of Milne Bay. Massive outcrops of biotite-pyroxenite occur in the Basadidi River, where it is associated with gabbro of the Watuti River stock, and as inclusions in some of the coarser rock types of the Magavara Syenite (Fig. 25).

The *pyroxenite* consists of grains of clinopyroxene (up to 1.5 cm), smaller rounded grains of opaque oxides, and interstitial biotite, with minor olivine (usually partly altered) and apatite. The biotite content is variable and in some specimens equals that of clinopyroxene. The pyroxenite inclusions in the silica-rich rocks of the Magavara River area commonly contain partly altered interstitial potash feldspar and plagioclase; less commonly, hornblende, melanite, and sphene may be present. These minerals are characteristic of the host rocks and have probably been formed by reaction with the pyroxenite inclusions.

The *basic* rocks in the near-saturated group have an equigranular texture and their grain-size ranges from fine (0.1 mm average) to coarse (5 mm average); medium to fine-grained rocks predominate. They consist of plagioclase (An_{50-65}), clinopyroxene, opaque oxides, and varying amounts of biotite and olivine. Some specimens also contain interstitial potash feldspar and a fine-grained mesostasis. Rare secondary minerals include serpentine or iddingsite (after olivine), pale green amphibole (after clinopyroxene), zeolite (after feldspar), and epidote. The biotite content ranges from less than 1 percent to 20 percent. The basic rocks in the undersaturated group typically contain more biotite and potash feldspar than those of the near-saturated group, but apart from this the mineral assemblages are essentially the same.

The *monzonite* and *diorite* are typically medium-grained (1-2 mm average grainsize), and the undersaturated varieties are commonly porphyritic. They consist of perthitic potash feldspar and andesine (An_{35-45}), subordinate clinopyroxene, biotite, opaque oxides, and accessory apatite and sphene. Calcite and amphibole (after clinopyroxene) are common secondary minerals. Some of the monzonites of the near-saturated group contain quartz and primary light brown to green amphibole, which is a common secondary mineral in the quartz-free monzonites.

The monzonites of the undersaturated group commonly contain small phenocrysts of melanite, and zoned aegirine-augite or aegirine.

The *syenites* are medium to coarse-grained, and the undersaturated varieties are typically porphyritic. They consist of large plates and phenocrysts of potash feldspar accompanied by small crystals of mafic minerals and rare plagioclase. The mafic minerals in the near-saturated syenites are commonly aegirine-augite and pale green hornblende or rarely riebeckite. The undersaturated syenites contain melanite and biotite in addition to clinopyroxene and amphibole. The accessories in the syenites include opaque oxides, apatite, sphene, zircon, and interstitial fine-grained zeolite.

The *absarokites* of the undersaturated group are fine-grained rocks composed of phenocrysts of biotite, clinopyroxene, and opaque oxides set in a fine-grained groundmass consisting mainly of potash feldspar and plagioclase.

The *banakites* of both the near-saturated and the undersaturated groups are composed of phenocrysts of andesine-labradorite, clinopyroxene, hornblende, biotite, opaque oxides, and less commonly potash feldspar, set in a groundmass of potash feldspar and plagioclase with minor clinopyroxene, hornblende, opaque oxides, biotite, and apatite. Secondary calcite, epidote, and zeolite may also be present.

The *sanidine-melanite porphyry* (Fig. 26) is undersaturated. It is composed of phenocrysts of sanidine, commonly up to 3 cm or more in length, and crystals of melanite, up to 4 mm across, set in a fine-grained groundmass of potash feldspar and plagioclase with minor clinopyroxene, hornblende, and biotite, and secondary calcite, zeolite, epidote, and chlorite. Clinopyroxene, hornblende, biotite, opaque oxides, and cancrinite also occur as phenocrysts in some specimens.

Chemistry

The composition of the shoshonitic intrusives in southeastern Papua have been discussed by Smith (1972). The distribution of the major elements is outlined below, and representative analyses are presented in Table 12.

The near-saturated rocks (Table 12, analyses 4-13) show regular major element trends. The range of SiO_2 is wide (40-65%); Al_2O_3 is variable (10-18%); FeO, Fe_2O_3, MgO, TiO_2, and CaO show a negative correlation with SiO_2; and Na_2O and K_2O show a positive correlation with SiO_2. The alkali content, especially K_2O, is high and TiO_2 (1.11-0.25%) is low. On an FMA diagram (Fig. 27) the analyses plot in a flat trend comparable to the volcanic calc-alkaline series.

In the undersaturated suite (Table 12, analyses 14-20) SiO_2 ranges from 45 to 60 percent; Al_2O_3 (14-21%) is typically higher, whereas MgO is lower than in the near-saturated suite. CaO is lower in the undersaturated rocks, especially in the more basic members of the suite, and K_2O is higher than in the near-saturated rocks (Fig. 28). The undersaturated suite is characterized by wide variations in the major elements; normatively the rocks are all undersaturated (nepheline, 1.98-12.56%).

The pyroxenites (Table 12, analyses 1-3) show large variations in some oxides over a narrow range of SiO_2 (42.4-44.7%). Fe_2O_3 (3.8-7.75%), K_2O (0.35-3.4%), and P_2O_5 (0.09-1.56%) show significant variations. As a group the pyroxenites are characterized by low SiO_2 and Al_2O_3 and high total iron, MgO, and CaO.

TABLE 12. REPRESENTATIVE CHEMICAL ANALYSES, SHOSHONITIC INTRUSIVES

	1	2	3	4	5	6	7	8	9	10
SiO_2	42.40	44.50	44.70	40.90	43.60	45.30	50.50	53.70	54.90	55.90
TiO_2	1.39	1.27	0.77	1.03	1.11	1.02	0.80	0.57	0.73	6.67
Al_2O_3	6.25	8.10	3.40	16.20	12.10	9.70	17.50	18.20	14.80	15.70
Fe_2O_3	6.95	3.80	7.75	8.75	9.75	6.65	4.75	3.05	4.05	4.95
FeO	6.70	6.25	6.90	5.75	6.55	6.60	4.25	3.60	3.95	2.85
MnO	0.23	0.20	0.24	0.15	0.19	0.21	0.15	0.15	0.14	0.15
MgO	15.00	13.60	15.40	7.75	8.10	11.50	8.40	7.30	7.20	6.60
CaO	16.70	15.60	18.60	16.50	13.90	15.80	3.95	2.70	5.35	3.30
Na_2O	0.42	0.54	0.39	0.87	1.62	1.14	3.85	3.90	3.25	3.80
K_2O	1.76	3.40	0.35	0.18	0.90	1.39	3.30	4.60	3.50	4.90
P_2O_5	1.28	1.56	0.09	0.30	0.54	0.32	0.60	0.41	0.52	0.51
H_2O+	0.32	0.46	0.34	1.20	0.11	0.44	1.38	0.90	1.05	0.29
H_2O-	0.16	0.16	0.28	0.20	0.11	0.16	0.20	0.38	0.27	0.19
CO_2	0.10	0.10	0.20	0.30	0.20	0.10	0.20	0.20	0.03	0.03
Total	99.66	99.54	99.41	100.08	99.78	100.33	99.83	99.66	99.74	100.11

All chemical analyses are taken from Smith (1972).

1 Pyroxenite, boulder, Basadidi River, (10°32′S, 150°18′E). (2109).
2 Pyroxenite, boulder, Wamira River, (10°12′S, 150°01′E). (3096).
3 Pyroxenite, boulder, Basadidi River, (10°32′S, 150°18′E). (2107).
4 Gabbro, Watuti River, (10°31′S, 150°16′E). Near-saturated group. (5012).
5 Basalt, boulder, Basadidi River, (10°32′S, 150°18′E). Near-saturated group. (2104).
6 Gabbro, Ulo Ulo mine, (10°27′S, 150°20′E). Near-saturated group. (5002).
7 Gabbro, boulder, Watuti River, (10°31′S, 150°16′E). Near-saturated group. (4282B).
8 Monzonite, Watuti River, (10°31′S, 150°12′E). Near-saturated group. (4307).
9 Monzonite, Imudat River, (10°14′S, 149°28′E). Near-saturated group. (3292A).
10 Monzonite, boulder, Imudat River, (10°13′S, 149°28′E). Near-saturated group. (3133).

TABLE 12 (CONT.)

	11	12	13	14	15	16	17	18	19	20
SiO_2	58.10	60.41	64.20	45.2	46.30	49.20	53.30	53.90	57.96	59.70
TiO_2	0.58	0.52	0.25	1.02	1.08	0.67	0.42	0.33	0.27	0.28
Al_2O_3	17.80	15.22	17.30	14.60	18.20	15.50	18.80	19.10	20.91	19.70
Fe_2O_3	3.20	4.88	0.85	6.85	4.25	2.90	2.95	2.35	3.02	1.24
FeO	2.10	n.d.	1.50	6.30	5.35	4.55	1.81	1.36	n.d.	0.78
MnO	0.20	0.09	0.03	0.22	0.14	0.15	0.19	0.14	0.15	0.06
MgO	2.90	3.38	0.95	6.20	4.75	3.95	0.86	0.85	0.68	0.29
CaO	5.30	4.93	1.40	9.35	8.55	7.50	6.00	4.15	5.10	2.20
Na_2O	4.80	4.25	7.25	2.35	3.25	3.25	3.40	2.20	4.92	2.50
K_2O	3.50	5.76	5.55	4.55	2.90	7.20	7.35	10.50	7.92	10.90
P_2O_5	0.80	0.61	0.10	0.14	0.08	0.10	0.09	0.09	0.07	0.04
H_2O+	0.10	n.d.	0.20	2.38	4.05	1.69	4.20	2.65	n.d.	1.37
H_2O-	0.12	n.d.	0.14	0.24	0.35	0.15	0.15	0.51	n.d.	0.13
CO_2	0.05	n.d.	0.03	0.30	0.80	2.80	0.50	1.30	n.d.	0.05
Total	99.55	100.05	99.75	99.70	100.05	99.71	100.02	99.43	100.60	99.24

11 Monzonite, boulder, Gabahusuhusu Creek, (10°27′S, 150°25′E). Near-saturated group. (2225).
12 Syenite, Gabahusuhusu Creek, (10°27′S, 150°25′E). Near-saturated group. (2221).
13 Syenite, boulder, Gabahusuhusu Creek, (10°27′S, 150°25′E). Near-saturated group (2226).
14 Gabbro, boulder, Watuti River, (10°31′S, 150°16′E). Undersaturated group. (4322).
15 Gabbro, Watuti River, (10°32′S, 150°16′E). Undersaturated group. (5024).
16 Basalt, dyke, Muse River, (10°09′S, 149°53′E). Undersaturated group. (5089).
17 Sanidine porphyry, boulder, Wegulani River, (10°20′S, 150°01′E). Undersaturated group (2234).
18 Porphyritic monzonite, dyke, Muse River, (10°07′S, 149°53′E). Undersaturated group (5097).
19 Sanidine porphyry, boulder, Wegulani River, (10°17′S, 150°02′E). Undersaturated group. (5045A).
20 Syenite, boulder, Goodenough Bay, (10°04′S, 149°54′E). Undersaturated group. (3291A).

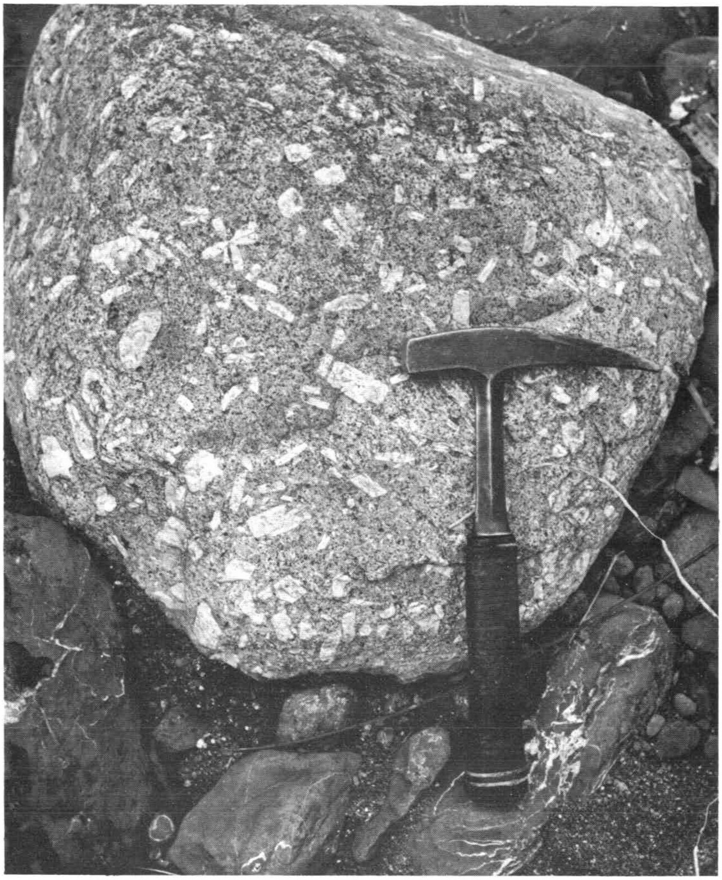

Fig. 26. Sanidine melanite porphyry. Wamira River.

DYKES

Dykes are associated with most of the intrusives and with some of the volcanic rocks. The swarms of dykes southwest of Milne Bay are similar to the Fife Bay Volcanics and are thought to represent feeder dykes. The dyke swarms in the Watuti River and its tributaries are probably related to the Watuti Gabbro.

Papp & Nason-Jones (1930) recorded the presence of dykes in the Dabi Volcanics on Cape Vogel peninsula. No dykes were seen during the regional mapping, but cobbles collected immediately west of Castle Hill (10°40′S, 149°51′E) are petrographically and chemically distinct from the Dabi Volcanics and probably represent a younger (Pliocene?) series of dykes. The cobbles consist of porphyritic rocks containing clinopyroxene and plagioclase, and are comparable to the calc-alkaline lavas of Mount Victory and Mount Trafalgar.

STRUCTURE

The main structural trends in southeastern Papua are southeast, parallel to the trend of the axial mountain ranges. In the west the rocks of the Papuan ultramafic belt represent a former gently dipping thrust sheet with a root zone to the north under Upper Cainozoic sedimentary and volcanic rocks. The thrust sheet has been arched and ruptured by faulting and now forms a series of block mountains (the Sibium-Didana, Keman, and Awariobo Ranges) separated by depressions (e.g. the Musa valley). The underthrust part of the thrust couple

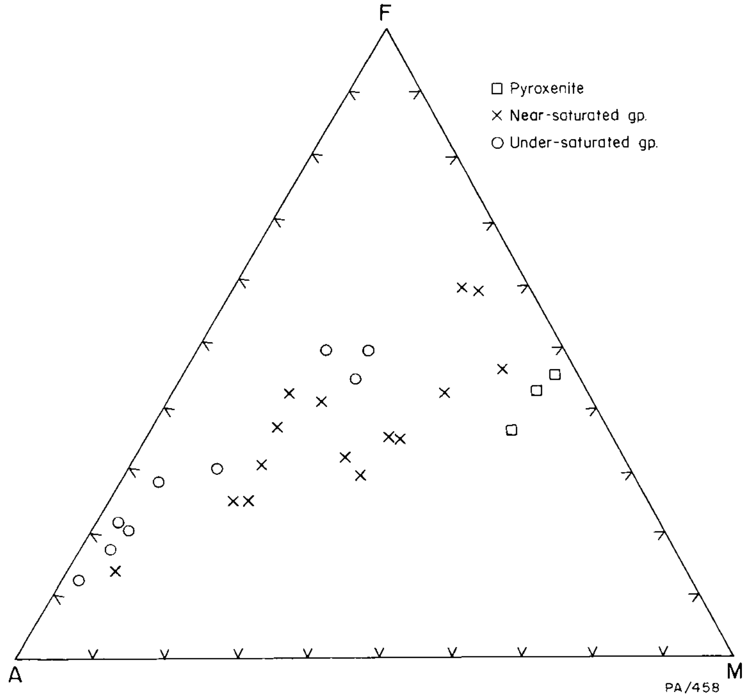

Fig. 27. FMA ($FeO+0.9Fe_2O_3$, MgO, Na_2O+K_2O) diagram for the shoshonitic intrusives. Data from Smith (1972).

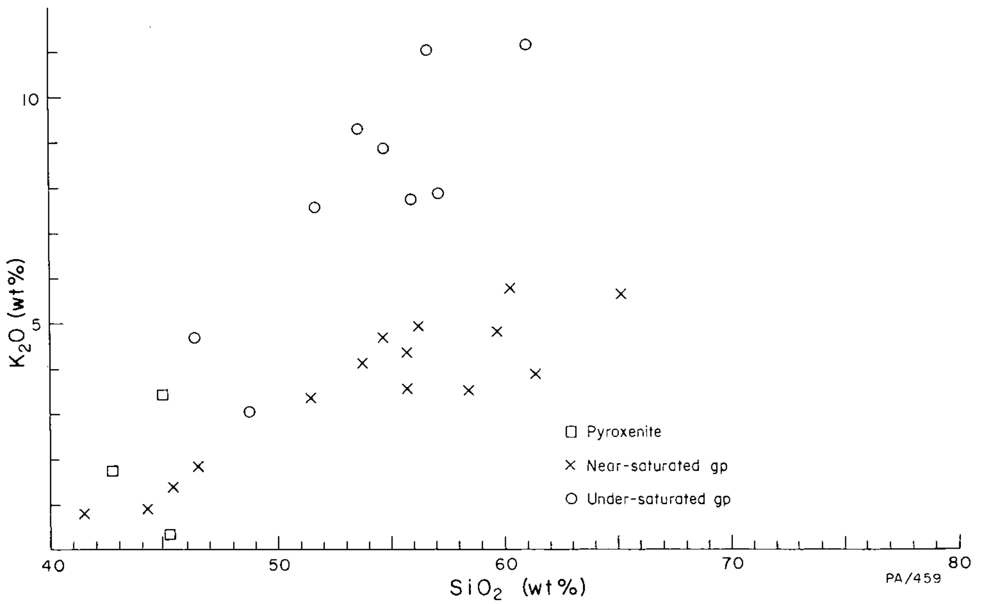

Fig. 28. K_2O/SiO_2 plot of the shoshonitic intrusives.

is now represented by rocks forming the Suckling-Dayman massif. Here the thrust plane has been arched upward by later vertical movements; uplift at the western end of the massif is greater than in the east with the result that the western end is more deeply dissected. Parts of the arched thrust plane are preserved in the east as the surface of the Dayman Dome.

The southeastern ranges consist of fault-bounded blocks tilted by Late Cainozoic movements. Altitude and relief are greatest in the northwest and decrease to the southeast. The topography of parts of the south coast, particularly the Suau coast between Bona Bona Island and Samarai, is mainly the result of subsidence. Milne Bay is a graben, bounded by faults to north and south. A low area extends west from Milne Bay to Mullins Harbour and separates the main ranges from the southeastern mountain block centred on Mount Suau (10°3′, 150°15′E).

Folding

Some of the plutonic rocks of the Papuan ultramafic belt show cumulus crystal layering which, according to classical concepts, must have developed at a near-horizontal attitude. The present attitude of the layering varies considerably even in adjacent outcrops, probably owing to disruption by block-faulting rather than folding. Less commonly the dip is consistent over a true thickness of 1 to 2 km of section, as for example in Sivai Creek (9°33′S, 148°47′E) where the dip ranges from 65° to 80° toward the southeast, but is not concordant with the adjacent boundaries of the ultramafic rocks. From this evidence, and because of the prevalence of strong jointing, particularly in the gabbros, it is concluded that the rocks of the Papuan ultramafic belt have responded to stress by fracturing and minor faulting rather than by folding.

The Cretaceous and Eocene basalts which form the axial ranges are characteristically poorly bedded and massive. Bedding planes have only rarely been recognized and no fold structures have been mapped. The presence of gently dipping limestone horizons, such as the Touiawaira Limestone Member of the Kutu Volcanics, suggests that there has been little folding in the basalts, and they too are thought to have responded to tectonic stress mainly by fracture. An exception is found in the Dayman Dome, where schistosity in the metabasalt has been folded into a broad partly closed anticline. This is evidence for broad folding on a regional scale as in the Mesozoic metamorphic rocks in the D'Entrecasteaux Islands to the north (Davies & Ives, 1965). The schistosity is thought to parallel former bedding but may be locally discordant.

The Cretaceous and Eocene sediments south of the main ranges (Godaguina Beds, Juliade Limestone, and Badila Beds) are commonly moderately to steeply dipping and are thought to be broadly folded. Highly contorted folding in the limestone-chert sequence on Juliade Island is probably due to post-depositional slumping.

The Miocene and Pliocene sediments of the Cape Vogel Basin and the Pliocene sediments of the Musa valley have been tilted, folded, and faulted. The regional structure on Cape Vogel peninsula is anticlinal and the Oligocene lavas in the north-central part of the peninsula are thought to be a partly faulted anticlinal core.

The Upper Cainozoic volcanics are not obviously folded, but have probably been tilted during faulting like some of the Quaternary sedimentary rocks in the Musa valley.

Faulting

Major faults dominate the basement geology of southeastern Papua; they can be classified into three types: (i) thrust faults; (ii) east-west dip-slip faults, possibly with some transcurrent movement; and (iii) northerly and northeasterly trending dip-slip faults. The east-west, northerly, and northeasterly faults post-date the thrust faults.

The Mai'iu Fault (Fig. 2) is a former thrust fault which defines the northern front of the Suckling-Dayman massif and extends to within about 10 km of Goodenough Bay. The same thrust plane is exposed immediately south and southwest of Mount Suckling and the surface of the Dayman Dome probably consists of a series of former slip planes parallel to the main thrust. The thrust plane was probably initially nearly horizontal and has probably been arched upward and locally faulted by later vertical movements. In the field the thrust plane is marked by an increase in the grade of metamorphism in the rocks below the thrust. In places there are remnants of the ultramafic rocks which formed the upper plate in the thrust zone. Some of the remnants have been severely altered to opaline silica/magnesite breccias which pseudomorph the textures of the original brecciated ultramafic rock (e.g. 6 km north of Mount Masasoru at 9°50′S, 149°36′E).

The east-west dip-slip faults provide the major control on the present structure and topography. There is topographic evidence of vertical displacement of thousands of metres on these faults, but no evidence of transcurrent movement. The main faults in this category are the series of faults that run through the Keveri valley near the southern margin of the Tufi Sheet area (Keveri Fault Zone), the fault that bounds the Dayman Dome on the south side (Onuan Fault), those that bound the Musa valley (Silimidi and Bereruma Faults), the Gwoira Fault along the northern front of Gwoira Range with its interpreted extension offshore on the southern side of Goodenough Bay, and several faults on the eastern edge of the Managalase Plateau. Smaller faults have been recognized south of Milne Bay in the main ranges south of Goodenough Bay. Milne Bay is a graben defined by faults to the north and south. South of the Goropu Mountains and Milne Bay the trend of the faults ranges from west to northwest.

