COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Records 1970/116

Geology of Eastern Papua: A Synthesis

by

H. L. Davies and I. E. Smith

GEOLOGY OF EASTERN PAPUA: A SYNTHESIS

by

H.L. Davies & I.E. Smith

Records 1970/116

CONTENTS

ILLUSTRATIONS

ABSTRACT

Eastern Papua is a southeasterly-trending mountainous peninsula with islands to the east and southeast, between 7-12°S and 146-155°E. The peninsula and islands consist of a linear core of mesozoic sialic metamorphics flanked by Mesozoic and younger mafic rocks and partly concealed by still younger sediments and volcanics. The mesozoic sialic rocks are exposed in a belt 900 km long and up to 60 km wide. They consist of Cretaceous (and possibly older) sediments which were metamorphosed in the Palaeocene or Eocene. Metamorphic grade is generally greenschist facies, but is higher in the D'Entrecasteaux Islands and on part of Misima Island; lawsonite occurs only within a few kilometres of the Owen Stanley Fault which bounds the mainland metamorphics on the north and northeast. Mesozoic mafic rocks include peridotite, gabbro and basalt of the Papuan Ultramafic Belt, metabasalt exposed in the Suckling-Dayman mountain block and on Normanby and the Deboyne Islands, and unmetamorphosed basalt elsewhere on the mainland. These rocks are, at least in part, Cretaceous. Younger mafic rocks include Eocene basalt on the southeastern mainland, and Upper Oligocene and Lower and Middle Miocene tuff and lava at scattered localities. Eocene sediments consist of chert and deep-water limestone along the south coast of the mainland at Port Moresby and Magarida, and Eocene clastic sediments inland from Port Moresby and near Tapini. No Lower or Middle Oligocene rocks are known. Upper Oligocene, Miocene and Pliocene sediments in the Aure Trough (145°-146°E) have a maximum thickness of about 12,000 m; the sediments are mainly alternating mudstone and greywacke, and are probably turbidites. Middle Miocene reef limestone on the eastern hingeline of the Trough at 146°E is 1000 m thick. Middle Miocene and younger clastic sediments in the Cape Vogel Basin (150°E) are at least 4000 m thick. Pliocene and Quaternary volcanics range in composition from basalt to rhyolite and include some potash-rich rocks. Intrusive rocks include Eocene tonalite in the Ultramafic Belt, Oligocene? gabbro near Port Moresby, Middle Miocene granodiorite west of Salamaua and alkali-rich intrusives on the southeastern mainland, and younger andesitic porphyries. Granodioritic intrusives in the D'Entrecasteaux Islands are late Pliocene.

The Cretaceous (and possibly older) sialic sediments are thought to have been metamorphosed in the Palaeocene or Eocene at the time of emplacement of the Papuan Ultramafic Belt. The Ultramafic Belt is thought to be part of a thrust slice of oceanic mantle and crust which rode over or was underridden by the Cretaceous sediments on a low-angle fault (the Owen Stanley Fault). The metamorphic rocks were partly exposed in the Eocene but there was no major land mass in the area until the Upper Oligocene. In the Upper Oligocene, Miocene and Pliocene the sialic metamorphics emerged, perhaps isostatically. Erosion of the resulting mountain block and contemporary volcanism and limestone development contributed great volumes of sediment to the Aure Trough and lesser volumes to the Cape Vogel Basin. The history of the area can be interpreted in terms of interaction between Australian and Pacific lithospheric plates, and opening of the Coral Sea by rifting.

GEOLOGY OF EASTERN PAPUA: A SYNTHESIS

by

H.L. Davies and I.E. Smith

Records 1970/116

INTRODUCTION

Interest in the geology of the Territory of Papua and New Guinea has recently increased due to the development of the concept of plate tectonics, and the discovery of porphyry copper mineralization and potentially commercial volumes of natural gas. The Australian Bureau of Mineral Resources has been engaged in regional (1:250,000 scale) geological mapping of the Territory since the 1950's, and much information is now available in published and unpublished reports. This paper synthesizes information from these and other (mainly oil company) sources and from current work.