The northerly and northeasterly trending faults are marked by vertical displacements of the present land surface, and thus are probably younger than the east-west faults. Few of the faults coincide with rock unit boundaries and most do not extend over great strike distances. These features indicate that they may be relatively superficial features; on the other hand the presence of strong northerly to northeasterly trending aeromagnetic lineaments (CGG, 1971) suggests that these faults may in fact reflect a major structural trend.

DISCUSSION AND SYNTHESIS

Eastern Papua is a part of the complex zone of interaction between the Pacific and Australian plates and the geology of the area can therefore be interpreted in terms of plate boundary processes. The geology and plate tectonics of eastern Papua have been discussed by Davies & Smith (1971). The present discussion is concerned with the development of southeastern Papua as a geological entity and is essentially an expanded geological history in which the stratigraphic units described in earlier sections are placed within the scheme of tectonic events in the area.

The two major tectonic events in southeastern Papua are an Early Tertiary episode dominated by thrust movements and a period of Late Tertiary and Quaternary uplift. The basement (Papuan ultramafic belt, Goropu Metabasalt, and Kutu Volcanics) is oceanic crust which has been caught up in a thrust zone between two crustal plates. Subsequent uplift of this segment provided a source of sediment for the sedimentary basins flanking the rising landmass; the supply of sediment was augmented by contemporaneous terrestrial volcanic activity.

Davies (1971) has presented evidence to show that the Papuan ultramafic belt represents an overthrust segment of oceanic crust and upper mantle. In southeast Papua, where the southeastern end of the complex crops out, the evidence supports Davies' hypothesis. In southeast Papua rocks of the Papuan ultramafic belt are widely distributed along fault zones and as fault-bounded blocks. The basal contact is exposed only on Mount Suckling, where the contact with the underlying Goropu Metabasalt dips at 55° to the southeast. The regional gravity evidence suggests that the ultramafic rocks to the south of Mount Suckling are large surface blocks with no continuity at depth (J. S. Milsom, pers. comm.). The distribution of the ultramafic rocks suggests that the ultramafic thrust sheet, which originally covered the present position of Mount Suckling, was subsequently broken up during uplift. Much of the ultramafic material shed from the rising mountains was incorporated in the ultramafic breccias (Sivai Breccia Member and Ibau Breccia) which crop out in the Musa valley to the west of Mount Suckling.

If the thrust hypothesis is accepted the Goropu Metabasalt must represent the underthrust member of the plate couple. The relatively high tectonic pressures and significant increase in temperature accompanying the thrust probably account for the metamorphism of the Goropu Metabasalt. The following observed features lend support to this hypothesis:

1. The dynamic nature of the metamorphism as demonstrated by the cataclastic texture of many of the schists in the Goropu Metabasalt.

2. The zonation of metamorphic mineral assemblages with greenschist assemblages near

faulted contacts in the north, pumpellyite-bearing greenschist away from faulted contacts, and lower grade assemblages (prehnite-pumpellyite facies) south of the Dayman Dome and Biman dip-slopes.

3. The occurrence of high-pressure/high-temperature minerals especially in the north; lawsonite is found in the Mount Suckling area, aragonite north and east of Mount Dayman, and glaucophane in scattered localities generally adjacent to faulted contacts.

4. The overall morphology of the Dayman Dome and the apparent parallelism of foliation with the surface of the dome. The surface of the dome and the Biman dip-slopes to the east of Mount Dayman probably represent surfaces parallel to the original thrust plane.

Evidence for a thrust surface is not found southeast of the Biman dip-slopes. It is possible that the thrust surface dips southeastward and that the basalts to the southeast are part of the overlying plate, although ultramafic rocks are virtually absent in this area. To the south of the Biman dip-slopes metamorphosed basalts apparently grade southward into unmetamorphosed basalts. The Late Cretaceous fossils collected ät scattered localities in this area indicate that the unmetamorphosed basalts (Kutu Volcanics) are of the same age as the Goropu Metabasalt. It is more likely, therefore, that the northern part of the Kutu Volcanics represents part of the lower plate of the thrust couple not directly affected by thrusting and that an eastward continuation of the thrust plane should be looked for to the north of the southeast Papuan mainland.

To the south and southeast the Kutu Volcanics are of middle Eocene age, although they are indistinguishable from the Upper Cretaceous basalts. Fossil data are sparse and scattered, and it is not known whether the basalts were erupted continuously during the period from the Late Cretaceous to the middle Eocene, or whether there was a hiätus during the Palaeocene and early Eocene. South of Mount Dayman the Cretaceous metabasalts are separated from middle Eocene basalts by a major fault (Onuan Fault) that passes to the southeast into other faults and lineaments along the axis of the main range. It is possible, therefore, that there was a major structural break on the sea floor between the areas occupied by the Upper Cretaceous and middle Eocene basalts, which were subsequently faulted into juxtaposition during the thrusting associated with the formation of the Papuan ultramafic belt. Alternatively, it is possible that the middle Eocene basalts were erupted as new sea floor during the separation of Papua from Queensland.

The age of the thrust movements that resulted in the formation of the Papuan ultramafic belt is not known. Davies (1971) considers that the thrusting took place in the earlier Eocene on the basis of a 55 m.y. K-Ar age of a tonalite intruding the Papuan ultramafic belt in the west, and a 52 m.y. age from a hornblende granulite in the thrust zone. Chemical analyses of these tonalites show them to be tholeiitic in character, as are the enclosing basalts, and it is not inconsistent for them to have been a part of the oceanic crust before thrusting. The 52 m.y. date from a hornblende granulite remains as evidence for an early Eocene event.

If the thrusting took place during the early Eocene the eruption of the middle Eocene basalts in southeast Papua may perhaps have been linked with the opening of the Coral Sea. On the other hand, if it were of late Eocene age the juxtaposition of the Cretaceous and Eocene sea floor on oposite sides of a zone of crustal shortening would be explained.

The fossils in the Cretaceous and Eocene sediments in southeastern Papua (Badila Beds, Juliade Limestone, and sediments associated with the submarine volcanics) with one exception all indicate a deep-water marine environment. The exception is the Touiawaira Limestone Member of the Kutu Volcanics, which contains shallow-water benthonic foraminifera, and was presumably deposited on a local shelf on the sea floor. The Padowa, Debolina, and Modewa River Beds in the Milne Bay area contain late Oligocene to middle Miocene benthonic foraminifera, and it appears that by this time the effects of the late Tertiary/Quaternary episode of uplift were beginning to be felt in southeast Papua. The tuffaceous content of the sediments indicates that there was some contemporaneous volcanic activity. Shallow-water Miocene limestones are found in the Keveri valley area (Adau Limestone) and on Cape Vogel peninsula (Castle Hill Limestone).

The oldest sediments derived from a terrestial source area are probably the lower Miocene rocks (Woruka Siltstone) resting unconformably on the submarine Dabi Volcanics in the northern part of Cape Vogel peninsula. The Dabi Volcanics represent the volcanic basement on which the Cape Vogel sedimentary sequence was laid down. A single K-Ar whole rock age from the Dabi Volcanics indicates that they are of middle Oligocene age.

Terrigenous sedimentation in the Cape Vogel Basin began in the middle Miocene, and presumably coincided with uplift of the main ranges to the south. Uplift and active erosion of the main range provided an abundant supply of clastic material which was laid down to form the Ruaba Sandstone. During the Pliocene, when the supply of sediment appears to have been reduced, the Awaitapu Claystone was deposited. Near the end of this period the basement underlying the Cape Vogel peninsula area began to rise and an island probably existed from time to time in the central part of what is now the peninsula. Reefs developed at the eastern end of the island, but the volume of sediment brought down from the mountains prevented the development of reefs at the western end. With the gradual rise of the Cape Vogel anticline, reef development extended to the east.

Sedimentation continued in a paralic environment along the southern margin of the basin, where the Gwoira Conglomerate and Uga Sandstone were laid down. The paralic sediments are coarser and more poorly sorted than the sediments offshore. The Gwoira Conglomerate was presumably deposited in an embayment, whereas the Uga Sandstone was probably laid down in a series of deltas which coalesced to form a narrow strip along the coast.

The sedimentary record in southeastern Papua indicates that uplift of the ocean floor began in middle or late Oligocene time and that a landmass was being rapidly eroded by the late Miocene. The presence of raised areas of subdued topography interpreted as remnants of erosion surfaces (Smith, 1970; Smith & Simpson, 1972) implies that there have been at least two stages of uplift, and the sedimentary succession in the Cape Vogel Basin suggests a period of relative tectonic calm during the Pliocene when the Awaitapu Claystone was laid down. Raised erosion surfaces and coral limestone benches provide evidence of at least 1500 m of uplift since the Pliocene, and the presence of uplifted and incised Quaternary sediments in the Musa valley and along the north coast shows that uplift continued into very recent times.

The early phase of uplift in the Milne Bay area was accompanied by the intrusion of shoshonitic stocks and dykes. The intrusion of shoshonitic rocks during this period of block-faulting and vertical movement is consistent with Joplin's (1968) suggestion that shoshonitic rocks are associated with periods of crustal stabilization. The shoshonitic volcanics along the south coast (Fife Bay and Cloudy Bay Volcanics) and some of those in the Musa valley area are probably also associated with this early phase of uplift. The suggestion that shoshonitic rocks follow the eruption of calc-alkaline rocks of the island arc association (e.g. Jakes & White, 1969; and Gill, 1970) is not consistent with their mode of occurrence in southeast Papua.

The hornblende K-Ar ages (9-10 m.y.) of the granitic rocks in the Mount Suckling area show that they were also emplaced at an early stage in the uplift of the area. The biotite K-Ar ages of 3 m.y. obtained on these granitic rocks probably date the main stage of uplift of the Suckling-Dayman massif.

The Pliocene to Holocene volcanic rocks are predominantly calc-alkaline, although there are Pliocene and Quaternary shoshonitic lavas in the Musa valley area. The calc-alkaline rocks are high-potassium andean types (Jakes & White, 1972) typical of those found on continental margins rather than of island-arc type calc-alkaline rocks. In southeastern Papua an appreciable thickness of crust was probably developed at a minor plate boundary without passing through an island-arc stage of development.

Present day seismicity in southeastern Papua is confined to a weak shallow seismic lineament trending eastward along the north coast (Denham, 1969). Despite continuing volcanic activity there is no evidence for a Benioff zone, although there is an apparent K_2O polarity (cf. Dickinson, 1968) from the calc-alkaline volcanoes on the north coast southward to contemporaneous K_2O-rich shoshonitic lavas in the Musa valley area.

Southeastern Papua appears to provide an example of the formation of an appreciable thickness of crust at a plate boundary. Overriding of adjacent plates of oceanic crust initially caused a crustal thickening which appears to have provided the conditions necessary for the generation of magma and uplift.

ECONOMIC GEOLOGY

Gold and a little platinum are the only minerals which have been mined commercially in southeastern Papua. In recent years prospecting has been concentrated mainly on the possibility of finding nickel and chromium in the Papuan ultramafic belt, and copper in association with the intrusive rocks, particularly those in the Milne Bay area. The search continues for offshore petroleum, and the hydroelectric potential of the Musa valley is also being investigated.

Gold and Platinum

Alluvial gold has been produced in the Keveri valley/Suzy Creek area in the west, and alluvial gold and a little lode gold and platinum in the area south of Milne Bay.

Alluvial gold has been won from the western end of the Keveri valley (9°53′S, 148°42′E), and to a lesser extent from the Domara River and from Suzy Creek 17 km west-southwest of the Keveri diggings. The Keveri Goldfield was proclaimed in 1904 and enlarged in 1919 (Macnab, 1967). Total production was 133.56 kg of fine gold, most of which was won between 1904 and the mid-1920s. The most productive area was the lower Wavera River and its tributary Umu Creek, immediately above Apaewa village. According to Macnab some of the workings were in elevated beds of alluvium overlying the Domara River Conglomerate. Macnab has suggested that the gold mineralization may be related to the pyritic Mio-Pliocene porphyries, but the only sample of porphyry analysed was found to be barren. Gold and silver (3 g/tonne Au, 20 g/tonne Ag) occur with chalcopyrite in a mineralized shear zone on the Domara River.

Alluvial gold has been won from the Magavara River (10°10′S, 149°57′E) (Thompson & Fisher, 1965), and a little alluvial gold is at present being won by villagers in the middle reaches of the Imudat River (10°14′S, 149°28′E); both occurrences are probably related to the middle Miocene intrusives.

Alluvial gold and platinum have been worked intermittently since the turn of the century in the area south of Milne Bay between 150°15′E and 150°30′E. Total production is about 500 kg of gold and about 6 kg of platinum. The records are apparently incomplete, and information given here is from Nye & Fisher (1954, pp. 7, 9, 14). The first recorded production was 30 kg of alluvial gold in 1905-06; total production to June 1909 was 385 kg, and to June 1926, 400 kg. In 1926 mining ceased, but in 1930 or 1931 attempts were made to work some of the gold-bearing reefs and applications were made for dredging leases. In 1938-39 three small mines produced 30 kg of gold. The most successful was the Rough Ridge mine, which produced 22 kg from 1320 tonnes of ore; others were the June, Jumbo, and Louise. The Louise mine was apparently at Ulo Ulo (Oura Oura), but the other two have not been relocated.

Alluvial platinum was discovered in 1931 and production was at a peak from 1933 to 1935. Official records suggest that the platinum discovery was not a rich one; total production for Papua in the period from 1933 to 1941 was only 6 kg, and some of this probably came from the Yodda goldfield near Kokoda in northeast Papua.

Thompson (1962, p. 32) has noted that gold and platinum were mined from gravels along the Sagarai River, Gabahusuhusu Creek, and Debolina Creek (platinum only). He has suggested that the platinum was shed from small bodies of peridotite, and that at Debolina it has been concentrated in the stream bed, where moderately dipping Miocene sediments form natural riffles (Thompson & Fisher, 1965, p. 129). The gold and platinum mineralization is probably related to the upper Oligocene to middle Miocene potash-rich intrusives, some of which include an ultramafic fraction, although this type of intrusive is not known in the Debolina Creek catchment area. Gold and minor copper mineralization occurs in one of these intrusives at Ulo Ulo and has been investigated by Anaconda Australia Inc. (Phillips & Yates, 1968). The Watuti and Sige Lele Gabbros contain some disseminated pyrite and chalcopyrite, and the East Cape Gabbro some pyrite.

Nickel

Nickel sulphides occur in rocks of the Papuan ultramafic belt in the Musa valley area and in the area to the south. Concentrations of nickel occur in the residual soils on the peridotites.

The search for workable deposits of lateritic nickel has been unsuccessful, probably because erosion has kept pace with chemical weathering and prevented the development of thick residual soils. Exploration for lateritic nickel has been concentrated in three areas: Wowo Gap,

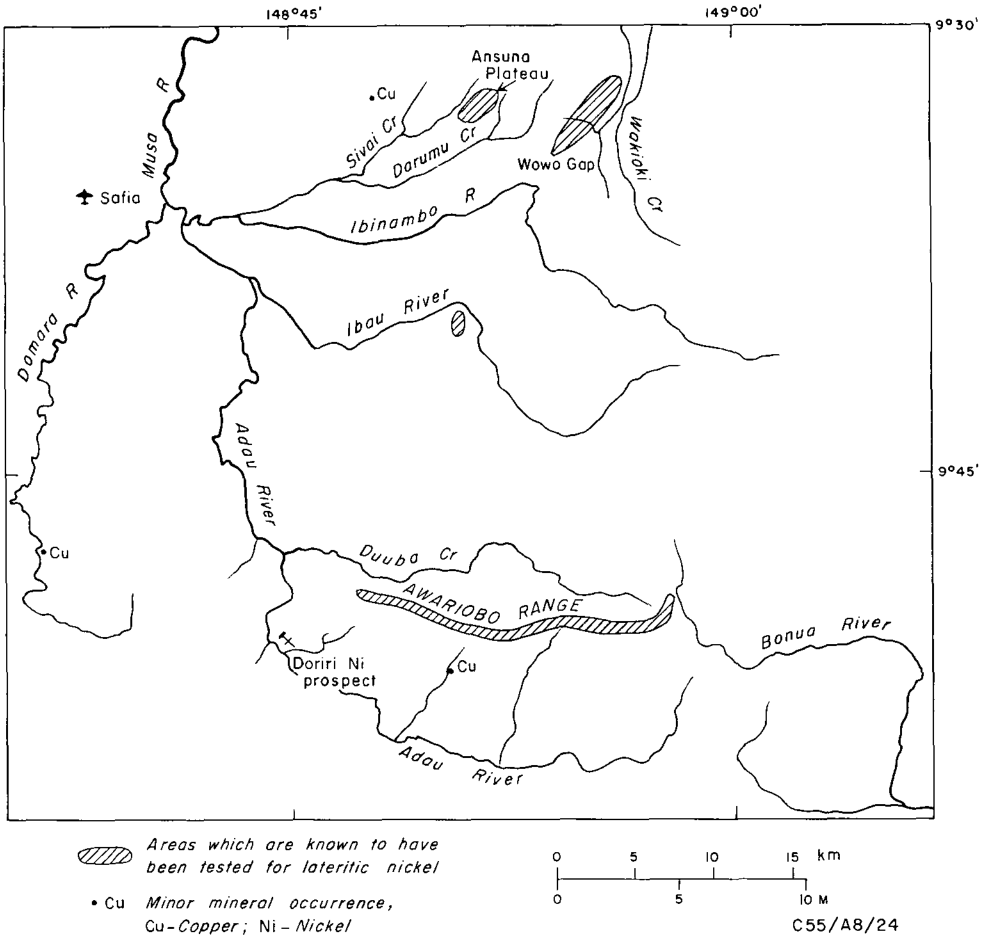

Fig. 29. Lateritic nickel test areas.

the Ibau River, and the Awariobo Range (Fig. 29). The first two areas were tested by hand-augering, and by drilling through the soil into the underlying zone of fractured rock in the hope of finding nickel concentrations in the fractures; in the third area, which was tested by auger holes and pits, the soils were generaly found to be shallow (Davies & Smith, 1974).

Nickel sulphide mineralization has been discovered on Doriri Creek (9°51'S, 148°45'E) (Figs 30, 31), a tributary of the Adau River (Davies, 1969). Residual soil sampling and costeaning by CRAE (Klinger, 1967) defined two sulphide-rich lenses, measuring 75 m by 7.5 m and 27 m by 7 m, with average grades up to 2.43 percent Ni. Later drilling by INSEL is understod to have shown that the mineralized lenses pinch out at shallow depth. The host rock is sheared and hydrothermally altered peridotite enclosed in gabbro; some of the gabbro and peridotite has a cumulus texture.

The mineralization in Doriri Creek is younger than the shearing, though the sulphides may have been concentrated in this zone before shearing. Davies (1969) has suggested that the mineralization may be related to Mio-Pliocene porphyries, some of which are very pyritic (Macnab, 1967). The nickel sulphide minerals include pentlandite, with marginal alteration to bravoite and possible inclusions of awaruite (Ni_2Fe) in one sample, and violarite [$(NiFe)_3S_4$] in another (Davies, 1969). Magnetite is the predominant opaque mineral (30-50% of all opaque minerals) in the mineralized specimens. A trace of chalcopyrite is present in some specimens.

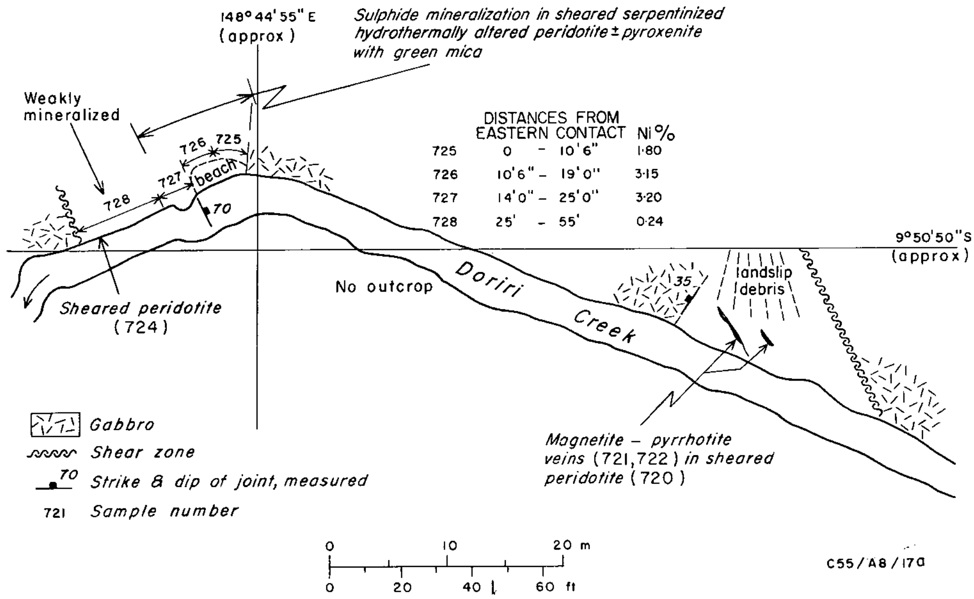

Fig. 30. Doriri Creek nickel prospect before costeaning.

Macnab (1967, sample 6669.1241) found a boulder in the headwaters of the Domara River, 10 km west of the Doriri Creek prospect, which assayed 34 percent Ni; the main sulphides in the sample are heazlewoodite (Ni_3S_2) and pentlandite [$(FeNi)_9S_8$] (Appendix 3 by J. A. MacDonald, in Davies, 1969). Mining companies subsequently found several small (e.g. 0.15 x 3 m) nickel and copper-rich sulphide lenses in the same area.

Copper

Smith & Green (1961), Macnab (1967), and Davies (1969) have recorded chalcopyrite-pyrite mineralization in the headwaters of the Foasi, Domara, and Adau Rivers south of the Musa valley. Some of the mineralization is in shear zones in the Kutu Volcanics and some in shear zones in gabbro of the Papuan ultramafic belt. A little chalcopyrite is associated with the nickel sulphide mineralization in Doriri Creek. Native copper fills vesicles in Eocene basalt at the eastern end of the Keveri valley (9°54′S, 148°48′E; Macnab, 1967).

Disseminated chalcopyrite was noted in a websterite boulder on the north side of the High Didana Range, in an outcrop of Goropu Metabasalt in Novai Creek (9°35′S, 149°03′E), and in basalt of Korala Volcanics south of Baborobo (9°22′S, 148°31′E). A shear zone in the Korala Volcanics in Girewa Creek contains chalcopyrite with some silver, lead, and zinc mineralization (Cu, 1250; Pb, 700; Zn, 870 ppm; Ag 48 g/tonne; Girewa Creek is a tributary of the Pongani River at 9°05′S, 148°30′E).

Stanley (1916) and Hamilton (1963) briefly discuss copper mineralization 3 to 5 km inland from Pem Mission on the northern side of Cape Vogel peninsula. Both concluded that it is minor contact mineralization, probably related to Plio-Pleistocene dykes.

In the southeastern ranges and in the Milne Bay area sulphide mineralization is associated with the middle Miocene intrusives. In the Mase and Magavara Rivers (10°10′S, 149°53′-58′E) there is an extensive zone of disseminated pyrite associated with a major shear. The mineralization occurs in both the country rock (Kutu Volcanics) and in the intrusives, to which it is probably related. In the Imudat River, disseminated pyrite is associated with monzonite and trachyandesite of the Imudat Monzonite.

Copper carbonates and red copper oxide have been reported from near the Ulo Ulo mine south of Milne Bay, and minor disseminated copper and iron sulphides are associated with gabbro in the Watuti (10°33′S, 150°18′E) and Sige Lele (10°33′S, 150°07′E) Rivers. Iron sulphides are associated with the East Cape Gabbro north of Milne Bay.

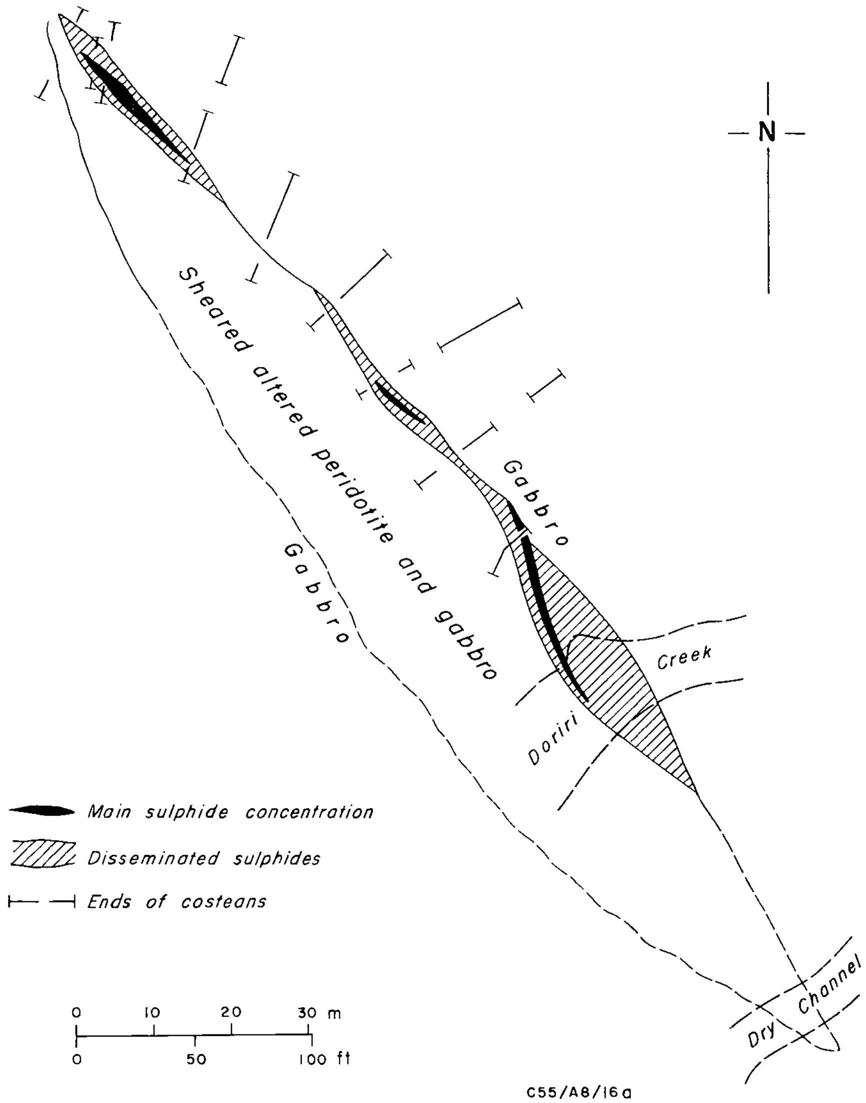

Fig. 31. Doriri Creek nickel prospect (after Klingner, 1967).

Chromium

Although chromite is disseminated throughout the olivine-rich ultramafic rocks in the Papuan ultramafic belt, no concentrations of chromite have been found except at one locality in the headwaters of the Bonua River (9°52′S, 148°59′E), where there are several veinlets of chromite from 1 to 3 cm thick.

Chrome mica occurs in altered basalt in a tributary of Arobora Creek (9°54′S, 148°53′E).

Phosphate

The limestones and other sediments in the Badila Beds in the Nigo Nigo River (10°20′S, 149°54′E) contain some phosphate. Seventeen samples collected by J. E. Thompson from the Nigo Nigo and Wegulani Rivers were below economic grade; the highest values recorded were 3.5 to 5.5 percent P_2O_5 in a calcareous glauconitic sandstone.

Petroleum

Offshore areas east of Milne Bay and around Cape Nelson are currently held under permit for petroleum exploration. Aeromagnetic surveys indicate an east-west basin north of Cape Nelson, from which a tongue of sediments 2100 m thick extends into Collingwood Bay

(CGG, 1971). A marine geophysical survey by a petroleum exploration company is planned.

Previously, interest was centred on the Cape Vogel peninsula, where there are several springs from which an unidentified gas (CO_2?) is bubbling. Stanley (1916) noted that the presence of folded Upper Tertiary sediments and the occurrence of a brine spring indicated that the area might be prospective for oil. Vogel (Papua) Petroleum Co. drilled three shallow exploratory wells at the site of the former village of Kukuia (9°41′S, 149°47′E) in the period from January 1927 to August 1928. The first two wells were drilled at the same site to depths of 54 and 310.5 m. Gas and traces of light violet oil were recorded in the deeper well at depths between 67 and 188 m. Papp & Nason-Jones (1930) recorded bubbles of odourless, colourless, inflammable gas escaping at the well site in 1928, and concluded that this was probably a mixture of methane and nitrogen. They tested drill cuttings, but were unable to verify the reported occurrence of oil. In the third well, which was sited 150 m southwest of the first two wells and which reached a depth of 66 m, gas was reported at 45 m. Paterson & Kicinski (1956) reviewed the geology and petroleum prospects of the Cape Vogel Basin, but there was no further exploration until the area was taken up by General Exploration Co. Australasia Pty Ltd in 1967 (Bickel, 1969).

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The people of Alotau, Raba Raba, and the Agaun Mission gave considerable assistance to the survey, for which we are grateful. Particular thanks are due to Mr Bruce Evans and Mr John Arthurson, helicopter pilots, whose contribution to the early fieldwork was invaluable.

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APPENDIX

FORAMINIFERA AND AGE OF SAMPLES FROM SOUTHEASTERN PAPUA

by

D. J. Belford

SUMMARY

Foraminiferal faunas of Late Cretaceous, Eocene, late Oligocene, Miocene, Pliocent, and Pleistocene ages, identified mainly from random thin sections, are described. One Late Cretaceous sample, and some other samples ranging from middle Miocene to possibly Quaternary in age, yielded free specimens of foraminifera, often including a rich planktonic fauna.

The Late Cretaceous faunas consist almost wholly of planktonic species. The Eocene rocks contain both planktonic and 'larger' foraminifera, and the late Oligocene to Miocene limestones are dated by means of 'larger' foraminifera. Ages given for younger beds are based on both planktonic and smaller benthonic foraminifera.

Representative foraminiferal specimens and rock types are illustrated (Pls 1-23, which follow p. 86).

INTRODUCTION

The samples discussed in this Report have been collected over a period of some 15 years by many geologists, mainly attached to field parties of the Bureau of Mineral Resources; some were collected by geologists of the Land Research Division of the Commonwealth Scientific and Industrial Research Organization. A list of the samples studied is included, and localities are shown on the geological map.

Many of the collections have been studied previously and the results presented in unpublished Records of the Bureau of Mineral Resources, or included in Reports dealing with particular areas. This paper attempts to coordinate all the palaeontological information, and to consider the relationship of the different rock types of different areas. Some conclusions are necessarily tentative because of the nature of the material, and also because of the widely spaced samples collected during what have been either reconnaissance or regional surveys of different areas. Much palaeontological work remains to be done in this area, but detailed geological mapping and close sampling of any available rock sequences will be necessary to determine the stratigraphic relationship of the different rock types and faunas observed.

ACKNOWLEDGEMENTS

I wish to thank Mr S. F. Schuyleman for discussions on the identification of Eocene planktonic foraminifera in thin section, and Dr J. G. Binnekamp and Dr C. G. Adams for checking the identification of some of the 'larger' foraminifera.

UPPER CRETACEOUS

Samples: 6552-0177; 6552-0178; 6552-0179; 6552-0181; 6552-0282; 6552-0283; 6852-2242; 6852-2505; 6852-2507; 6852-2584; 6852-3233; 6852-4322; 6852-5765F; MH64.

The Upper Cretaceous sedimentary rocks include sheared and recrystallized calcareous siltstones and limestones, tuffaceous rocks, and hard dark grey siltstones.

Sample 6852-2584 is a sheared red calcareous siltstone containing very poorly preserved specimens and fragments of *Globotruncana*. Definite specific identifications cannot be made, but a single-keeled specimen possibly referable to *Globotruncana elevata* (Brotzen) is present; the sample most probably is Maestrichtian in age. From the Papuan ultramafic belt farther west the four samples 6552-0177, 6552-0178, 6522-0179, and 6552-0181 are still more strongly sheared, and only 0177 and 0178 contain fragments which are interpreted as globotruncanid. A lithologically similar sample, somewhat more calcareous, from the Dilava River area, Central District, Papua (6869-1534), contains rare well preserved specimens and abundant fragments of *Globotruncana* spp. Single-keeled specimens again possibly referable to *G. elevata* occur, and also small double-keeled specimens of the *G. arca* (Cushman) type. This sample also is considered to be Maestrichtian in age.

Sample 6852-2507 is conglomeratic, consisting of pebbles of sheared calcareous siltstone with *Globotruncana* spp.; fine-grained red limestone with *Globotruncana* spp; and radiolarian limestone. The specimens of *Globotruncana* are poorly preserved, but many may be referable to the *G. elevata* and *G. contusa* (Cushman) groups; the age is again Maestrichtian.

Sample 6852-2242 is a fine-grained dark grey tuffaceous rock containing very rare *Globotruncana* spp., common *Racemiguembelina* sp., or *Planoglobulina* sp., *Rugoglobigerina* sp., *Hedbergella*? spp., *Globigerinelloides* sp., *Heterohelix* sp., and rare *Bolivinitella*? sp.; this sample is also considered to be Maestrichtian in age. Sample 6852-4322 is lithologically similar, but the fauna is less diverse, consisting only of rare, very small *Heterohelix* sp. and *Hedbergella* sp., and small specimens of *Globotruncana* spp.

Samples of fine-grained recrystallized limestone are 6552-0282, 6552-0283, 6852-2505, 6852-3233, and 6852-5765F. In two (6552-0283 and 6852-5765F), small irregular patches of greenish calcareous siltstone remain, forming foci of recrystallization. The fauna consists mainly of specimens and fragments of *Globotruncana* spp. with rare *Rugoglobigerina*? sp. The specimens of *Globotruncana* are referable to the *G. elevata, G. arca,* and ?*G. gansseri* Bolli groups, and the samples are regarded as Maestrichtian in age.

One sample of hard dark grey siltstone, MH64, has been examined and has yielded abundant but poorly preserved free specimens of planktonic foraminifera. Species occurring are *Globotruncana arca* (Cushman), *G. elevata* (Brotzen), *Pseudotextularia elegans* (Rzehak), *Planoglobulina glabrata* (Cushman), *Heterohelix striata* (Ehrenberg), *Bolivinoides draco draco* (Marsson), *Marssonella oxycona* (Reuss), and species of *Dorothia, Nodosaria, Bulimina, Anomalinoides,* and *Ammodicus.* This sample is also of Maestrichtian age.

EOCENE

A fine-grained limestone, red, green, or grey in colour, usually strongly calcite-veined and containing abundant planktonic foraminifera, is the most common rock type among the samples of Eocene age. Rocks containing abundant radiolaria, or sponge spicules, or with a mixed foraminiferal-radiolarian fauna, are also referred to the Eocene. As has been pointed out by Glaessner (1959a, b), a sequence similar to that in eastern Papua occurs in New Caledonia (Routhier, 1953; Tissot & Noesmoen, 1958); the New Caledonian sequence includes beds containing radiolaria and sponge spicules, very similar to those from eastern Papua. Routhier (1953) gave a Palaeocene to early Eocene age to the New Caledonian rocks containing *Globigerina* and *Globorotalia,* based on specific identifications of the planktonic foraminifera suggested by J. Cuvillier after examination of the specimens in thin section only. Tissot & Noesmoen (1958) dated the radiolarian cherts and associated limestone with *Globigerina* and *Globorotalia* as early to middle Eocene, followed by similar middle to upper Eocene beds.

Routhier (1953) noted that definite determinations of planktonic foraminifera are not possible with thin section examination only;

Luterbacher (1964) also noted that an exact specific determination of *Globorotalia* in thin section is possible only exceptionally, but that approximate age determinations are often possible. In the eastern Papuan samples most of the specimens have a rounded rather than a keeled margin, that is, there are more 'globigerinid' than 'globorotaliid' types. This feature was also noted by Routhier in material from New Caledonia. Keeled, compressed, and angulo-conical globorotaliids do occur in the eastern Papuan samples, and many specimens have been figured (see Pls 6, 7); both groups become extinct at the top of the middle Eocene. Other illustrated forms are considered to be closely comparable to *Truncorotaloides* (*T.*) *rohri* Bronnimann & Bermudez and *T.* (*T.*) *topilensis* (Cushman) (see Pls 5-7). A thick-walled coarsely perforated globigerinid with a mamillated test surface also occurs rarely; the final chamber covers the umbilical area of the earlier whorls, and multiple sutural apertures are present. These specimens are closely comparable to the *Globigerinatheka index* (Finlay) group. Some samples contain fragments which may be referable to *Hantkenina* sp. (Pl. 7, fig. 11), but this identification cannot be taken as definite. The range given for *Truncorotaloides rohri* by Blow (1969) is from within zone P. 10 to the top of P. 14. *T. topilensis* ranges from within zone P. 11 to within P. 18. The genus *Hantkenina* does not occur before the middle Eocene.

On the available evidence a middle Eocene age is given to these fine-grained limestones. The proportionate rarity of conical keeled globorotaliid species in the fauna possibly is connected with the decline and disappearance of this group in the middle Eocene. However, this age determination must be regarded as approximate, in the absence of any definite specific identifications.

Samples of fine-grained limestones suggested to be of middle Eocene age are:

6552-0955	6852-2297	6852-4247B	MH51
6552-0956	6852-2298	6852-4822F	MH52
6552-1318	6852-2300	6852-5047	MH63
6552-1319	6852-2301	6852-5053	MH75
6552-1748	6852-2302	6852-5055	P346
6552-1853A	6852-3023		P363
6852-2071	6852-3155		P400
6852-2137	6852-3315B		229
6852-2204	6852-4024		248A
6852-2230	6852-4062A		274A
6852-2248	6852-4063		334
6852-2263	6852-4063A		
6852-2269	6852-4064		
	6852-4068		
	6852-4069		

In some areas these fine-grained limestones are closely associated with foraminiferal limestone containing *Discocyclina* spp. and *Nummulites* spp. and the two types may grade laterally into each other.

In addition to the fine-grained planktonic foraminiferal limestones of Eocene age, samples representing many other rock types are also considered to be Eocene, although the evidence in many cases is not conclusive. Rocks containing abundant radiolaria and sponge spicules are included in this section, but their stratigraphical relationship to the fine-grained foraminiferal limestones is not known. Samples are discussed individually and those for which an Eocene age is tentative are indicated.

P1274. Fine-grained recrystallized tuffaceous limestone with abundant poorly preserved planktonic foraminifera, mainly Globigerinidae, with rare keeled angulo-conical *Truncorotaloides* (*Morozovella*) spp.; regarded as middle Eocene.

P1275. Tuffaceous limestone with abundant poorly preserved recrystallized planktonic foraminifera, including *Truncorotaloides* (*Morozovella*) spp. and one specimen possibly of *Hantkenina* sp.

P1277. Fine-grained grey to green slightly sheared limestone with small planktonic foraminifera, usually fragmentary, but including *Truncorotaloides* (*Morozovella*) spp. and other specimens possibly referable to *T.* (*T.*) *rohri*.

P1278. Red volcanic ash? with abundant fragmentary or recrystallized planktonic foraminifera including *Truncorotaloides* (*Morozovella*) spp., and possible *T.* (*T.*) *rohri*.

6552-0696. Red tuffaceous siltstone containing abundant planktonic foraminifera, poorly preserved, often fragmentary and recrystallized. The fauna includes keeled, compressed, and angulo-conical specimens (*Morozovella* spp. and *Planorotalites* spp.), spinose Globigerinidae and some rare specimens of possible *Globotruncana* sp. This sample is considered to be Eocene (middle? Eocene), with possible reworked Late Cretaceous. Sample 6552-0695 is similar, and contains mainly fragments of Globigerinidae, with rare *Truncorotaloides* (*Morozovella*) spp. and is also considered to be Eocene (middle? Eocene).

6552-0950. Grey calcareous tuff? with common small planktonic foraminifera, mainly Globigerinidae, but also with some rare *Truncorotaloides* (*Morozovella*) spp.; considered to be most probably Eocene.

6525-1335. Red fine-grained limestone with abundant planktonic foraminifera, broken fragments of which form the rock matrix. Preservation is poor, but possible *T.* (*T.*) *rohri* types occur, and also thick-walled mamillate specimens similar to the *Globigerinatheka index* (Finlay) group. A definite age for this sample cannot be determined but it is considered to be most probably Eocene.

6852-2045. Green recrystallized limestone, containing abundant foraminifera, often fragmentary, but including specimens of *Truncorotaloides* (*Morozovella*) spp., specimens possibly referable to *Truncorotaloides* (*T.*) *rohri*, and also a spinose fragment possibly from a specimen of *Hantkenina*. Other samples from the same general locality as this sample contain Eocene larger foraminifera.

6852-2231. Green fine-grained limestone, strongly calcite-veined, containing abundant foraminifera, usually small or fragmentary, but with some rare specimens of *Truncorotaloides* (*Morozovella*) spp. and also fragments of a thick-walled globigerinid, possibly referable to the *Globigerinatheka index* group; considered to be probably middle Eocene.

6852-2249. Green or grey fine-grained recrystallized limestone, strongly calcite-veined, containing abundant foraminiferal fragments some of which appear to be from specimens of *Truncorotaloides* (*Morozovella*) spp.; radiolaria also occur. No definite age can be given to this sample on the basis of the observed fauna; it is closely associated with sample 6852-2248, a fine-grained red limestone included in the previous section, which contains a fauna considered to be of middle Eocene age.

6852-2573. A red fine-grained sheared calcareous siltstone, with extensive calcite veining, containing mainly foraminiferal fragments with no definitely indentifiable specimens being observed. Some specimens appear to be referable to *Truncorotaloides* (*Morozovella*) spp. and the sample is regarded as doubtfully of Eocene age.

6852-3223. This sample of sheared tuffaceous siltstone containing only poorly preserved, recrystallized and usually fragmentary planktonic foraminifera is possibly Eocene, but no definite age determination can be made. Rare specimens of probable *T.* (*Morozovella*) spp. and also possible specimens of *T.* (*Truncorotaloides*) sp. are present.

6852-4248. A grey fine-grained planktonic foraminiferal limestone, not in situ. It contains abundant small Globigerinidae, including finely hispid and spinose specimens. No definite age can be given; this sample is from an area (locality 60, Samarai) where other samples considered to be Eocene were collected.

6852-4336B. Two rock types are represented in this sample. One is a green to grey fine-grained limestone, strongly calcite-veined, and containing abundant foraminiferal fragments, rare complete specimens, and also abundant radiolaria, preserved only as simple spheres with no internal structure evident. The foraminifera (small globigerinids and truncorotaliids—?*Morozovella* spp., *Planorotalites* spp.) are thought to indicate an Eocene age, but this determination is tentative. The second rock is a red fine-grained limestone also strongly calcite-veined and including crystals of a ferromagnesian mineral. Rare foraminifera occur and also rare possible radiolaria; no age can be given to this part of the sample on the basis of the observed fauna.

6852-4336A. Fine-grained grey limestone with foraminiferal fragments and also radiolaria occuring as simple spheres. There is no direct indication of age and it is placed in the Eocene only by association with the previous sample.

6852-4822D. Red crystallized limestone containing abundant inclusions of dark red silty limestone. Abundant planktonic foraminifera occur, mainly Globigerinidae, and although several specimens show a 'spinose' wall, and other specimens resembling *Truncorotaloides* (*T.*) *rohri* occur, no definite determination of Eocene age can be made. This sample is associated with a sample of fine-grained limestone of suggested middle Eocene age.

Two samples, 6852-2264 and 6852-4247A, are associated with fine-grained limestones containing abundant planktonic foraminifera, and considered to be middle Eocene in age. Each of these samples is a fine-grained grey silty limestone, containing rare to abundant small planktonic foraminifera, mainly Globigerinidae, similar to those in sample 6552-0950, and common to abundant radiolaria. These samples are given an Eocene age on the basis of their field relationships; Glaessner (1952) recorded foraminifera and radiolaria in beds of Eocene age in the Port Moresby area.

Sample 6852-2240 is lithologically and faunally identical with the two samples just discussed and although it is not directly associated with any definite Eocene beds comes from an area of Eocene sediments and is also assigned an Eocene age.

Following on from these samples an Eocene age is given to a group of samples containing rare to abundant small thin-walled planktonic foraminifera, mainly Globigerinidae, and also radiolaria, or radiolaria only. These samples, which include tuffaceous rocks and dark grey silty limestones, are: 345; 6552-0948; 6552-1313; 6552-1314; 6852-2283 (radiolaria only); 6852-2326 (radiolaria only); 6852-2610 (radiolaria only); 6852-2610 (radiolaria only); 6852-3069; 6852-3070; 6852-3132; 6852-3222 (radiolaria only); 6852-3330D; 6852-4256; 6852-5035; 6852-5963; 6852-6022B.

Sample 6852-3326E is a dark grey calcareous siltstone with abundant planktonic foraminifera (globigerinids and truncorotaliids), often small and fragmentary but including some keeled angulo-conical and biconvex specimens, and also some specimens similar to *Truncorotaloides* (*T.*) *rohri*. Associated with this sample is sample 6852-3326D, which is a fine-grained grey limestone also with abundant small planktonic foraminifera and rare larger specimens. No definite age determination can be made on the basis of the observed fauna in this sample, but because of its close association with and lithological similarity to sample 6852-3326E it is also referred to the Eocene. By comparison with sample 6852-3326D an Eocene age is given to two samples, 6852-2177 and 6852-3067, which contain a similar fauna. Sample 6852-2177 is a fine-grained grey limestone with abundant small planktonic foraminifera, mainly Globigerinidae, and rare larger specimens; sample 6852-3067 is a fine-grained limestone, with some calcite veining, which also contains abundant small planktonic foraminifera and rare large thick-walled specimens, the fauna comprising mainly Globigerinidae with some small specimens of Heterohelicidae.