Aspects of the geology of Papua - New Guinea have been discussed in general terms by Glaessner (1950), Thompson and Fisher (1965) and Thompson (1967), and a comprehensive bibliography has been prepared by Manser and Freeman (in press). The geology of western and central Papua has been described by Australasian Petroleum Company (1961) and Rickwood (1968), and of central Papua by Pitt (1966). The regional gravity pattern has been described by St. John (1967) and the gravity pattern of eastern Papua by Milsom (in prep.). Airborne magnetometer surveys cover the Gulf of Papua and part of the mainland (Compagnie Generale de Geophysique, 1969) and a survey of the southeastern mainland is in progress. Information on the geology of the Solomon Sea has been presented by Rose and others (1968) and Khan and Woollard (1968), and on the Coral Sea by M. Ewing and others (1970), J. Ewing and others (1970) and Gardner (1970). Detailed information on the seafloor off the north coast of eastern Papua has been presented by von der Borch (in press) and on the Milne Bay area by Jongsma (in press). Information from current work (Smith and others, in prep.) has been included in the following text without literature references. Some of this information was presented in an earlier compilation (Davies and others, 1968).

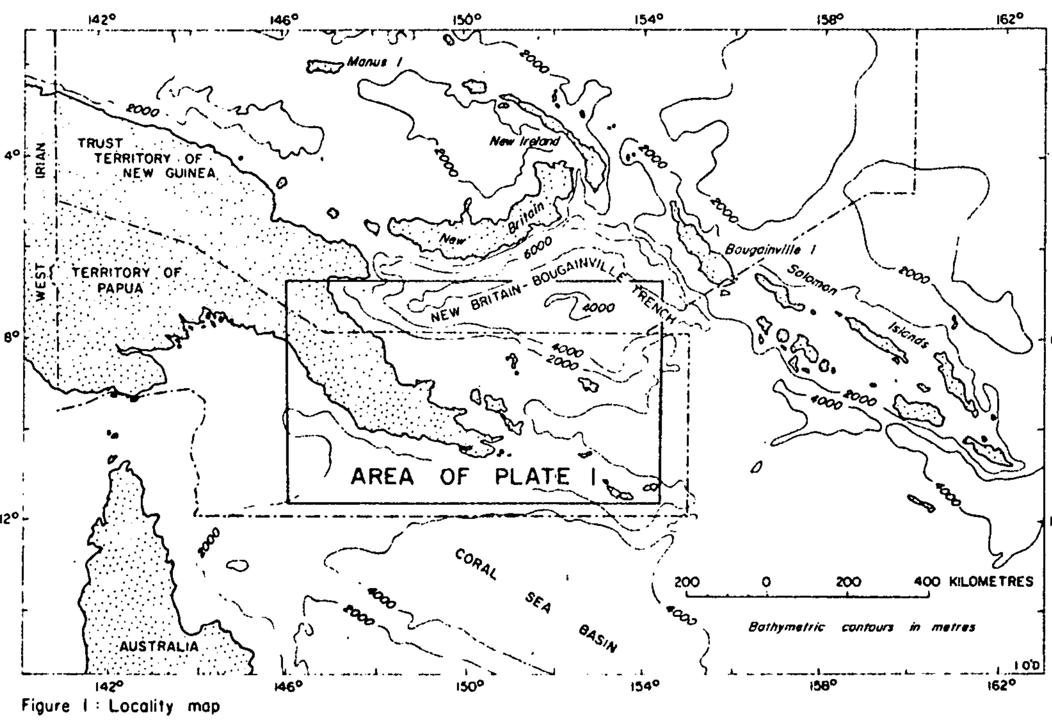

Figure 1 : Locality map

To accompany Record 1970/116

P/A 335

ACKNOWLEDGEMENTS

We have drawn heavily upon the unpublished work of our colleagues at B.M.R. and in the Geological Survey of Papua - New Guinea. In particular we are indebted to D.J. Belford, R.W. Page, G. Cifali, D.J. Grainger, R.F. Heming, P.D. Hohnen, R.P. Macnab, P.E. Pieters and J.A.J. Smit. R.W. Kistler of the U.S. Geological Survey kindly carried out K-Ar age determinations on two samples of low-K gabbro, and R.G. Coleman and others at the Menlo Park branch of the Survey have encouraged and advised on current study of the metamorphic rocks. In an earlier draft this paper was critically read by R.R. Compton, W.R. Dickinson and G.A. Thompson of Stanford University and in final form it was read by G.E. Wilford; this assistance is much appreciated. We are grateful to W.R. Dickinson, D.A. Falvey and J.S. Milsom for a useful exchange of views on regional tectonics and gravity data interpretation.

PHYSIOGRAPHY

The eastern Papuan mainland is a southeasterly trending mountainous peninsula 600 km long and up to 190 km wide. The Owen Stanley Range extends the length of the peninsula and is for the most part an impressive mountain mass with peaks 3000 to 4000 m above sea level. The main offshore islands are the D'Entrecasteaux Islands, Woodlark Island and the Louisiade Archipelago which includes Sudest, Rossel and Misima Islands (Pl. 1). Tropical rain forest covers most areas. Seasons are controlled by southeast (May-October) and northwest (December-March) monsoons.

GEOLOGY