Sample 6852-3346 is a fine-grained recrystallized grey limestone consisting wholly of specimens and fragments of planktonic foraminifera and rare indeterminable benthonic foraminifera. The planktonic foraminifera include *Truncorotaloides* (*T.*) *rohri* types, other angulate truncorotaliids and also numerous specimens of a thick-walled globigerinid with a mamillate surface and multiple apertures comparable to the *Globigerinatheka index* (Finlay) group. An Eocene age is given to this sample. Sample 6852-3323A is from a similar limestone, more strongly recrystallized and with less well preserved planktonic foraminifera, which are, however, comparable to those in sample 6852-3346; sample 6852-3323A is also regarded as Eocene in age. Another lithologically and faunally similar sample referred to the Eocene is 6852-5070. Sample P1279 is a fine-grained limestone containing some tuffaceous material and with abundant planktonic foraminifera, including rare fragments of a large thick-walled globigerinid, rare small and indeterminable benthonic foraminifera, numerous algal fragments, and very rare fish teeth; this sample is also placed in the Eocene. Sample 6552-1337 is a recrystallized limestone lithologically similar to sample 6852-3346, and contains numerous specimens of planktonic foraminifera, mainly Globigerinidae, set in a fine-grained matrix of foraminiferal fragments; it is also regarded as Eocene.

From the suggested Eocene age for sample 6852-3323A, an Eocene age is also given to the associated sample 6852-3323C, a fine-grained silty limestone with rare small thin-walled planktonic foraminifera, mainly Globigerinidae, rare radiolaria, and abundant sponge spicules. Other similar fine-grained limestones containing planktonic foraminifera, sponge spicules, and in some cases also radiolaria are also assigned an Eocene age; these are: 207A; 6852-2122; 6852-2303; 6852-2308; 6852-3293; 6852-5043; 6952-3434.

The remaining Eocene samples contain larger foraminifera, mainly *Discocyclina* spp., and also have common algal fragments, coral, bryozoal, and molluscan remains.

6852-2039 is a skeletal calcarenite with foraminiferal and algal specimens and fragments set in a comminuted matrix of organic material. The foraminifera are *Discocyclina* sp., *Gypsina* sp., *Heterostegina* sp., *Nummulites* sp., and *Amphistegina* sp. The *Discocyclina* sp. is the same inflated and narrowly pillared species as in sample 6852-4343A; the *Nummulites* sp., of which only one specimen is present, is large and inflated with strongly developed pillars.

6852-2042 is lithologically similar to sample 6852-2039 and contains the same species of *Discocyclina,* with one specimen being more strongly pillared. Sample 6852-2043 and 6852-2248 are also foraminiferal-algal skeletal calcarenites with the same fauna. Sample 6852-2203 consists mainly of algal limestone with considerable calcite veining; the foraminiferal fauna consists of specimens and fragments of *Discocyclina* sp., with rare *Gypsina* sp., *Operculina* sp., ?*Textularia* sp., and planktonic foraminifera (Globigerinidae).

6852-4343A is a foraminiferal, bryozoal, and algal limestone with Bryozoa forming most of the rock. The foraminifera include *Discocyclina* sp., *Operculina* sp., *Amphistegina* sp., *Gypsina* sp., rare Miliolidae, and ?*Textularia* sp. The *Discocyclina* sp. is a large inflated species with numerous narrow and discontinuous pillars; no specific identification has been made.

UPPER OLIGOCENE TO MIDDLE MIOCENE

(Tertiary *e* and *f*)

A series of samples, including skeletal calcarenites, limestone breccias, tuffaceous limestones, and also some tuffs, are referred to this stratigraphical interval. Most of the samples are considered to be upper *e* in age, but the fauna is generally poorly preserved and sparse, and some of these samples could well be of lower *e* age. A few samples are considered to be definite lower *e*, and others are most probably lower *f*.

The first group to be considered consists of skeletal calcarenites or limestone breccias containing foraminifera, algae, Bryozoa, corals, echinoid spines, and molluscan fragments. Many of the limestones may consist of recemented worn pebbles, the outline of which can be clearly observed in thin section; it is possible, however, that the structure is due to the development of stylolites. Other samples consist of broken foraminiferal and other organic fragments set in a finely comminuted organic matrix. There is no indication of any significant time interval between the deposition of the limestone and subsequent weathering and recementation; both the limestone fragments and individual specimens may have been subjected to rolling by wave action, or they have been transported for some distance before recementation. The fauna recorded from these samples includes *Lepidocyclina* (*N.*) cf. *ferreroi* Provale, *L.* (*N.*) cf. *japonica* (Yabe), *L.* (*E.*) sp., *Miogypsina* spp., *Spiroclypeus margaritatus* (Schlumberger), *Cycloclypeus* sp., *Heterostegina* sp., *Austrotrillina* cf. *striata* Todd & Post, *Cycloclypeus* (*Katacycloclypeus*) cf. *martini* van der Vlerk, and *Planorbulinella* sp. Reworked Eocene specimens may occur, mainly *Discocyclina* sp., *Nummulites* sp., and possibly *Spiroclypeus* sp. Samples of this type are: P377; P383; P385; LB109; MH69A; 6552-0702 6552-1328; 6552-1329; 6852-2113; 6852-2114; 6852-3120; 6852-3154; 6852-5044; P1247; P1276.

Samples 6852-3154 and 6852-2113 contain very rare small specimens of *Halkyardia* sp., which occur together with *Lepidocyclina* (*Nephrolepidina*) sp. and *Heterostegina* sp. These samples are considered to be from a lower *e* limestone; no specific identification of the specimens of *Halkyardia* can be made, but there is no evidence to indicate that they have been reworked from older beds. Clarke & Blow (1969) showed *Halkyardia* spp. ranging into the base of lower *e*, and Adams (1965) showed the genus ranging into the basal part of *d*; in a later paper, Adams (1970) extended the range of the genus into the lower *e*. In sample 6852-2113, *Eulepidina* could be represented by small fragments of axial sections showing a thick equatorial layer with sinuous septa; small specimens of *Nephrolepidina* sp. also occur in the sample (Pl. 16, figs 1-3). Eames, Banner, Blow, Clarke, & Smout (1962, p. 295) stated that sinuous septa were characteristic of *Eulepidina*, but Cole (1963, p. 37) did not agree with this view. J. G. Binnekamp (pers. comm.) has found specimens of *Nephrolepidina* from limestones on New Britain which show sinuous septa in axial section. Sample 6852-3154 is most probably of lower *e* age, but may be of *d* age. Only one species of *Lepidocyclina* appears to be present in the sample (Pl. 16, figs 4, 5). These specimens resemble *Lepidocyclina* (*Nephrolepidina*) *augusticamera* Cole, except that the nucleoconch is somewhat more 'eulepidine' than in Cole's specimens. In material from New Britain, J. G. Binnekamp (pers comm.) has found a complete gradation from 'eulepidine' to 'nephrolepidine' nucleoconchs in specimens referred to *L.* (*N.*) *augusticamera;* the 'eulepidine' specimens closely resemble some illustrations of *L.* (*E.*) *formosa* Schlumberger [= *L.* (*E.*) *ephippioides* (Jones & Chapman)]. *L.* (*N.*) *augusticamera* was described from doubtful *d* and lower *e* beds, and in New Britain occurs with *L.* (*N.*) *isolepidinoides* van der Vlerk in samples regarded as basal lower *e* in age.

Sample 6852-5044 contains *Eulepidina* sp. and specimens of *Spiroclypeus* referred to *S. margaritatus* (Schlumberger). This sample is Tertiary *e* in age, but no more precise determination is possible. Sample P383 contains abundant *Lepidocyclina* spp; one horizontal section (Pl. 15, fig. 3) closely resembles *L.* (*N.*) *japonica* Yabe, which is known from upper *e* to lower *f*. A heavily pillared species of *Miogypsina* in this sample, and also in sample LB109, has been observed only in random vertical sections. Sample 6552-1412 contains *Lepidocyclina* (?*N.*) sp., *Miogypsina* sp., *Amphistegina* sp., *Acervulina* sp., *Carpenteria* sp. or *Sporadotrema* sp., and *Planorbulinella* sp., and is of upper *e* or lower *f* age.

Sample 6852-3120 contains reworked Eocene specimens of *Discocyclina* sp., *Nummulites* sp., *Heterostegina* sp., and *Spiroclypeus* cf. *vermicularis* Tan, with small specimens of *Lepidocyclina* (*Nephrolepidina* and possibly *Eulepidina*) spp. and one specimen of *Austrotrillina* cf. *striata* Todd & Post, which indicate an *e* (upper? *e*) age.

Sample 6552-0702 contains *Cycloclypeus* (*Katacycloclypeus*) cf. *martini* van der Vlerk, small *Miogypsina* sp., *Lepidocyclina* (*N.*) sp., *Carpenteria* sp. (fragments), *Planorobulinella* sp., and rare planktonic foraminifera, and is referred to the lower *f*. The *Planorbulinella* sp. of this fauna is the same form as that recorded by Paterson & Kicinski (1956) as *Linderina* sp. indet., in a fauna referred to the lower *f*, although its occurrence in rocks of *e* age was also mentioned. Coleman (1963) recorded specimens with thickened laminated layers as *Planorbulinella* cf. *P. larvata* (Parker & Jones), ranging from lowermost Miocene to Holocene. Sample LB142 contains *Cycloclypeus* (*Katacycloclypeus*) sp., fragments of *Lepidocyclina* sp., *Heterostegina* sp., ?*Amphistegina* sp., *Planorbulinella* sp., and indeterminable smaller foraminifera. Sample LB142B has abundant foraminifera and algae, the foraminifera including *Lepidocyclina* spp., *Cycloclypeus* (?*Katacycloclypeus*) sp., *Amphistegina* sp., *Planorbulinella* sp., and indeterminable smaller foraminifera. These two samples are also considered to be lower *f* in age.

The tuffaceous limestones and other tuffaceous rocks contain worn specimens and fragments of foraminifera and also coral, bryozoal, and rare molluscan fragments. Small inclusions of fine-grained tuffaceous siltstone containing planktonic foraminifera occur in several samples. The samples are referred to the *e* stage, both lower and upper *e*, and also possibly lower *f*. The samples included here are: MH65; MH66; MH68; MH69B; MH71; 6552-0965; 6552-1326; 6852-2156; 6852-2157; 6852-2158; 6852-2293; 6852-2337; 6852-3068; P344; P367; P382; P388.

The foraminiferal fauna includes *Lepidocyclina* (*Eulepidina, Nephrolepidina*) spp., *Spiroclypeus* cf. *margaritatus* (Schlumberger), *Miogypsina* sp., *Cycloclypeus* sp., *Heterostegina* sp., *Carpenteria* sp. or *Sporadotrema* sp. (fragments), *Gypsina globulus* Reuss, *Amphistegina* sp., *Operculina* sp., *Miogypsinoides* sp., and rare planktonic foraminifera; several samples also contain specimens of *Discocyclina* sp., *Nummulites* spp., and *Spiroclypeus* cf. *vermicularis* Tan reworked from Eocene sediments.

Sample 6852-2156 contains specimens similar to *Lepidocyclina* (*Eulepidina*) *ephippioides* (Jones & Chapman), a lower *e* species, and also has one specimen of *Miogypsinoides* sp.; sample 6852-2157 also has some *Miogypsinoides* fragments, including an incomplete oblique section through the initial chambers. The specimens are referable to the *M. complanata* (Schlumberger)/*M. bantamensis* Tan group and also indicate a lower *e* age. Sample 6852-2157 also contains reworked specimens of *Nummulites* sp. and *Spiroclypeus* cf. *vermicularis*; other samples containing reworked Eocene specimens are P367 and P382, and in the case of P367 the total fauna, which includes *Discocyclina* sp., a partial median section of *Spiroclypeus* sp., *Operculina* sp., *Carpenteria* sp. or *Sporadotrema* sp., and ?*Textularia* sp., could be derived. However, other samples from the same formation in the same area contain *e* stage foraminifera, and sample P367 is also regarded as of that age.

Sample 6852-2293 contains a species of *Lepidocyclina* which as observed in random thin sections has a nephrolepidine-trybliolepidine nucleconch (Pl. 18, figs 4, 5), and has the equatorial chambers arranged in an indistinct polygonal pattern. These specimens resemble species such as *L.* (*Nephrolepidina*) *angulosa* (Provale)/*L.* (*N.*) *japonica* (Yabe). reported from upper *e* and lower *f* beds. In sample 6852-2337 an assemblage of *L.* (*Eulepidina*) sp., *Spiroclypeus margaritatus*, and *Miogypsina* sp. indicates an upper *e* age.

Some fine-grained samples containing planktonic foraminifera and also in some cases fragments of larger foraminifera (*Lepidocyclina* sp., *Miogypsina* sp.) are also placed in the upper *e* to lower *f*. These samples are: 6852-2146; 6852-2147; 6852-3062; 6852-3003; 6852-3577; MH55. Sample 6852-2147 contains a small *Lepidocyclina* (*Nephrolepidina*) sp.

and *Miogypsina* sp., and also both *Orbulina universa* d' Orbigny and *O. suturalis* Bronnimann; a lithologically similar sample, 6852-5066, has *O. universa.* This indicates that these samples are not older than zone N.9 of the planktonic foraminiferal scale discussed in detail by Blow (1969), and in terms of the 'letter' classification are lower *f* in age.

Some samples cannot be given a definite age. Sample 6852-2073 is a fine-grained tuffaceous? siltstone containing minute planktonic foraminifera (mainly Globigerinidae and very rare Heterohelicidae). Sample 6852-5036 is a fine-grained sheared calcareous siltstone containing small specimens and fragments of planktonic foraminifera. Only a general Miocene age can be given to sample 6852-3566; this is a micritic calcarenite containing foraminifera, algae, Bryozoa, molluscan, and coral fragments; the foraminifera are mainly *Victoriella* sp., with rare indeterminable smaller foraminifera and rare planktonic foraminifera.

One group of samples cannot be given a definite age, but all appear to be from younger sediments, some not older than Pliocene, others not older than Miocene (middle? Miocene.) These samples are:

6852-3315F. A skeletal limestone containing foraminifera, corals, algae, and echinoid spines. The foraminifera include *Amphistegina* sp., *Calcarina* sp., *Operculina* sp., *Cellanthus* sp., fragments of *Sorites*? sp., very rare planktonic specimens, and rare small benthonic foraminifera, possibly including *Ammonia* sp. This sample is regarded as not older than Pliocene, but no more definite indication of age can be given.

6852-6037. A tuffaceous algal-coral-bryozoal limestone with very rare echinoid spines and rare small benthonic foraminifera (?*Ammonia* sp.). This sample could be from one of the younger formations in this region, but no definite age determination can be made.

6852-7008. A tuffaceous siltstone containing abundant large Gastropoda and also abundant small benthonic foraminifera identified as *Ammonia beccarii* (Linné). The foraminifera indicate only that the sample is not older than Miocene (middle? Miocene), and again no definite indication of age can be given.

Sample 6852-5040 is from a skeletal calcarenite containing foraminifera, algae, molluscan fragments, and echinoid spines. The foraminifera are *Alveolinella quoyi* d'Orbigny, *Operculina* sp., *Cellanthus* sp., fragments of *Marginopora* sp., *Amphistegina* sp., *Calcarina* sp., and *Ammonia* (?*A. beccarii*). This sample is considered to be not older than Pliocene.

260. A mainly coral limestone with rare foraminifera including *Amphistegina* sp., fragments of *Carpenteria* sp. or *Sporadotrema* sp. and *Marginopora* sp., miliolids, an indeterminable rotaline genus, and other indeterminable smaller foraminifera; the age is indefinite.

260A. A fine-grained skeletal calcarenite containing foraminifera, algae, and molluscan fragments. The foraminifera are *Amphistegina* sp. (abundant), *Cellanthus* sp., *Neoeponides* sp., and very rare small planktonic specimens. This sample is considered to be not older than Pliocene.

251B is a grey recrystallized limestone with foraminifera, corals, algae, and molluscan fragments. The foraminifera are *Amphistegina* sp., *Carpenteria* sp. or *Sporadotrema* sp., and *Sphaerogypsina* sp. This sample is close to 6852-3085, which contains an uppermost Miocene or Pliocene planktonic assemblage, and is probably from the same stratigraphical interval.

254 contains foraminifera, algae, coral, and molluscan fragments. The foraminifera include *Amphistegina* sp., *Carpenteria* sp. or *Sporadotrema* sp., *Sorites* sp., *Sphaerogypsina* sp., *Planorbulina* sp., planktonic specimens, Miliolidae, and indeterminable smaller foraminifera. The age is indefinite, but is considered to be late Miocene or younger.

Sample 6852-2299 is not older than Pleistocene. It is a porous skeletal calcarenite containing foraminifera, algae, corals, Mollusca, and very rare echinoid spines; the foraminifera are *Baculogypsina sphaerulata* (Parker & Jones) and *Amphistegina* sp.

Sample 6852-3316 is also placed in the group of younger sediments; it contains foraminifera, algae, and molluscan fragments. The foraminifera are *Peneroplis* sp., *Marginopora* sp. (fragments), small *Amphistegina* sp., miliolids, rare planktonic specimens, and indeterminable smaller foraminifera.

Sample LB114 contains only abundant molluscan fragments. No definite age can be given, but it is included in the group of younger samples.

The following two samples cannot be given any definite age:

6852-3343 is a conglomerate containing tuffaceous pebbles and fragments of fine-grained limestone and siltstone. The limestone fragments are from fine-grained Eocene limestone, with abundant planktonic foraminifera; the siltstone contains abundant radiolaria. This sample is considered to be from a post-Eocene detrital deposit, but there is no indication of the true age of the rock. Sample 6852-2161 is a fine-grained sheared tuffaceous siltstone with small inclusions and streaks of fine-grained white limestone containing recrystallized foraminifera and algae. The foraminifera are *Amphistegina*? sp., rare thick-walled planktonic foraminifera (Globigerinidae), which seem to be younger Tertiary in type, and one small fragment possibly of the median chambers of a lepidocyclinid. This sample probably should be included with other Miocene tuffaceous samples.

The last samples to be discussed are a group collected from clastic sediments; foraminifera are usually abundant, and some of the samples contain an extensive planktonic fauna. The samples range from middle Miocene to possibly Quaternary in age.

Sample 6852-3576 contains poorly preserved planktonic foraminifera, which include *Globigerinoides quadrilobatus immaturus* Le Roy, *G. quadrilobatus* cf. *altiapertutus* Bolli, *Orbulina suturalis* Bronnimann, *O. universa* d'Orbigny, and rare benthonic specimens. Blow (1969) recorded specimens referred to as *Globigerinoides quadrilobatus* cf. *altiaperturus* from the N.10 to N.12 zonal interval. The present specimens appear to be referable to the taxon discussed by Blow, and sample 6852-3576 is therefore referred to the N.10 to N.12 interval (middle Miocene).

Sample 6852-3572 contains very poorly preserved planktonic foraminifera, which are corroded and broken; *Orbulina* is the only recognizable form and no definite age can be given. Other samples for which no definite age can be given are: 6852-2417, which contains rare small mollusca and rare poorly preserved foraminifera, including *Amphistegina* sp., *Elphidium* sp., and *Nodosaria* sp.; 6852-3563, which contains only very rare mollusca, fish teeth, and one specimen of *Chara;* and 6852-5122, which contains only one foraminiferal species, *Eponides praecinctus* (Karrer).

Sample 6852-3085 contains an abundant and well preserved foraminiferal fauna including the following species:

Globigerinoides quadrilobatus quadrilobatus (d'Orbigny)
G. quadrilobatus immaturus Le Roy
G. bollii Blow
G. ruber (d'Orbigny)
G. conglobatus conglobatus (Brady)
Globigerina bulloides d'Orbigny
Globigerinita incrusta Akers
Orbulina universa d'Orbigny
Globorotalia (*G.*) *crassula crassula* Cushman & Stewart
Neogloboquadrina humerosa (Takayanagi & Saito)
Bolivinita quadrilatera (Schwager)
Pseudorotalia gaimardi (d'Orbigny)
Ammonia beccarii (Linné)
Bulimina marginata d'Orbigny
'Eponides' margaritiferus (Brady)
Planorbulinella sp.
Melonis affinis (Reuss)
Brizalina patula Belford
Globocassidulina subglobosa (Brady)
Siphogenerina costata Schlumberger

The planktonic foraminiferal fauna indicates an age within the zonal intervals N.18 to N.21 of Blow (1969), that is, latest Miocene or Pliocene.

Sample 227 contains rare small planktonic and benthonic foraminifera of indefinite age significance; the following species occur:

Globigerinoides quadrilobatus immaturus
G. bollii
Globigerinita incrusta
Globigerinoides conglobatus conglobatus
G. bulloides bulloides d'Orbigny
Bulimina marginata
Euuvigerina flinti (Cushman)
Globorotalia (*Turborotalia*) *obesa* Bolli

On the basis of this fauna sample 227 can be placed within the N.16 to N.21 interval (late Miocene to Pliocene).

Sample 256 also contains an abundant well preserved fauna, including the following species:

Orbulina universa
Globigerinoides conglobatus conglobatus
G. quadrilobatus quadrilobatus
G. quadrilobatus sacculifer (Brady)
G. ruber
Globorotalia (*Turborotalia*) *acostaensis acostaensis* Blow
Pulleniatina obliquiloculata praecursor Banner & Blow
P. obliquiloculata obliquiloculata (Parker & Jones)
Globorotalia (*G.*) *cultrata cultrata* (d'Obigny)
G. (*G.*) *tumida* (Brady)
Sphaeroidinella dehiscens dehiscens (Parker & Jones)
Euuvigerina schwageri (Brady)
E. flinti
'Eponides' margaritiferus (Brady)

Pseudorotalia schroeteriana (Parker & Jones)

This sample is Pliocene, zones N.19 to N.21, in age.

Sample 258 contains abundant foraminifera, mainly specimens of *Cellanthus* spp., including *C. craticulatus* (Fichtel & Moll) and *Tinoporus spengleri* (Gmelin). A tentative Quaternary age is given to sample 258 and also to 259, which contains foraminifera, Bryozoa, corals, and algae. The foraminifera are very poorly preserved and include rare specimens of *Spiroloculina* sp. and ?*Marginopora* sp.

Sample 253 is of indefinite age, but is possibly also Quaternary. It contains foraminifera, corals, and algae; the foraminifera are poorly preserved and include *Globigerinoides quadrilobatus quadrilobatus*, *Operculina* sp., *Amphistegina* sp., and *Tinoporus* sp.

Sample MH72 contains foraminifera, Ostracoda, Mollusca, Bryozoa, and echinoid spines. The foraminifera include:

Globigerinoides quadrilobatus sacculifer
Pseudorotalia schroeteriana
Cellanthus craticulatus
Elphidium macellum (Fitchell & Moll)
Amphistegina sp.
Discorbinella bertheloti (d'Orbigny)
Florilus elongatus (d'Orbigny)
Planorbulinella larvata (Parker & Jones)
Ammonia cf. maculosa Belford

This sample is Pliocene or younger.

Sample MH74 contains rare foraminifera and Mollusca; the foraminifera include *Cellanthus craticulatus*, *Amphistegina* sp., and *Heterostegina* sp. and this sample is also considered to be Pliocene or younger in age.

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TABLE A. SAMPLE LIST

Sample No.	*Locality No.*	*1:250 000 Sheet Area*	*Collector and Date*	*Assigned Age*
LB109	10	Tufi	J. E. Thompson, 1955	Late Oligocene to early Miocene (Tertiary *e*)
LB114				Indefinite
LB142	12	Tufi		Middle Miocene (Tertiary lower *f*)
LB142B	12			Middle Miocene (Tertiary lower *f*)
P344	42		J. E. Thompson, 1958	Late Oligocene to early Miocene (Tertiary *e*)
P346	44			Eocene
P363	16			Eocene
P367	34			Late Oligocene to early Miocene (Tertiary *e*)
P377	32			Late Oligocene to early Miocene (Tertiary *e*)
P382	57	Samarai		Late Oligocene to early Miocene (Tertiary *e*)
P383	56			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
P385	58			Late Oligocene to early Miocene (Tertiary *e*)
P388	61			Late Oligocene to early Miocene (Tertiary *e*)
P400	40			Eocene
6552-0177*			H. L. Davies, 1965	Late Cretaceous
6552-0178*				Late Cretaceous
6552-0179*				Late Cretaceous
6552-0181*				Late Cretaceous
6552-0282	25			Late Cretaceous
6552-0283	25			Late Cretaceous
6552-0695	24	Tufi		Eocene
6552-0696	24			Eocene
6552-0702	20			Middle Miocene (Tertiary lower *f*)
6552-0948*				Eocene
6552-0950*				Eocene
6552-0955*				Eocene
6552-0956*				Eocene
6552-0965*				Late Oligocene to early Miocene (Tertiary *e*)
6552-1313	63			Eocene
6552-1314	63			Eocene
6552-1318	37			Eocene
6552-1319	37			Eocene
6552-1326	55	Samarai		Late Oligocene to early Miocene (Tertiary *e*)
6552-1328	55			Late Oligocene to early Miocene (Tertiary *e*)
6552-1329	55			Late Oligocene to early Miocene (Tertiary *e*)
6552-1335	62			Eocene
6552-1337	62			Eocene
6552-1412	1			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
6552-1748	26	Tufi		Eocene
6552-1853A	16	Tufi		Eocene
MH51	22	Abau	J. E. Thompson, 1965	Eocene
MH52	22			Eocene
MH55	20			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
MH63	21			Eocene
MH64	22			Late Cretaceous
MH65	27			Late Oligocene to early Miocene (Tertiary *e*)
MH66	25	Samarai		Late Oligocene to early Miocene (Tertiary *e*)
MH68	24			Late Oligocene to early Miocene (Tertiary *e*)
MH69A	26			Late Oligocene to early Miocene (Tertiary *e*)
MH69B	26			Late Oligocene to early Miocene (Tertiary *e*)
MH71	30			Late Oligocene to early Miocene (Tertiary *e*)
MH72	30			Pleistocene or younger
MH74	29			Pleistocene or younger
MH75	31			Eocene

TABLE A. SAMPLE LIST—*(cont.)*

Sample No.	*Locality No.*	*1:250 000 Sheet Area*	*Collector and Date*	*Assigned Age*
P1247	21		A. Renwick and R. P. Macnab, 1966	Late Oligocene to early Miocene (Tertiary *e*)
P1274	18			Eocene
P1275	23			Eocene
P1276	19	Tufi		Late Oligocene to early Miocene (Tertiary *e*)
P1277	22			Eocene
P1278	23			Eocene
P1279	17			Eocene
6852-2039	15		H. L. Davies, I. E. Smith, G. Cifali, et al., 1968	Eocene
6852-2042	15			Eocene
6852-2043	15			Eocene
6852-2045	15			Eocene
6852-2048	15			Eocene
6852-2071	43			Eocene
6852-2073				Indefinite
6852-2113	52			Late Oligocene (Tertiary lower *e*)
6852-2114	52			Late Oligocene to early Miocene (Tertiary *e*)
6852-2122	53			Eocene
6852-2137	54			Eocene
6852-2146	47	Samarai		Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
6852-2147	47			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
6852-2156	28			Late Oligocene (Tertiary lower *e*)
6852-2157	28			Late Oligocene (Tertiary lower *e*)
6852-2158	28			Late Oligocene to early Miocene (Tertiary *e*)
6852-2161				Indefinite
6852-2177	38			Eocene
6852-2203	15			Eocene
6852-2204	15			Eocene
6852-2230	17			Eocene
6852-2231	10			Eocene
6852-2240	23			Eocene
6852-2242	2			Late Cretaceous
6852-2248	3			Eocene
6852-2249	3			Eocene
6852-2263	16			Eocene
6852-2264	16	Abau		Eocene
6852-2269	10			Eocene
6852-2283	9			Eocene
6852-2293	8			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
6852-2297	15			Eocene
6852-2298	15			Eocene
6852-2299	15	Abau		Pleistocene or younger
6852-2300	15			Eocene
6852-2301	15			Eocene
6852-2302	15			Eocene
6852-2303	12			Eocene
6852-2308	11			Eocene
6852-2326	33	Tufi		Eocene
6852-2337	32			Late Oligocene to early Miocene (Tertiary *e*)
6852-2417				Indefinite
6852-2505	29	Tufi		Late Cretaceous
6852-2507	29			Late Cretaceous
6852-2573	1	Abau		Eocene
6852-2584	31	Tufi		Late Cretaceous
6852-2610	5	Abau		Eocene
6852-3003	59	Samarai		Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)

TABLE A. SAMPLE LIST—*(cont.)*

Sample No.	*Locality No.*	*1:250 000 Sheet Area*	*Collector and Date*	*Assigned Age*
6852-3023	66			Eocene
6852-3062	45			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
6852-3067	45			Eocene
6852-3068	45	Samarai		Late Oligocene to early Miocene (Tertiary *e*)
6852-3069	45			Eocene
6852-3070	45			Eocene
6852-3085	11			Late Miocene-Pliocene (N18-N21)
6852-3115	2			Eocene
6852-3120	21	Abau		Late Oligocene to early Miocene (Tertiary *e*)
6852-3132	13			Eocene
6852-3154	1			Late Oligocene (Tertiary lower *e*)
6852-3222	27	Tufi		Eocene
6852-3223	27			Eocene
6852-3233	30			Late Cretaceous
6852-3293	14	Abau		Eocene
6852-3315B	9	Samarai		Eocene
6852-3315F	9			Pleistocene or younger
6852-3316				Indefinite
6852-3323A	41			Eocene
6852-3323C	41			Eocene
6852-3326D	41			Eocene
6852-3326E	41	Samarai		Eocene
6852-3330D	41			Eocene
6852-3338	48			Middle Miocene (Tertiary lower *f*)
6852-3343				Indefinite
6852-3346	49			Eocene
6852-3563				Indefinite
6852-3566	2	Tufi		General Miocene age only
6852-3572				Indefinite
6852-3576	5	Tufi		Middle Miocene (N10-N12)
6852-3577	5			Early to middle Miocene (Tertiary upper *e*— Tertiary lower *f*)
6852-4024	36			Eocene
6852-4062A	35			Eocene
6852-4063	35			Eocene
6852-4063A	35			Eocene
6852-4064	35			Eocene
6852-4068	35			Eocene
6852-4069	35			Eocene
6852-4246	60			Eocene
6852-4247A	60			Eocene
6852-4247B	60	Samarai		Eocene
6852-4248	60			Indefinite
6852-4256	60			Eocene
6852-4322	50			Late Cretaceous
6852-4336A	19			Eocene
6852-4336B	19			Eocene
6852-4343A	33			Eocene
6852-4822D	18			Eocene
6852-4822F	18			Eocene
6852-5035	51			Eocene
6852-5036				Indefinite
6852-5040	23			Pleistocene or younger
6852-5043	23			Eocene
6852-5044	23			Late Oligocene to early Miocene (Tertiary *e*)
6852-5047	3			Eocene
6852-5053	4	Samarai		Eocene
6852-5055	7			Eocene
6852-5063	46			Eocene
6852-5066	46			Middle Miocene (Tertiary lower *f*)
6852-5070	39			Eocene

TABLE A. SAMPLE LIST—*(cont.)*

No. Sample	*No. Locality*	*1:250 000 Sheet Area*	*Collector and Date*	*Assigned Age*
6852-5122				Indefinite
6852-5765F	28	Tufi		Late Cretaceous
6852-6022B	4	Abau		Eocene
6852-6037				Indefinite
6852-7008	34	Tufi		Not older than Miocene (?middle Miocene)
207A	6	Abau	D. H. Blake, CSIRO, 1969	Eocene
227	65	Samarai		Late Miocene-Pliocene (N16-N21)
229	64	Samarai		Eocene
248A	54	Samarai		Eocene
251B	12	Samarai		Late Miocene or younger
253	14	Samarai		? General Quaternary age only
254	13	Samarai		Late Miocene or younger
256	8	Samarai		Pliocene (N19-N21)
258	6	Samarai		General Quaternary age only
259	6	Samarai		General Quaternary age only
260		Samarai		Indefinite
260A	5	Samarai		Pleistocene or younger
274A	7	Samarai		Eocene
334†		Samarai		Eocene
345	7	Abau		Eocene
6952-3594	6		I. E. Smith, 1969	Eocene

* These samples are on the Buna 1:250 000 Sheet, now being compiled, and will be included in the Explanatory Notes to that Sheet.

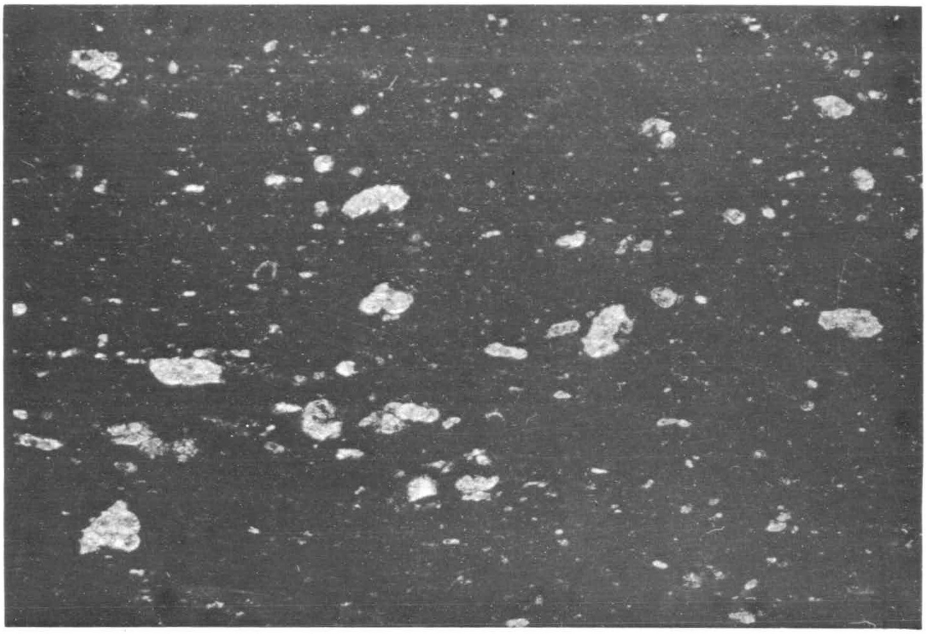
† Locality not shown

PLATE 1

Figures

1. Thin section, sample 6852-5765F; calcareous siltstone; Late Cretaceous. x 17.
2. Thin section, sample 6552-0283; recrystallized calcareous siltstone, with patches of green calcareous siltstone; Late Cretaceous. x 19.

PLATE 1



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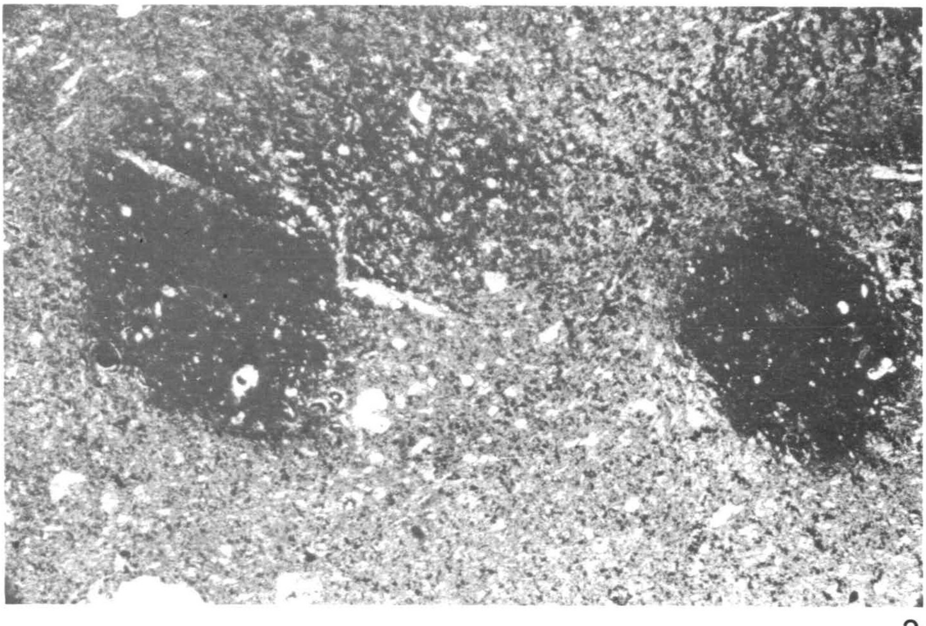


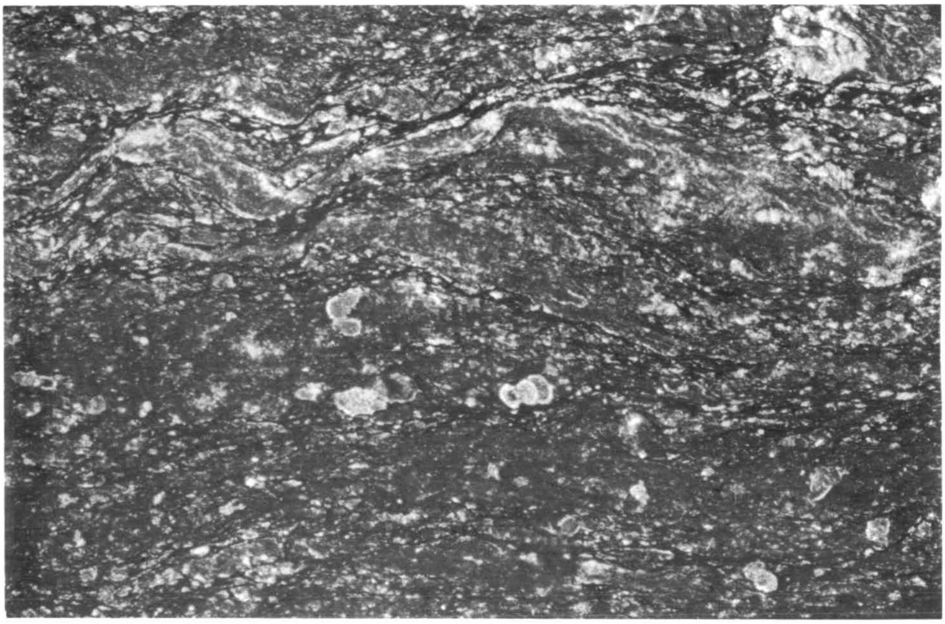
2

PLATE 2

Figures

1. **Thin section, sample 6552-0177; fine-grained sheared silty limestone, with poorly preserved *Globotruncana* spp.; Late Cretaceous. x 19.**
2. **Thin section, sample 6552-0178; fine-grained sheared silty limestone with poorly preserved *Globotruncana* spp.; Late Cretaceous. x 17.**

PLATE 2



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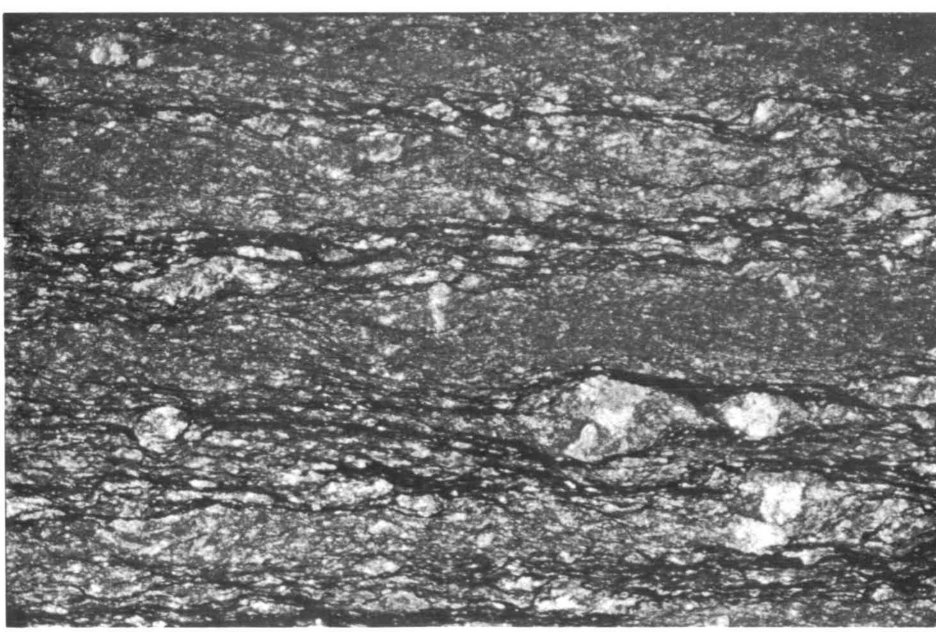


2

PLATE 3

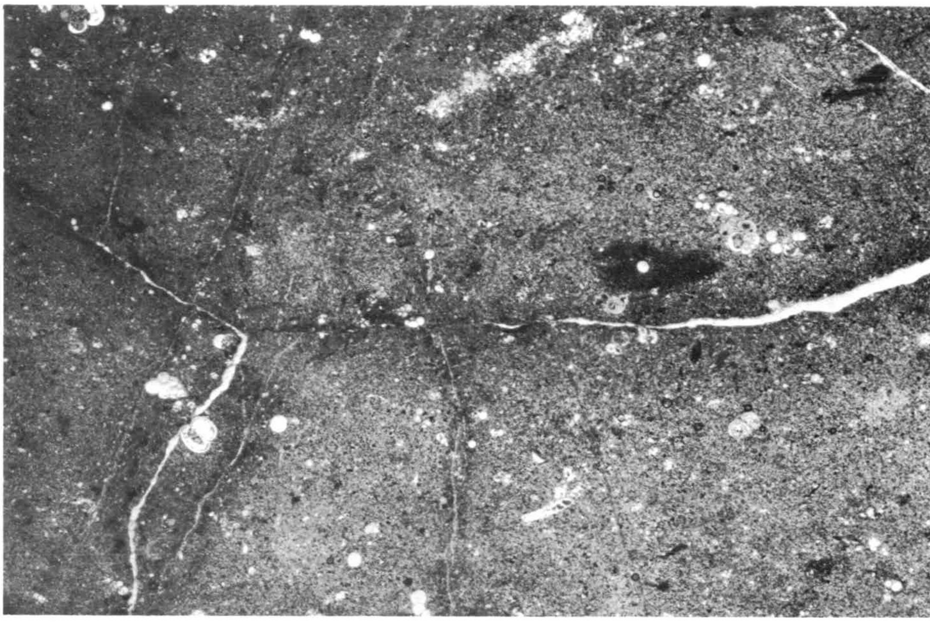
Figures

1. **Thin section, sample 6852-2242; calcareous volcanic ash? with** *Hedbergella* **spp.,** *Globigerinelloides* **sp., and Heterohelicidae; Late Cretaceous. x 19.**

2-5. *Globotruncana* **spp., CPC 13629-12632, sample 6852-5765F, all x 70. Figures 2 and 3, specimens of** *G. arca* **(Cushman) type; figure 5, specimen from** *G. elevata* **(Brotzen) group; figure 4,** ?*G. gansseri* **Bolli type.**

6. *Globotruncana* **sp. cf.** *G. arca* **(Cushman). CPC 13633, thin section, sample 6852-2505. x 70.**

PLATE 3



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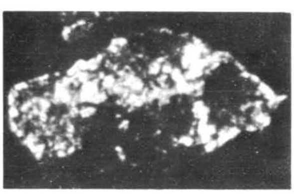

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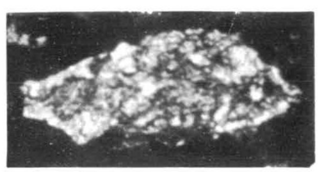

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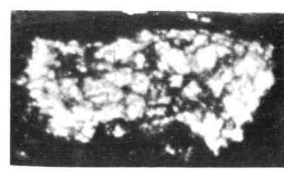

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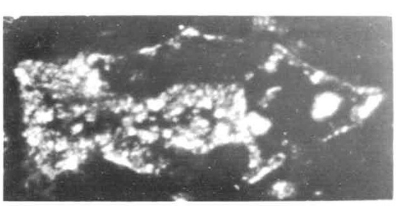

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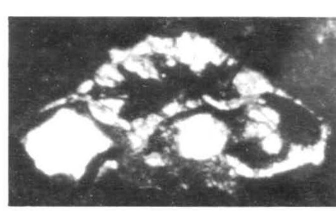

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PLATE 4

Figures

1. *Planoglobulina* **sp. or** *Racemiguembelina* **sp., CPC 13634, sample 6852-2242. x 70.**
2. *Bolivinitella*? **sp., CPC 13635, sample 6852-2242. x 70.**
3. *Heterohelix* **sp., CPC 13636, sample 6852-2242. x 70.**

4-5. *Hedbergella*? **sp., CPC 13637-13638, sample 6852-2242. x 70.**

6. *Globigerinelloides* **sp., CPC 13639, sample 6852-2242. x 70.**
7. **Thin section, sample 6852-4062A, fine-grained planktonic foraminiferal limestone; Eocene. x 19.**