The eastern Papuan mainland and islands consist of a west-north-westerly-trending core of sialic rocks flanked by predominantly mafic rocks and younger clastic and volcanic rocks. The exposed part of the sialic core consists of Mesozoic schist and gneiss and Tertiary granitic intrusives. The mafic flanks are predominantly basalt, gabbro and peridotite, but include some tonalite, monzonite, syenite, andesite, dacite, limestone and chert. We suggest that the sialic core is continental crust, and the mafic rocks are oceanic crust.

Mesozoic sialic rocks

Schist and gneiss of varied metamorphic grade make up the sialic core of eastern Papua. These rocks are exposed discontinuously in a belt, 900 km x 60 km, which extends from the northwest to the southeast corner of the map (Plate 1). The belt is more or less linear with a kink at 150°E, and an arcuate change in trend from 300° to 360° at the northwestern end. On the mainland the metamorphics are bounded on one side by the Owen Stanley Fault.

The metamorphics have formed from Cretaceous and possibly older sediments. Cretaceous megafossils have been found near Wau (7°20'S, 146°40'E; Glaessner, 1949; Skwarko, 1967, p. 89-101) and Upper Cretaceous microfossils occur in outcrop in the Auga and Dilava Rivers (8°30'S, 147°E; Macnab, 1969; Hohnen, 1968). The main metamorphic event was post-Cretaceous and probably pre-Eocene.

Metamorphic grade is most commonly greenschist facies, varying from low greenschist with only partial recrystallization, to completely recrystallized high greenschist. Lawsonite and glaucophane are developed in places. Metamorphic grade in some of the islands is amphibolite facies with small pockets of pyroxene granulite facies.

Owen Stanley Range. Graphite-quartz-feldspar-mica schists with minor marble and basic schist and rare schistose conglomerate, make up the main range of eastern Papua between 146°30' and 148°15'E. (information from reconnaissance traverses by P.E. Pieters and H.L. D.). Where the original sediment can be recognized it is most commonly tuffaceous lithic labile sandstone, siltstone, or mudstone, with quartz, plagioclase, acid volcanic clasts and some carbonaceous material. Metamorphic grade north of about 8°15'S is mostly low grade greenschist facies; the rocks are schist and less commonly subschist, some of which show incipient recrystallization of only the finer matrix minerals. There is some evidence that metamorphic grade may increase with depth. South of about 8°15'S metamorphic grade is generally higher greenschist facies characterized by complete recrystallization. Lawsonite occurs in metamorphics along the entire length of the Owen Stanley Fault in a zone probably a few kilometres wide. Lawsonite-glaucophane gneiss is exposed near the Owen Stanley Fault at 8°02'S but is not known elsewhere in the main range. Glaucophane appears to be more widespread than lawsonite. Lower grade phyllitic rocks on the western and southwestern flank of the Owen Stanley Range metamorphics may either grade into the metamorphics (Smit, in prep.) or be a separate and possibly younger rock unit. Contact aureoles around Middle Miocene granodiorite northeast of Wau include tourmaline and andalusite-bearing schists.