PLATE 4

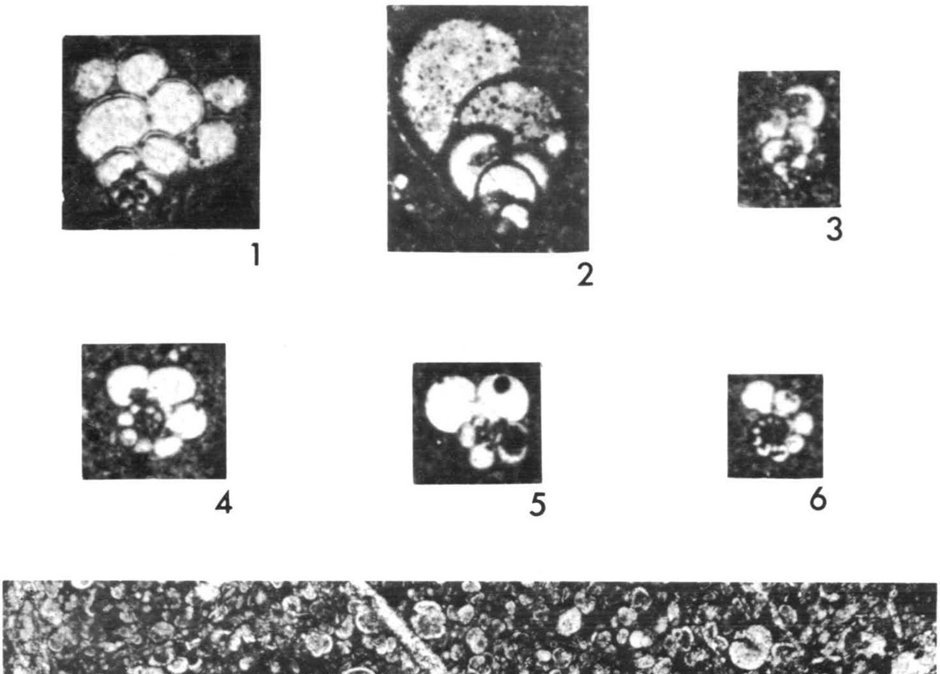


PLATE 5

Figures

1. **Thin section, sample 6852-3315B; fine-grained planktonic foraminiferal limestone; Eocene. x 19.**
2. **Specimen of** *Truncorotaloides (T.) rohri* **Bronnimann & Bermudez type, CPC 13640, sample 6852-3315B. x 80.**

3, 5. **Specimens of** *T. (T.) topilensis* **(Cushman) type, CPC 13641 and 13642, sample 6852-3315B. x 80.**

4. *Truncorotaloides (Morozovella)* **sp., CPC 13643, sample 6852-3315B. x 80.**

6, 7. **Thick-walled globigerinids with mamillated test surface, similar to the** *Globigerinatheka index* **(Finlay) group, CPC 13644 and 13645, sample 6852-3315B. x80.**

PLATE 5

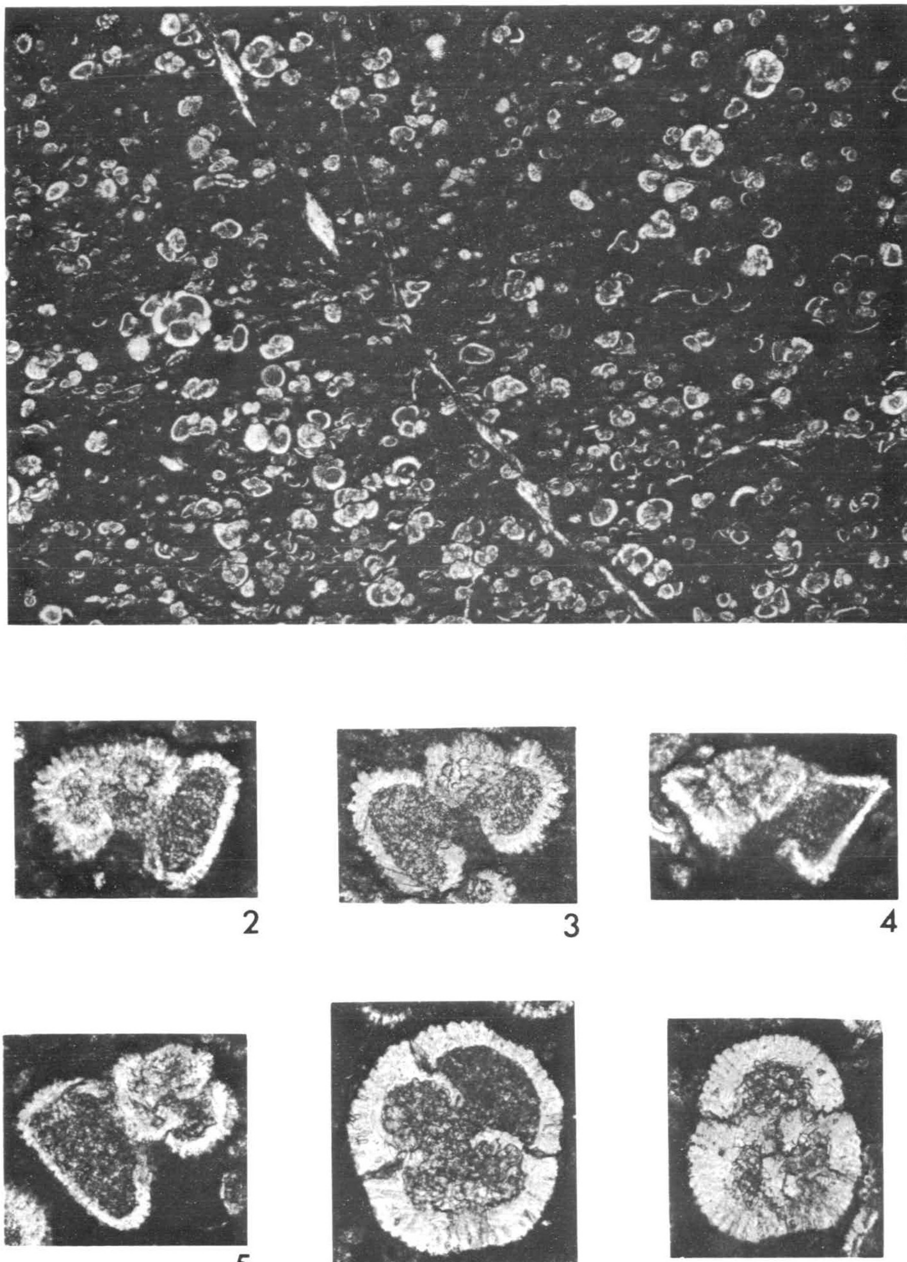


PLATE 6

Figures

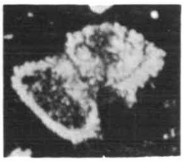
1-3. Specimens of *Truncorotaloides (T.) topilensis* **(Cushman) type, CPC 13646-13648, sample 6852-5047. x 80.**

4. *Truncorotaloides (Morozovella)* **sp., CPC 13649, sample P363. x 80.**

5, 6. Specimens of *T. (T.) rohri* **Bronnimann & Bermudez type, CPC 13650 and 13651, sample P363. x 80.**

7. Thin section, sample 6852-3346; fine-grained limestone consisting wholly of specimens and fragments of planktonic foraminifera; Eocene. x 19.

PLATE 6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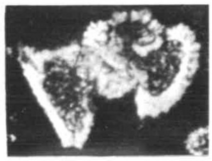
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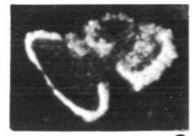
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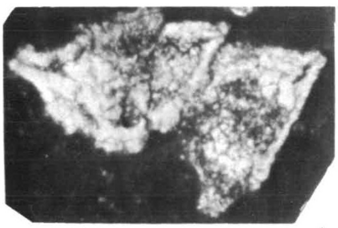
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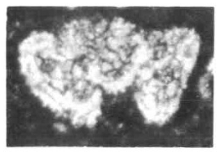
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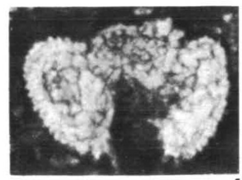
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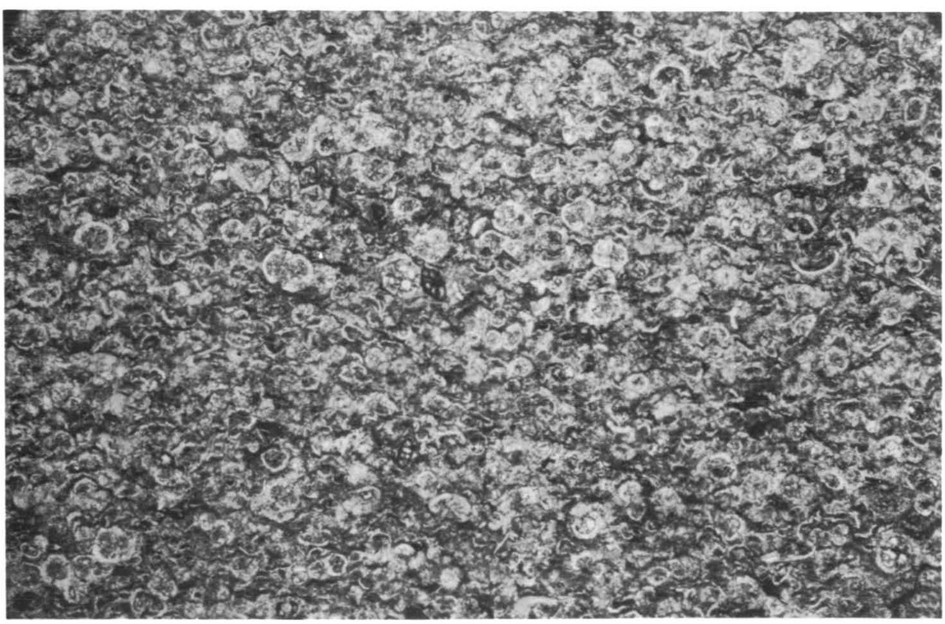
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PLATE 7

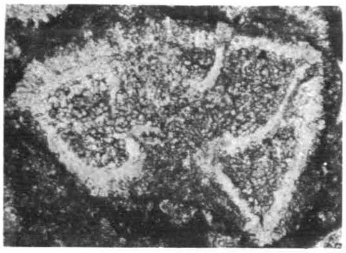
Figures

1. *Truncorotaloides* (*Morozovella*) **sp., CPC 13652, sample 6852-3326E. x 80.**
2. **Specimen of** *T.* (*T.*) *topilensis* **(Cushman) type, CPC 13653, sample 6852-3326E. x 80.**
3. *T.* (*Morozovella*) **sp., CPC 13654, sample 6852-3326E. x 80.**

4-7. **Specimens of** *T.* (*T.*) *rohri* **Bronnimann & Bermudez type, CPC 13655-13658, sample 6852-3346. x 80.**

8. **Thick-walled globigerinid, comparable to the** *Globigerinatheka index* **(Finlay) group, CPC 13659, sample 6852-3346. x 80.**
9. *Truncorotaloides* (*M.*) **sp., CPC 13660, sample 6852-2045. x 80.**
10. **Specimen of** *T.* (*T.*) *rohri* **Bronnimann & Bermudez type, CPC 13661, sample 6852-2045. x 80.**
11. **?Fragment of** *Hantkenina* **sp., CPC 13662, sample 6852-2045. x 80.**
12. *Truncorotaloides* (*M.*) **sp., CPC 13663, sample P1277. x 80.**
13. **Specimen of** *T.* (*T.*) *topilensis* **(Cushman) type, CPC 13664, sample P1277. x 80.**

PLATE 7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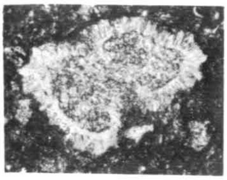
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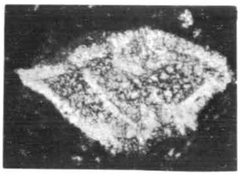
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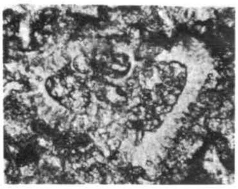
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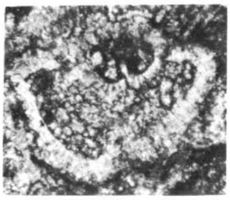
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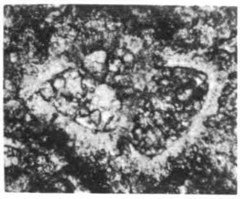
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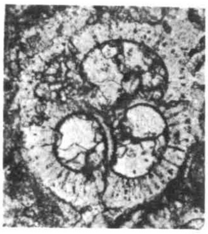
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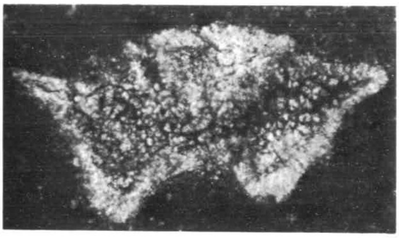
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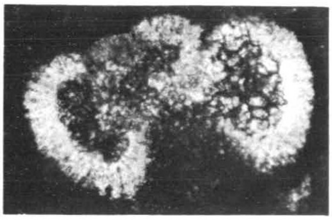
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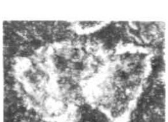
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PLATE 8

Figures

1-3. *Truncorotaloides* (*M.*) **spp., CPC 13665-13667, sample P1278. x 80.**

4. Specimen? of *T.* (*T.*) *topilensis* **(Cushman) type, CPC 13668, sample P1278. x 80.**

5. Thin section, sample 6852-3293, fine-grained calcareous siltstone with sponge spicules, radiolaria, and rare small planktonic foraminifera; Eocene. x 32.

6. Radiolarian, CPC 13669, sample 6852-3293. x about 200.

7. Radiolarian, CPC 13670, sample 6852-2122. x about 200.

8, 9. Radiolaria, CPC 13671 and 13672, sample 6852-3222. x about 200.

PLATE 8

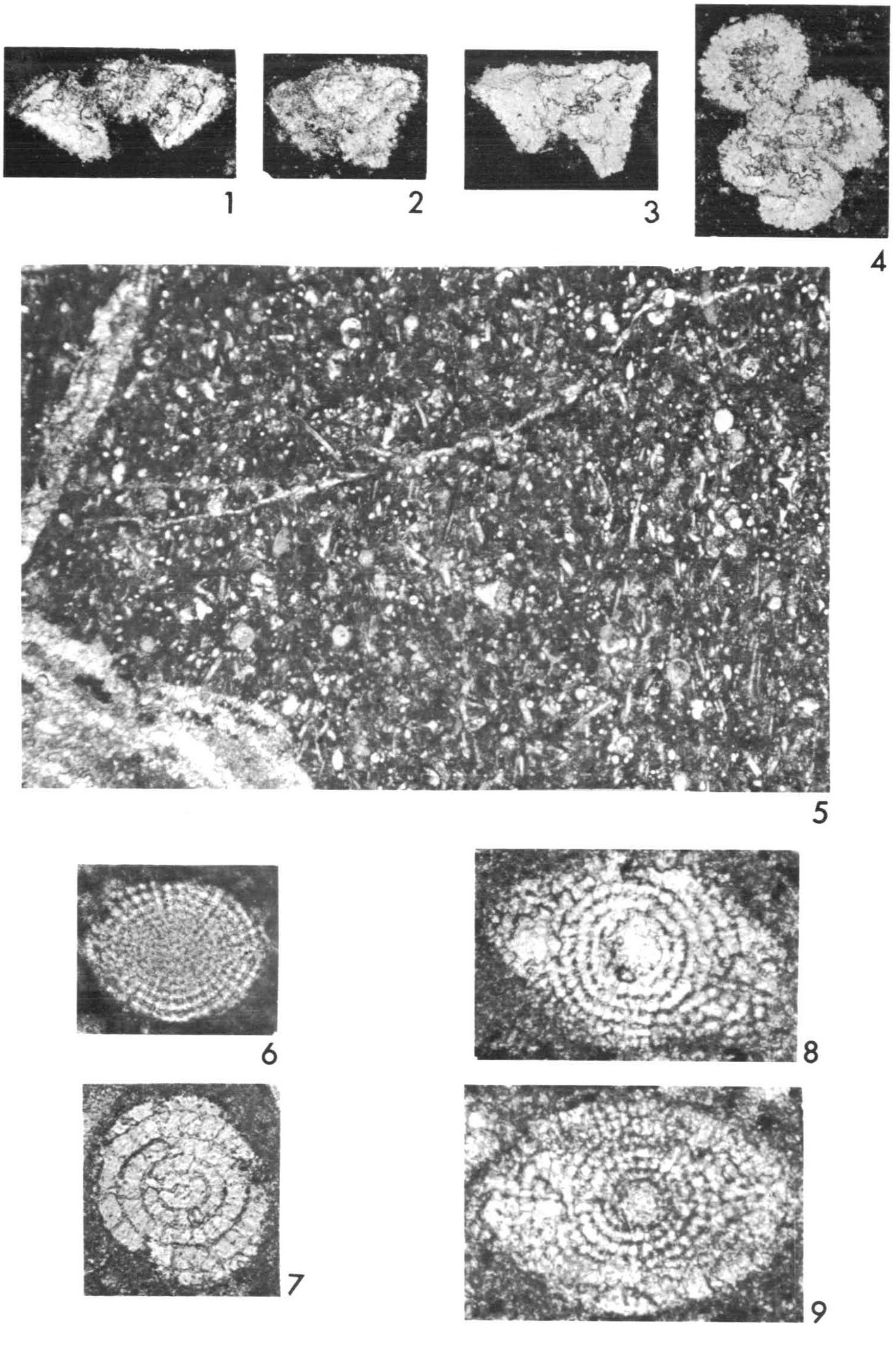
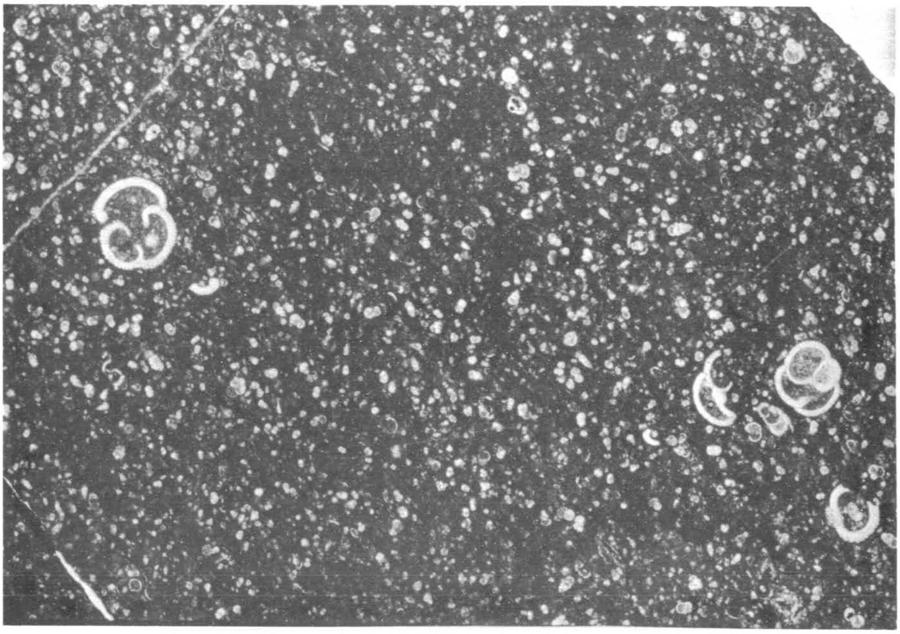


PLATE 9

Figures

1. Thin section, sample 6852-3067, fine-grained red limestone with abundant small and rare large specimens of planktonic foraminifera; Eocene. x 19.
2. Thin section, sample 6852-5043, fine-grained limestone with abundant sponge spicules and rare planktonic foraminifera; Eocene. x 19.

PLATE 9



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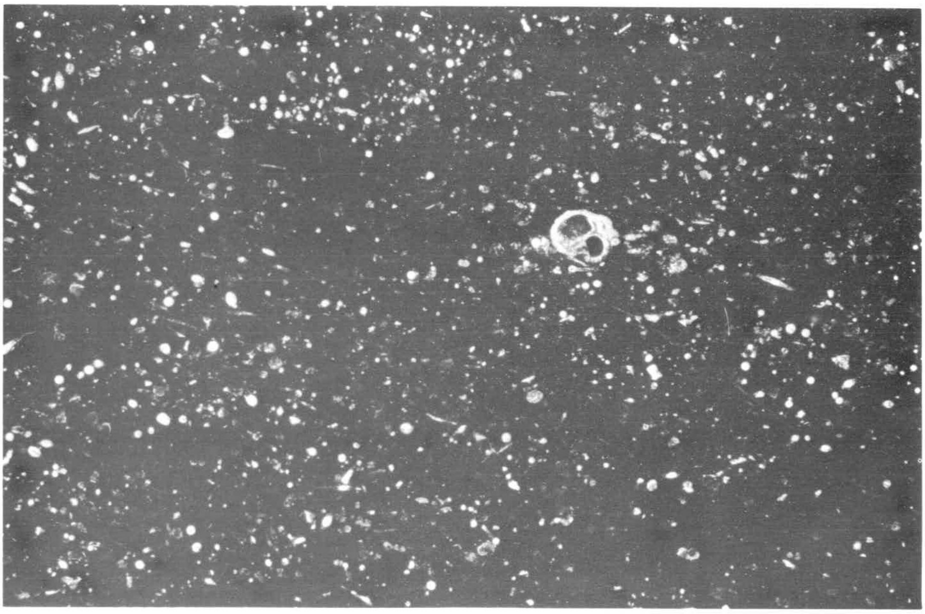

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PLATE 10

Figures

1. **Thin section, sample 6952-3594, fine-grained limestone with abundant sponge spicules and small planktonic foraminifera; Eocene. x 32.**

2-6. **Planktonic foraminifera, Globigerinidae, and Globorotaliidae, CPC 13673-13677, sample 6952-3594. x 80.**

7-9. **Sponge spicules CPC 13678-13680, sample 6852-5043. x 90.**

PLATE 10

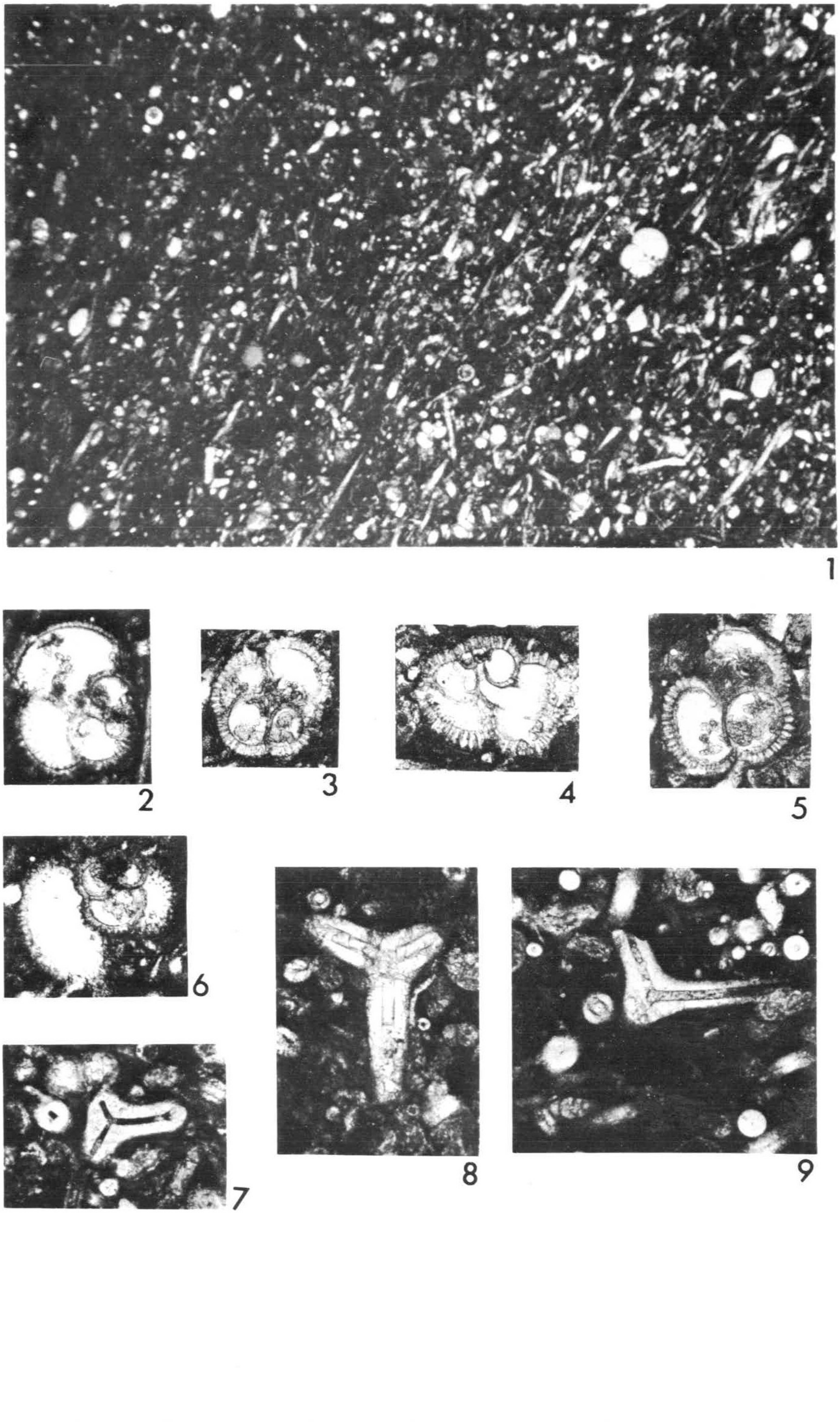
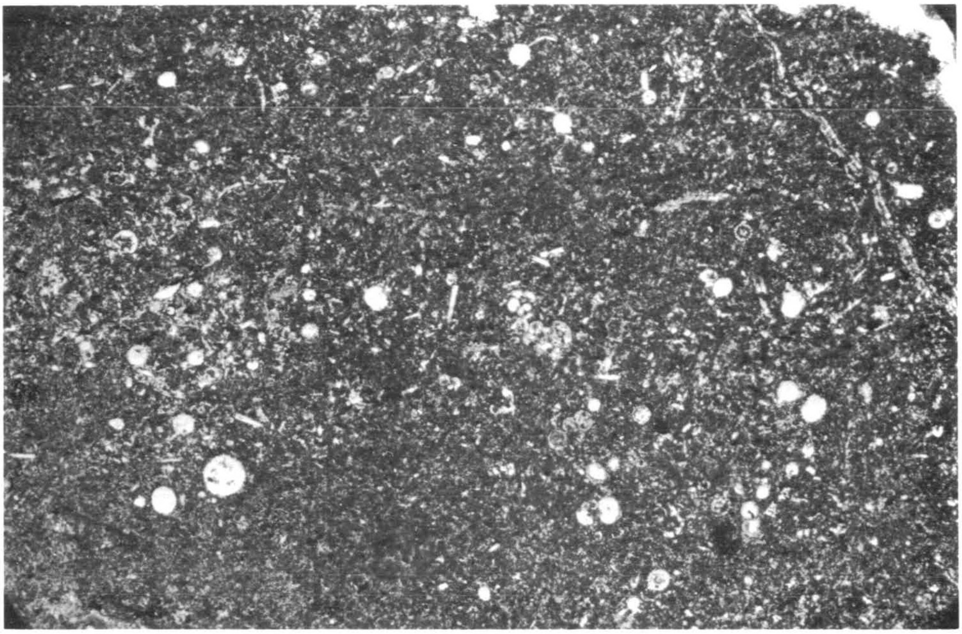


PLATE 11

Figures

1. Thin section, sample 6852-2240, fine-gained limestone with small planktonic foraminifera, radiolaria, and sponge spicules. x 32.
2. Thin section, sample 6852-6022B, fine-grained red limestone with abundant radiolaria and rare sponge spicules; Eocene. x 32.

PLATE 11



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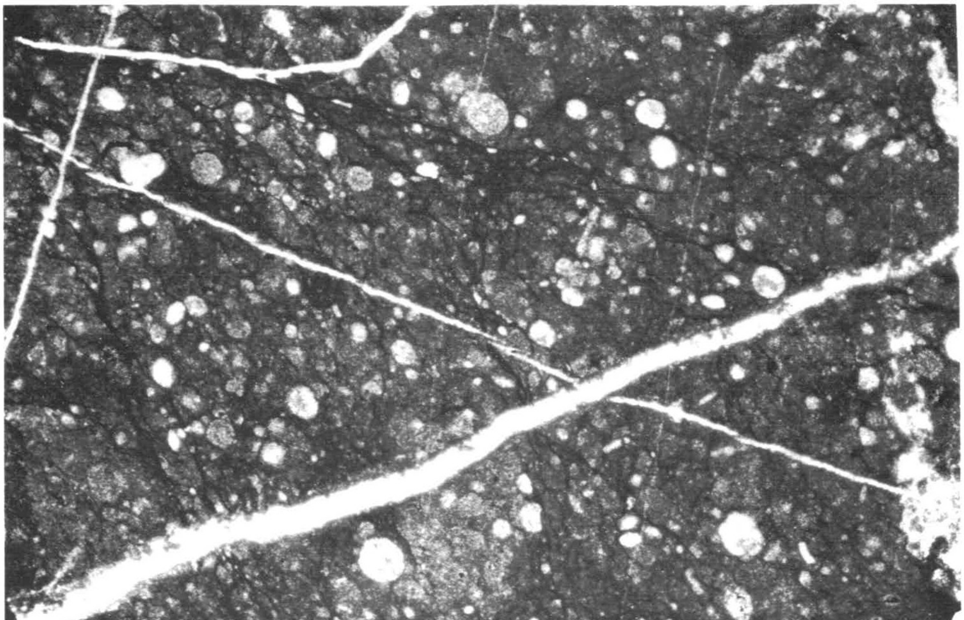

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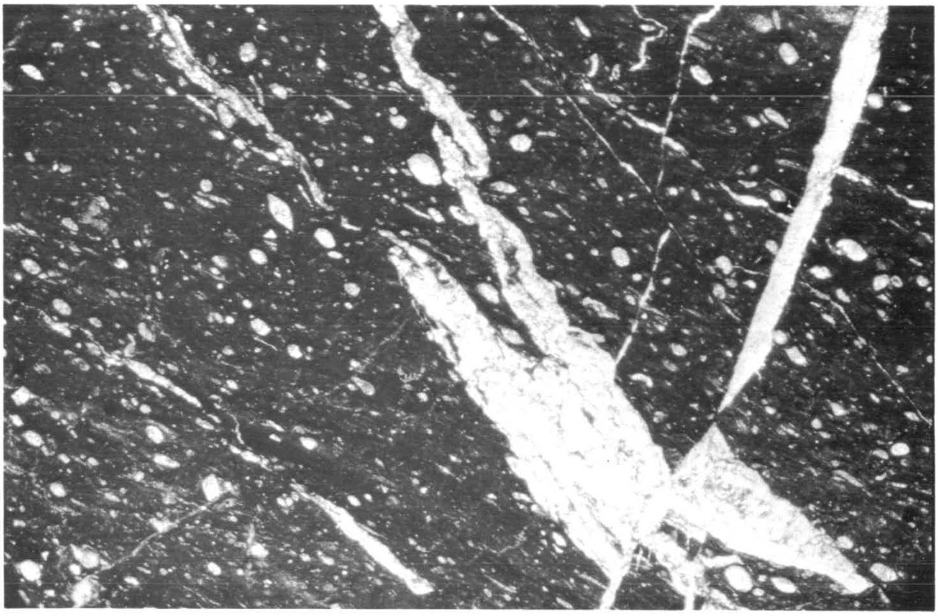
PLATE 12

Figures

1. **Thin section, sample 6852-2326, sheared fine-grained red limestone with abundant radiolaria; Eocene. x 29.**
2. **Thin section, sample 6852-3343, conglomerate with small pebbles of white fine-grained limestone with planktonic foraminifera and calcareous radiolarian siltstone; post Eocene? x 11.**

PLATE 12



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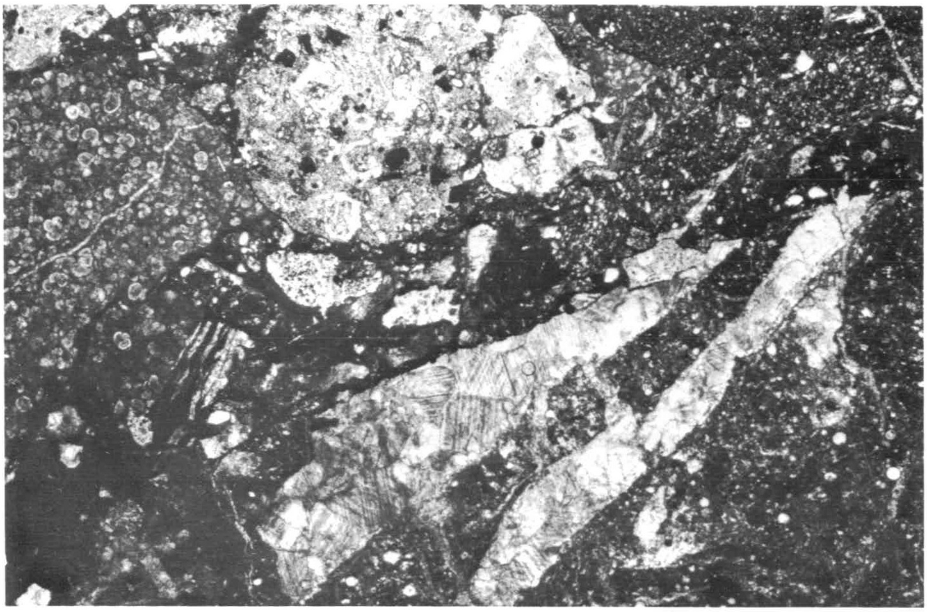

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PLATE 13

1. **Thin section, sample 6852-4343A, skeletal calcarenite with abundant Bryozoa and foraminifera, including** *Discocyclina* **sp. and ?***Textularia* **sp.; late Eocene. x 13.**
2. **Thin section, sample 6852-2042, skeletal calcarenite with foraminifera, algae, and bryozoal fragments.** *Discocyclina* **sp.; late Eocene. x 12.**

PLATE 13

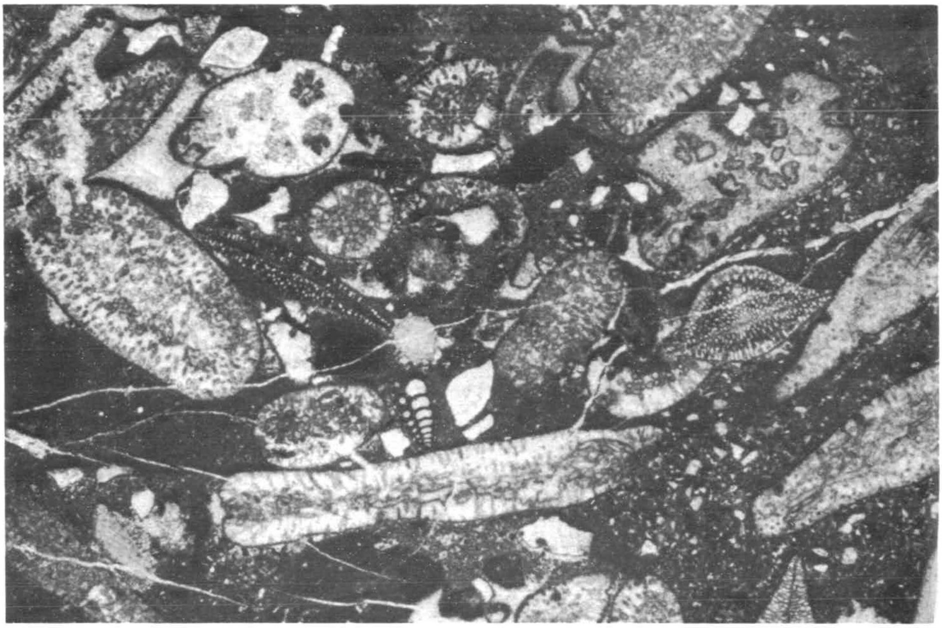

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PLATE 14

Figures

1. *Discocyclina* **sp., CPC 13681, sample 6852-4343A. x 20.**
2. *Discocyclina* **sp., CPC 13682, sample 6852-2042. x 20.**
3. *Nummulites* **sp., CPC 13683, sample 6852-2039. x 20.**
4. *Heterostegina* **sp., CPC 13684, sample 6852-2039. x 20.**
5. **Thin section, sample 6852-2114, skeletal calcarenite consisting wholly of worn tests and fragments of foraminfera.** *Lepidocyclina* **(*N*) sp. (?upper *e*, early Miocene).**

PLATE 14

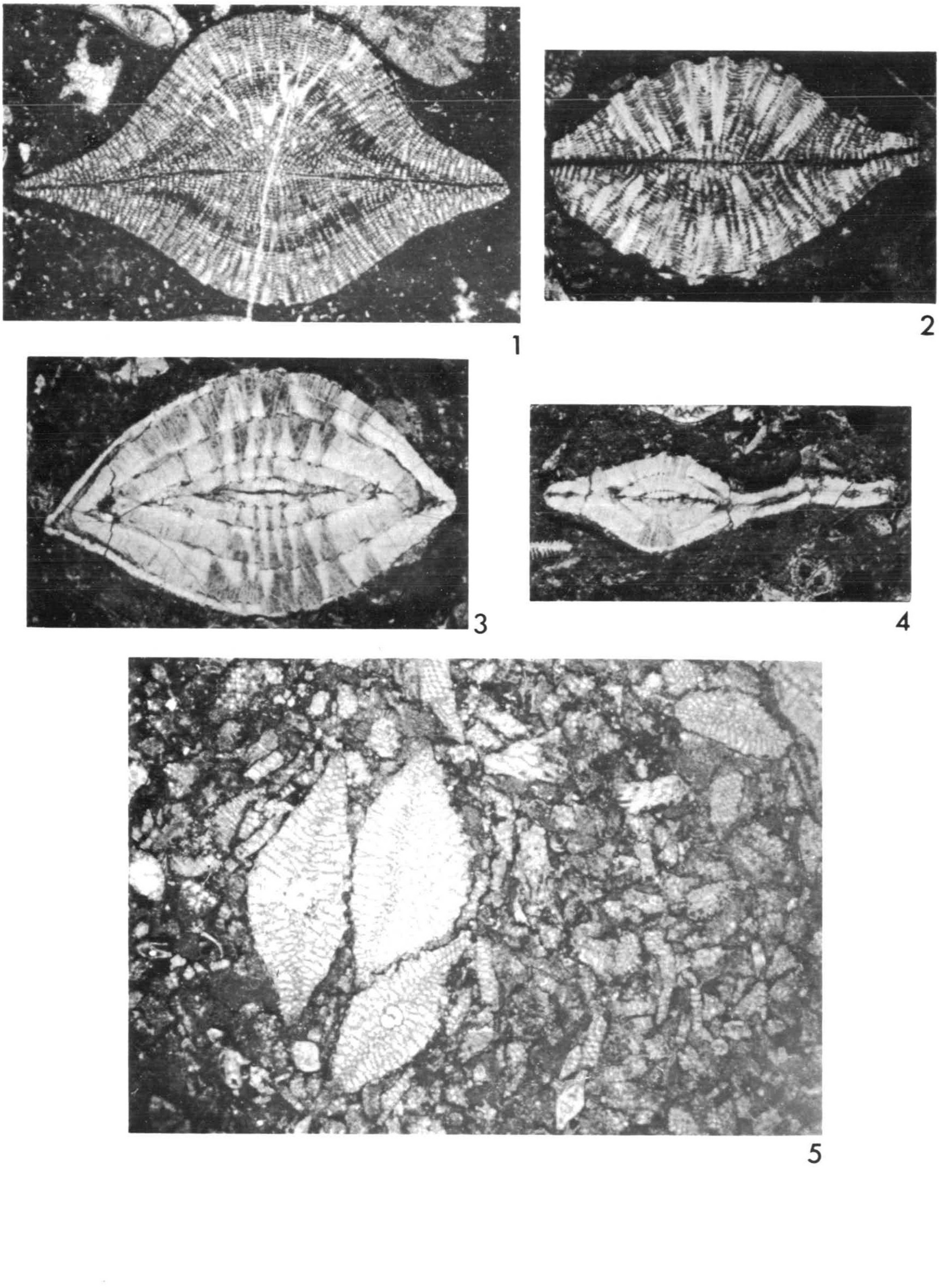


PLATE 15

Figures

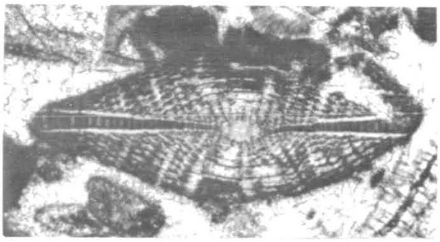
1-2. *Lepidocyclina* (?*N.*) **sp., CPC 13685 and 13686, sample P383. x 20.**

3. *Lepidocyclina* (*N.*) **sp. cf.** *japonica* **(Yabe), CPC 13687, sample P383. x 20.**

4. *Miogypsina* **sp., CPC 13688, sample P383. x 20.**

5. Thin section, sample 6852-2113, skeletal calcarenite with small specimens and fragments of foraminifera and algal fragments; lower *e* **(late Oligocene). x 14.**

PLATE 15



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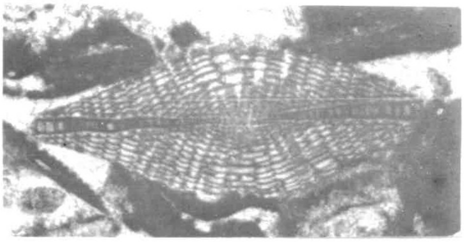

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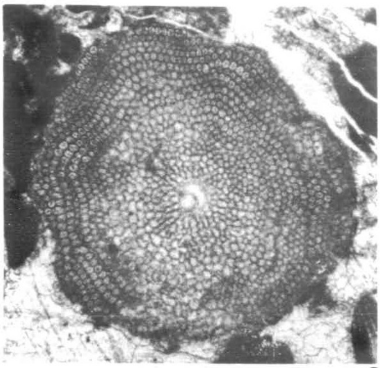

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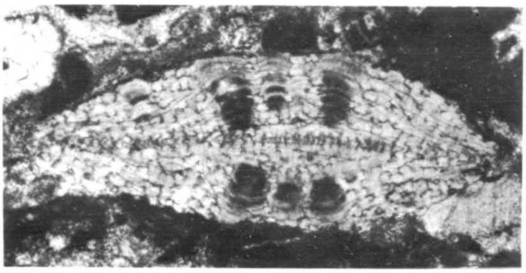

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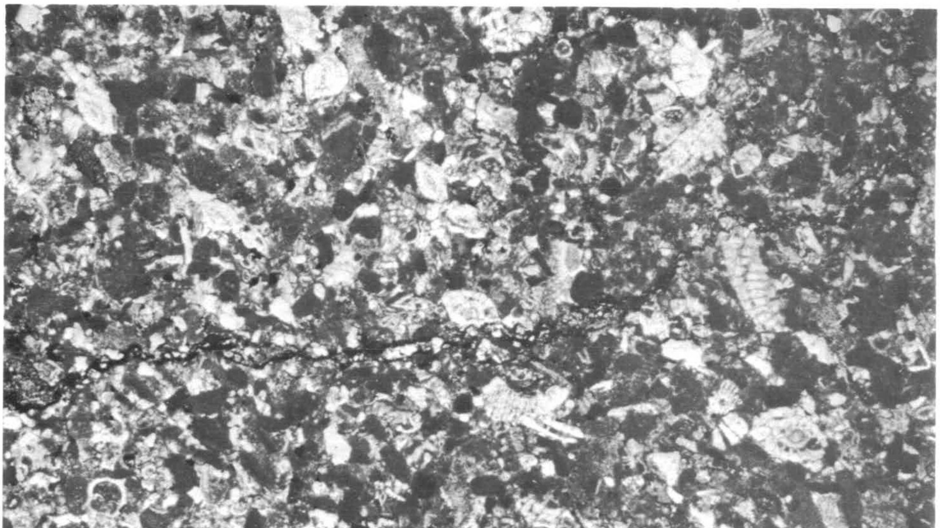

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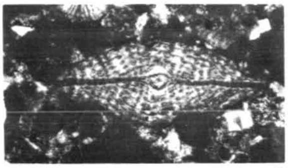
PLATE 16

Figures

- **1-3.** *Lepidocyclina* (*N.*) **sp., CPC 13689—13691, sample 6852-2113. x 20.**
- **4, 5.** *Lepidocyclina* (*N.*) cf. *augusticamera* **Cole, CPC 13692 and 13693, sample 6852-3154. x 20**
- **6, 7.** *Lepidocyclina* **spp., CPC 13694 and 13695. sample 6552-1328. x 20.**
- **8, 9.** *Spiroclypeus margaritatus* **Schlumberger, CPC 13696 and 13697, sample 6852-5044. x 20.**
- **10. 11.** *Halkyardia* **sp., CPC 13698, sample 6852-3154; CPC 13699, sample 6852-2113. x 80.**