Bedding is generally not preserved. The metamorphic foliation is tightly folded in places but elsewhere dips consistently as though uniformly tilted or folded into broad anticlinal structures. For instance, along most of the northeastern front of the range the foliation dips consistently to the northeast.

D'Entrecasteaux Islands. Schist and gneiss form the mountainous parts of the D'Entrecasteaux Islands (Davies & Ives, 1965). The metamorphic grade is amphibolite and locally pyroxene granulite facies, except on southeastern Normanby Island (Davies, 1969). About 90 percent of the exposed metamorphics have overall granodioritic composition, but calcic and mafic schist and amphibolite predominate in the upper part of the section. Aluminous and graphitic schists are rare, indicating that the original rocks included little siltstone, shale, or mudstone. Three main categories of metamorphics have been recognized on lithologic and structural grounds. These form a stratigraphic succession consisting of, from bottom to top: (1) quartzo-feldspathic gneiss with some migmatite, (2) quartzo-feldspathic gneiss which is well foliated and layered, and (3) layered amphibolite.

Fine-scale bedding is not preserved but probable large-scale bedding can be recognized in the form of major lithological variations, such as marble horizons in quartzo-feldspathic schist, and the interlayering of quartzo-feldspathic schist and amphibolite. The large-scale bedding is consistently parallel to metamorphic foliation. The metamorphic foliation is simply folded into domes and anticlines of 15-20 km half-wavelength and about 5 km amplitude, and these domes and anticlines form the main ranges. Late Pliocene granodiorite batholiths intrude the cores of the domes (K-Ar ages by Australian Mineral Development Laboratories, 1970).

Louisiade Archipelago. The islands of the archipelago (152°-$154^\circ 20'$E) are mostly made up of low grade fine-grained mica-bearing schists comparable to those of the Owen Stanley Range. On Misima Island both schist and the higher grade D'Entrecasteaux-type gneiss are present, the gneiss in the west and the schist in the east. Tertiary dacitic and andesitic porphyries intrude schist on Misima Island (de Keyser, 1961) and on islands at the western end of the Calvados Chain (Smith & Pieters, 1969).

Area between Owen Stanley Range and D'Entrecasteaux Islands. Gravity data (St. John, 1967; J.S. Milson, pers. comm., 1968) indicate that sialic rocks underlie part of the area east and west of Mount Suckling, between the Owen Stanley Range and the D'Entrecasteaux Islands, $9^\circ 30'$-10°S, $148^\circ 15'$-$149^\circ 20'$E. Outcrop in this area is generally mafic and ultramafic, although there are some calcic schists near Mount Suckling which contain up to 30 percent quartz. The only other evidence that sialic rocks might underlie the region is the occurrence of two granite stocks immediately south of Mount Suckling.

Mesozoic Mafic Rocks

Mesozoic mafic rocks in eastern Papua include peridotite, gabbro, and basalt of the Papuan Ultramafic Belt, the metamorphosed basalts of the Suckling-Dayman mountain block and Normanby Island, peridotite and gabbro in the D'Entrecasteaux Islands and on Rossel Island, and a large area of basalt in the southeastern mainland.

Papuan Ultramafic Belt. The Papuan Ultramafic Belt is 400 km long and up to 40 km wide and forms mountainous country on the north-eastern side of the Owen Stanley Range between 147° and 149°E (Smith and Green, 1961; Dow and Davies, 1964; Davies, 1968; in press). It consists of three layers (from bottom to top); peridotite (4-8 km), gabbro (4 km) and basalt (4-6 km). Most of the ultramafic rocks are harzburgite, dunite, and enstatite pyroxenite with allotriomorphic metamorphic textures. At the contact between the peridotite and gabbro layers is a discontinuous layer of ultramafic rocks with cumulus textures.