PLATE 16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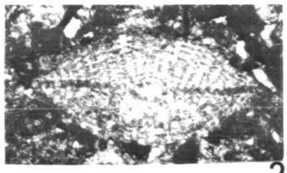
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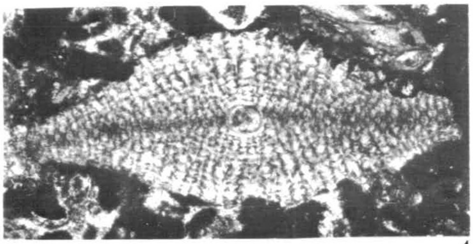
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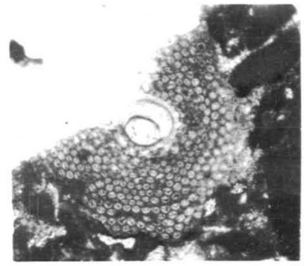
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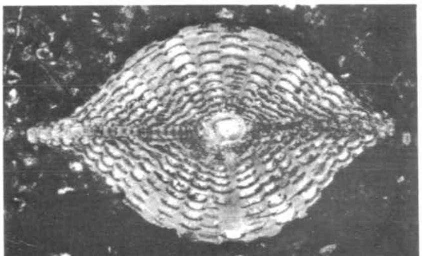
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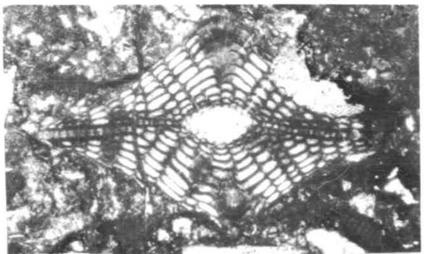
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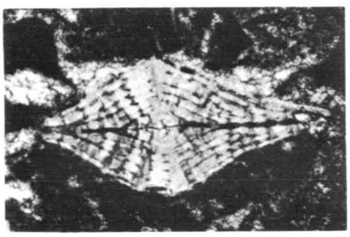
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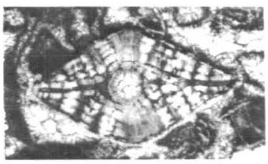
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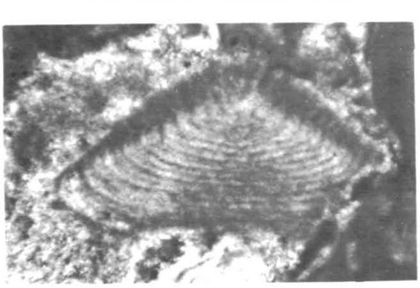
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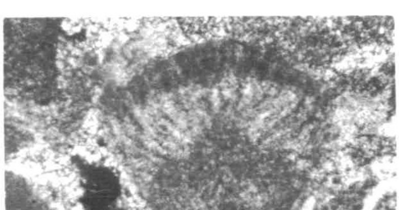
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PLATE 17

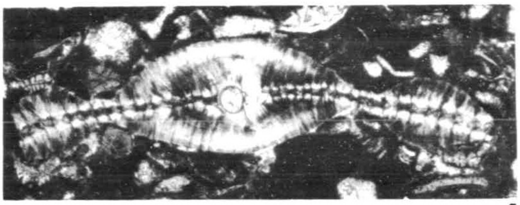
Figures

1. *Cycloclypeus* (*Katacycloclypeus*) **cf.** *martini* **van der Vlerk, CPC 13700, sample 6552-0702. x 20.**

2-4. *Planorbulinella* **sp., CPC 13701 and 13702, sample 6552-0702; CPC 13703, sample MH69B. x 20.**

5. **Thin section, sample 6852-2156, tuffaceous skeletal calcarenite; lower** *e* **(late Oligocene). x 14.**

PLATE 17



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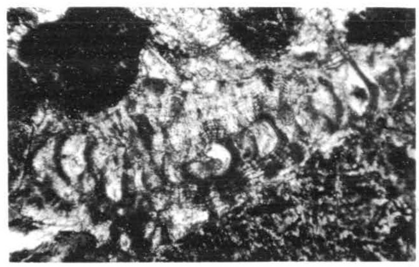

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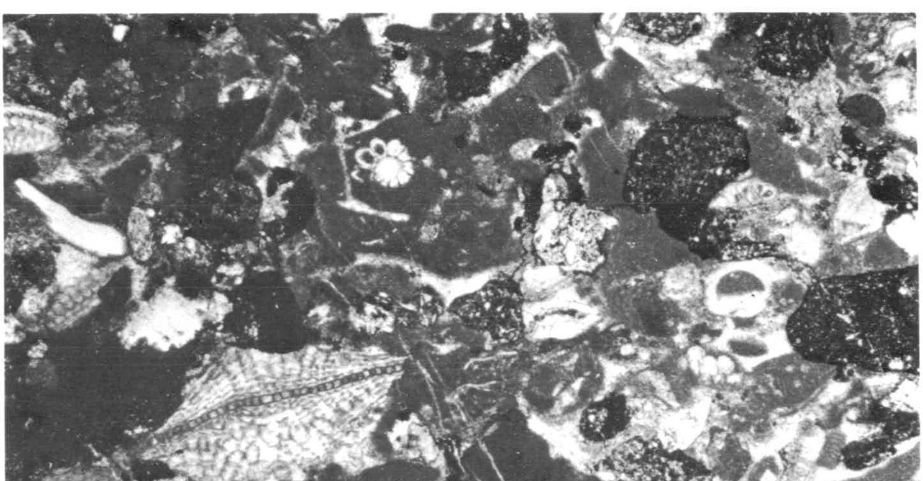

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PLATE 18

Figures

1. **Nucleoconch of** *Lepidocyclina (N.)* **sp., CPC 13704, sample 6852-2156. x 20.**

2. 3. *Heterostegina* **sp., CPC 13705 and 13706, sample 6852-2156. x 20.**

4, 5. *Lepidocyclina (N.)* **sp., similar to the** *L. angulosa* **(Provale)/***L. japonica* **(Yabe) group, CPC 13707 and 13708, sample 6852-2293. x 20.**

6. *Lepidocyclina* **sp., CPC 13709, sample 6852-2337. x 20.**

7. *Miogypsina* **sp., CPC 13710 and 13711, sample 6852-2337. x 20.**

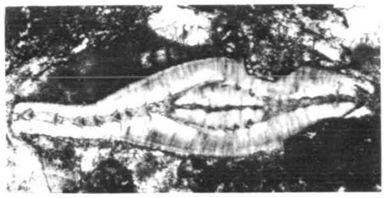
8. *Lepidocyclina (E.) ephippioides* **(Jones & Chapman), CPC 13712, sample 6852-2156. x 20.**

9. *Miogypsinoides* **sp.,** *M. complanata* **(Schlumberger)/***M. bantamensis* **Tan group, CPC 13713-13715, sample 6852-2157. x 20.**

10. **Enlargement of specimen of** *Miogypsinoides* **sp., shown in Figure 9, CPC 13715, some peri-embryonic chambers visible. x 75.**

PLATE 18

1



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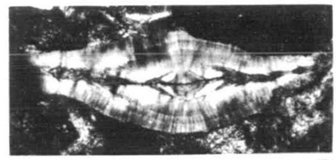

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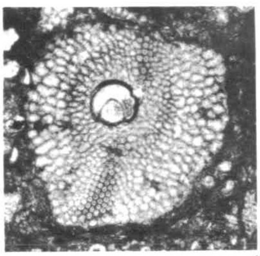

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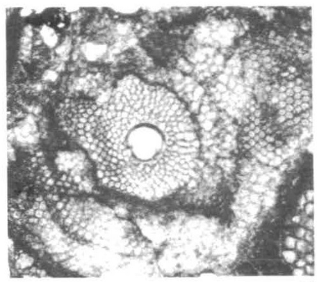

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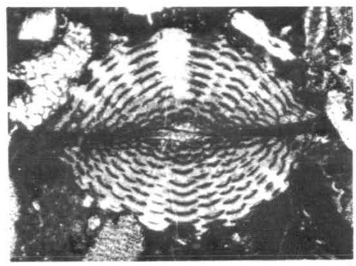

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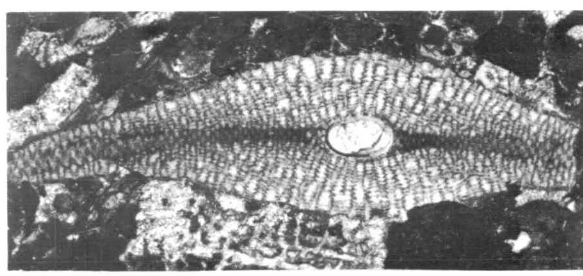

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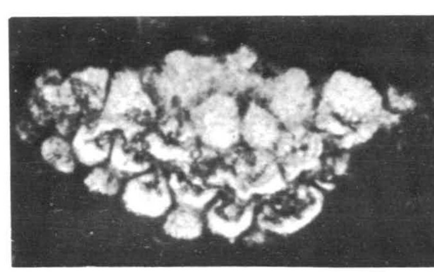

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PLATE 19

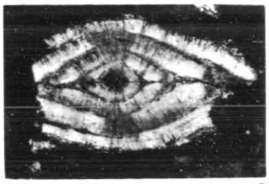
Figures

1-4. *Nummulites* **spp., 1-2, CPC 13716, 13717, sample 6852-2156; 3-4, CPC 13718, 13719, sample 6852-2157. x 20. (Reworked specimens).**

5. *Spiroclypeus vermicularis* **Tan., CPC 13720, sample 6852-2157. x 20. (Reworked specimen).**

6. Thin section, sample 6852-2147, tuffaceous skeletal calcarenite with fragments of larger foraminifera (*Lepidocyclina* sp., *Miogypsina* sp., *Cycloclypeus* sp.) and planktonic foraminifera; ?upper *e* (early Miocene). x 20.

PLATE 19



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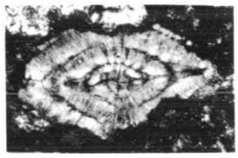

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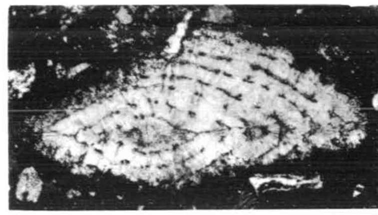

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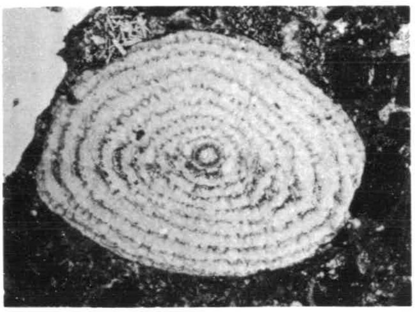

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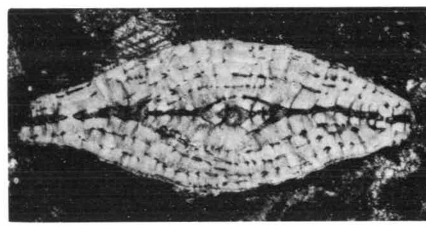

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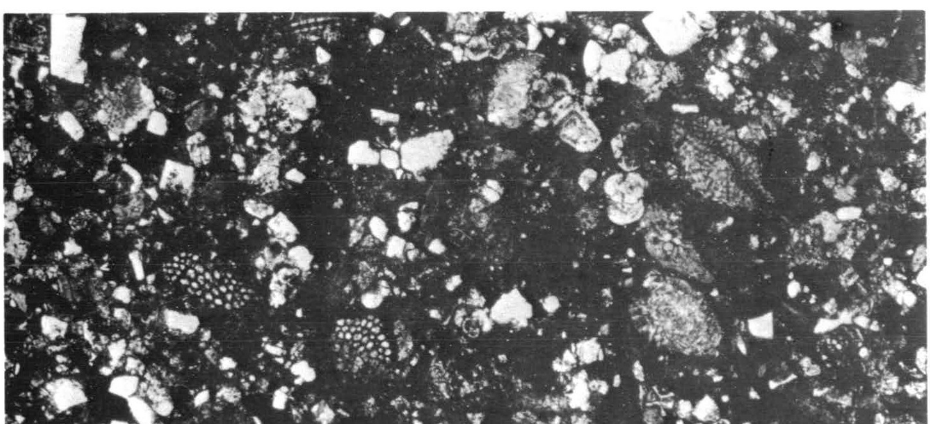

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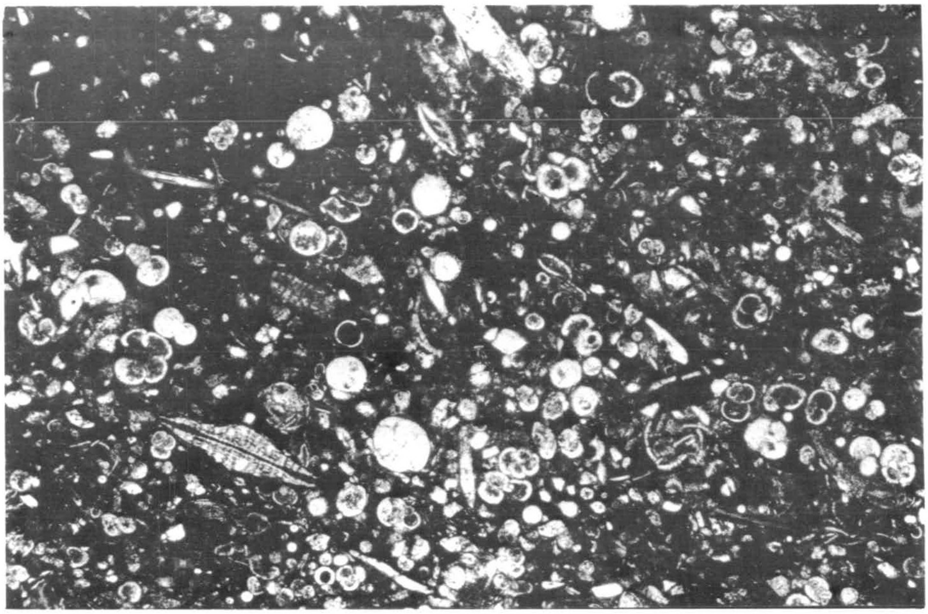
PLATE 20

Figures

1. **Thin section, sample 6852-3338, tuffaceous skeletal calcarenite with abundant planktonic foraminifera and rare small specimens of** *Lepidocyclina (N.)* **sp.; lower** *f* **(middle Miocene). x 20.**
2. **Fragment of** *Lepidocyclina (N.)* **sp., CPC 13721. sample 6852-2147. x 45.**
3. *Lepidocyclina (N.)* **sp., CPC 13722, sample 6852-3338. x 20.**
4. *Orbulina* **cf.** *O. suturalis*, **CPC 13723, sample 6852-3338. x 80.**
5. *Orbulina universa* **d'Orb., CPC 13724, sample 6852-3338. x 80.**

PLATE 20



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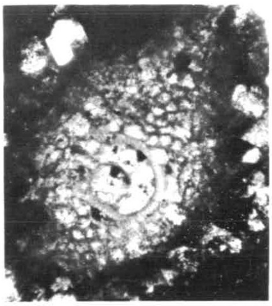

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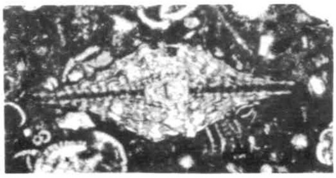

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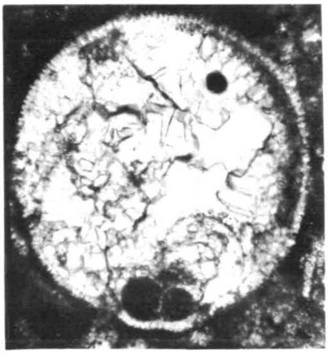

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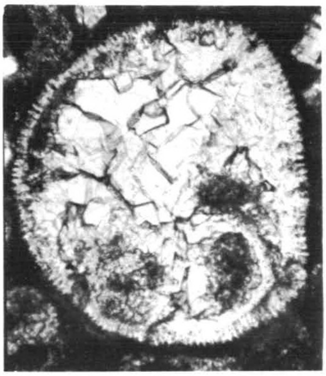

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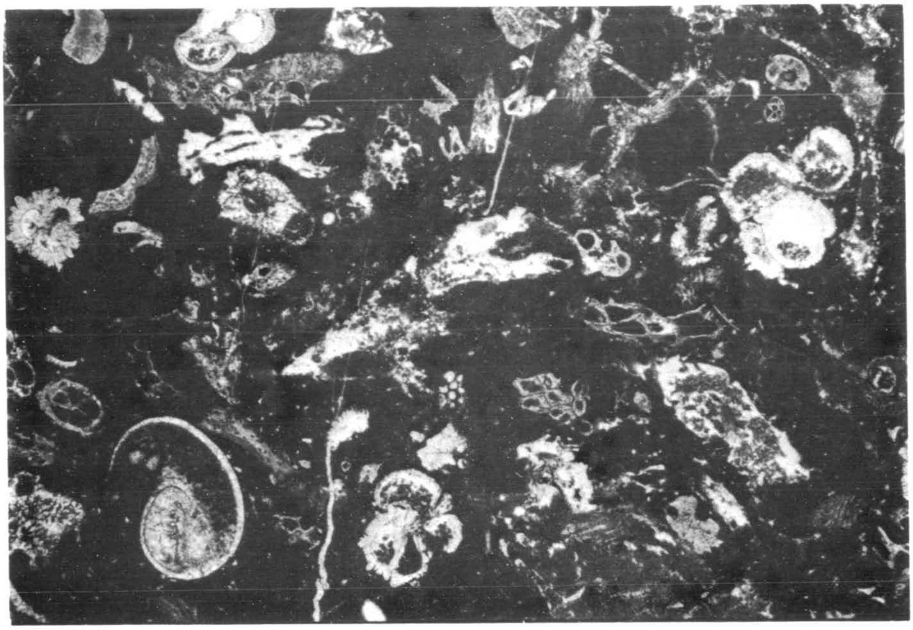
PLATE 21

Figures

1. **Thin section, sample 6852-3566, skeletal calcarenite with foraminifera (*Victoriella* sp.), Bryozoa, corals, algae, and Mollusca; Miocene. x 12.**
2. **Thin section, sample 6852-5040, skeletal calcarenite with foraminifera (*Amphistegina* sp., *Cellanthus* sp., *Operculina* sp., ?*Calcarina* sp.), Algae, molluscan fragments, and echinoid spines; Pliocene? x 15.**

PLATE 21



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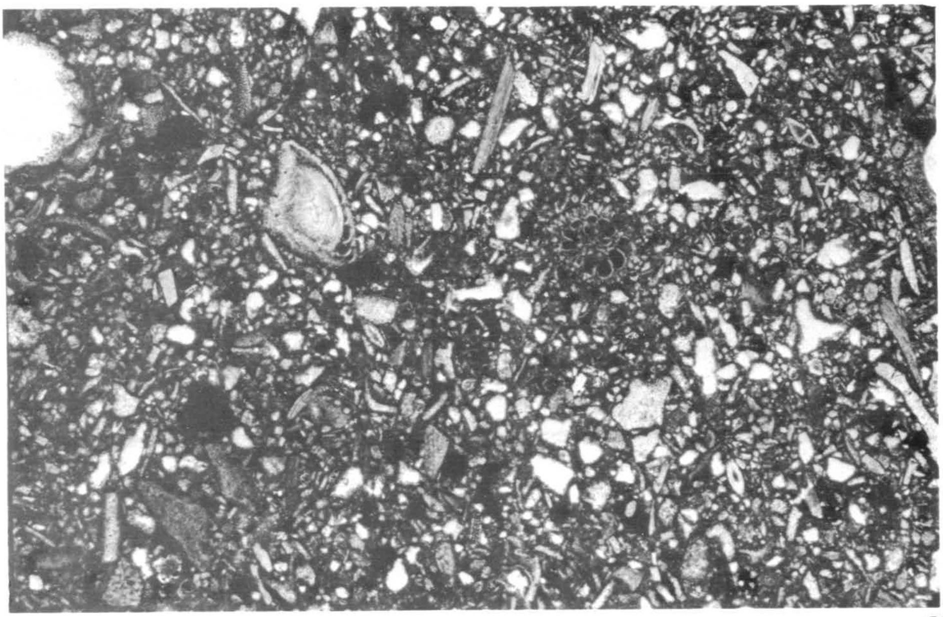

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PLATE 22

Figures

1. **Thin section, sample 6852-2299, porous skeletal calcarenite with foraminifera (*Baculogypsina sphaerulata* (Parker & Jones), *Amphistegina* sp.), Bryozoa, algae, and molluscan fragments; Pleistocene or younger. x 9.**
2. **Thin section, sample 6852-6037, tuffaceous skeletal calcarenite with algae, corals, Bryozoa, and rare smaller foraminifera including ?*Ammonia* sp.; age uncertain. x 9.**

PLATE 22

1

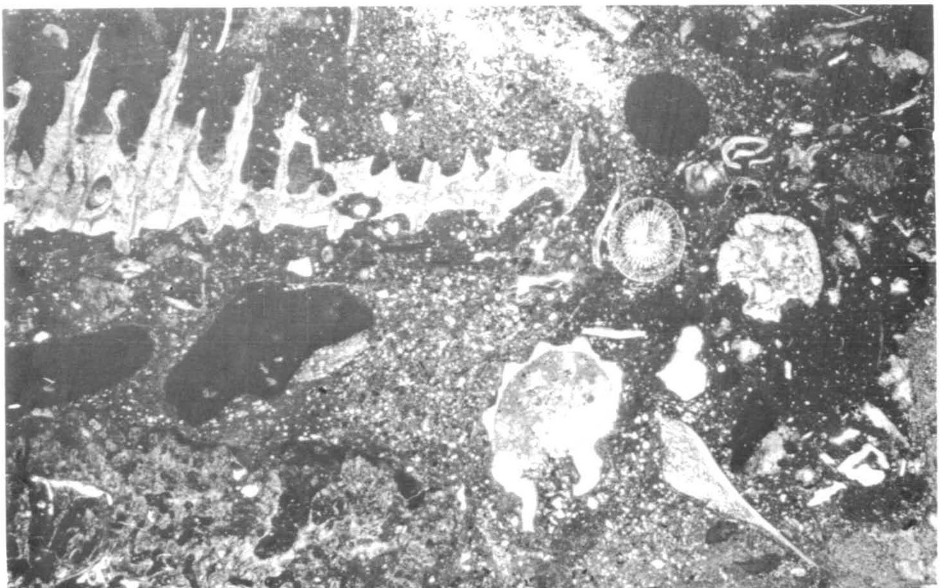

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PLATE 23

Figures

1. **Thin section, sample 6852-7008, tuffaceous micritic calcarenite with Mollusca (Gastropoda) and abundant smaller foraminifera (*Ammonia* sp.); not older than Miocene. x 16.**

2, 3. *Victoriella* **sp., CPC 13725 and 13726, sample 6852-3566. x 20.**

4, 5. *Baculogypsina sphaerulata* **(Parker & Jones), CPC 13727 and 13728, sample 6582-2299. x 30.**

6. *Alveolinella quoyi* **d'Orbigny, CPC 13729, sample 6852-5040. x 20.**

7. *Cellanthus* **sp., CPC 13730, sample 6852-5040. x 20.**

8. *Operculina* **sp., CPC 13731, sample 6852-5040. x 20.**

9. *Ammonia beccarii* **Linne, CPC 13732, sample 6852-7008. x 170.**

PLATE 23