Unlike the other ultramafics, these include some clinopyroxene along with the ubiquitous olivine, orthopyroxene and chromite (England & Davies, 1970). The gabbro layer consists of gabbro and norite, some with layering and cumulus textures, and some clearly intrusive into older gabbros. The cumulus gabbroic rocks grade downwards into the cumulus ultramafic rocks of the ultramafic layer. Elsewhere the contact between the two layers is intrusive, gabbro into peridotite. The basalt layer consists of massive basalt and submarine basalt lavas and pillow lavas; dacitic lavas and pyroclastics are developed locally. The contact between gabbro and basalt layers is in places transitional through a "high-level gabbro" or doleritic phase, but is commonly obscured by Eocene tonalite intrusions.

The age of crystallization of the gabbroic and basaltic parts of the Ultramafic Belt is Jurassic and/or Cretaceous. Two gabbros with K_2O content of .012% and .006% have K-Ar ages of 147 and 150 m.y. respectively (R.W. Kistler, pers. comm., 1970). Pyroxenes in a basalt sample gave a K-Ar age of 116 m.y. (R.W. Page, pers. comm., 1968). The Ultramafic Belt was emplaced by thrust faulting immediately after the Cretaceous, or in Eocene or Oligocene time. It is thought to be part of a thrust plate of oceanic mantle and crust which rode over, or was underridden by, the sialic metamorphics of eastern Papua (Thompson & Fisher, 1965; Davies, 1968; in press).

Suckling-Dayman mountain block. This mountain range (148°50' - 149°20'E) is 60 km long and 20 km wide. The highest points are Mount Suckling in the west (3591 m) and a peak in the east variously known as Mt Dayman, Orian, or Aniata (2986 m); the lowest point on the watershed (1800 m) is about midway between Suckling and Dayman. The eastern two-thirds of the mountain block has the shape of an elongate dome with only shallow stream dissection and this has been termed the Daymen Dome. The western third is deeply dissected, probably because of more vigorous recent uplift.

The mountain block is an east-west anticline developed in moderately metamorphosed basalt, gabbro, and limestone. Limestone near Mount Dayman contains Upper Cretaceous planktonic microfossils, and it is thought that most or all of the mafic rocks are Cretaceous. Schistosity is parallel to bedding in the few instances, such as at limestone horizons, where bedding can be determined. The degree of schistosity varies: at one locality where schistosity is poorly developed the basalt retains pillow texture. The degree of metamorphism also varies. The only recognizable metamorphic mineral in some mafic rocks from near Mount Dayman is pumpellyite, but others from near Mount Suckling contain actinolite and glaucophane, and calcic schists from near Mount Suckling contain lawsonite. Metamorphic grade thus seems to range from pumpellyite (-prehnite?) facies to intermediate between low-grade blueschist and greenschist facies.

East-southeast of the Goropu Mountains the Upper Cretaceous limestone grades into marble schist which can be traced for 25 km, and Cretaceous basalt may extend for as much as 100 km. The limits of unmetamorphosed Cretaceous basalt are not well defined because it cannot easily be distinguished from adjacent Eocene and possibly younger basalt. Upper Cretaceous microfossils occur in limestone associated with basalt immediately south and southeast of the Suckling-Dayman mountain block (Smith and others, in prep.), and in the western part of the map area, south of Tapini (Macnab, 1969; Hohnen, 1968).

D'Entrecasteaux Islands. Mesozoic mafic rocks in the D'Entrecasteaux Islands include gabbro and peridotite similar to those found in the Papuan Ultramafic Belt, and metabasalt similar to that which makes up the Goropu Mountains. Gabbro and peridotite form fault-bounded blocks on Normanby and Fergusson Islands, and peridotite occurs as thin fault-slices along the northeastern fault on Goodenough Island. Cretaceous(?) basalt on southern Normanby Island is metamorphosed to low greenschist or greenschist-blueschist facies, with development of some glaucophane and stilpnomelane (Davies & Ives, 1965; Davies, 1969).

Louisiade Archipelago. The Deboyne Islands (10°45'S, 152°25'E) are largely made up of metamorphosed basic volcanics and associated intrusives. On Rossel Island (11°20'S, 154°E) metagabbro is exposed in the north and east, and a clinopyroxenite sill intrudes sialic schists in the southwest (Smith & Pieters, 1969).

Mesozoic carbonate rocks

Limestone is associated with the Mesozoic sialic and mafic rocks discussed above. Metamorphosed limestone is present in varying amounts throughout the schists and gneisses of the Owen Stanley Range and is strongly developed at several localities (e.g. 9°10'S, 147°50'E; 9°30'S, 148°E). Limestone with the Mesozoic basalts and metabasalts occurs both as minor marly intercalations and as massive interbeds such as are exposed near Mount Suckling. Where diagnostic textures or fossils are preserved the limestone appears to be of deep rather than shallow-water origin. Isolated outcrops of Cretaceous limestone and some sandstone with planktonic foraminifera are also known from near Port Moresby (Glaessner, 1952; Yates and de Ferranti, 1967).

Palaeocene

Palaeocene planktonic foraminifera have been identified in siltstone from one locality on Cape Vogel peninsula, 9°35'S, 149°50'E (Thompson, 1967; Belford, 1968) and in specimens from several localities in the Port Moresby area (Australian Petroleum Company, 1961; D.J. Belford, pers. comm., 1970). Both of these occurrences are too small to be shown on Plate 1.

Eocene

Eocene rocks are known from the northern part of the Ultramafic Belt, near Tapini, near Port Moresby, and the southeastern mainland.

Eocene tonalite intrudes at and near the basalt-gabbro contact in the northern Ultramafic Belt; ages of 50-55 m.y. have been determined on a number of samples by K-Ar method (A.W. Webb, pers. comm., 1965; R.W. Page, pers. comm., 1967). Small bodies of tonalite at the gabbro-basalt contact in the central and southeastern part of the Ultramafic Belt are by analogy also possibly Eocene. Dacitic volcanics which overlie basalt in the northern Ultramafic Belt may be Eocene, and are possibly related to the tonalite intrusions. The dacitic volcanics are associated with jaspillitic limestone which contains Eocene planktonic foraminifera (D.J. Belford, pers. comm., 1970).

Eocene rocks near Tapini (8°20'S, 147°E) include bioclastic limestone with benthonic foraminifera (Terpstra, 1969). The limestone contains clasts of schist and strained quartz which have probably shed from the sialic metamorphics of the Owen Stanley Range. An adjacent sequence of interbedded sandstone and phyllitic shale and siltstone may also be Eocene. Other reported Eocene rocks south of Tapini (Mafulu Group of de Vertuil and Rickwood, 1946) are at least partly Upper Oligocene-Lower Miocene; Tertiary e stage foraminifera have recently been found in specimens which are otherwise completely dominated by Eocene forms (Macnab, 1969, Appendix 3).

Eocene chert and calcilutite form coastal foothills near Port Moresby (Port Moresby Beds: Glaessner, 1952; Yates & de Ferranti, 1967) and further east near Magarida. Inland from Port Moresby the cherts give way to fine-grained clastic sediments which in turn are transitional into basalt pillow lavas at about 148°E (Yates & de Ferranti, 1967; P.E. Pieters, pers. comm., 1970).

Basalt pillow lavas which make up much of the southeastern mainland are partly Eocene and partly Upper Cretaceous. The Eocene lavas are mainly exposed from 148° to 148°45'E and from 149°45'E to the eastern tip of the mainland. Ages are based on planktonic foraminifera in minor limestone lenses and interbeds. Benthonic foraminifera have been found at only one locality, a limestone interbed 3-7 m thick, north of Milne Bay. The microfaunas indicate upper Middle to lower Upper Eocene age.

Eocene or Oligocene volcanics (Loluai Volcanics) are exposed on Woodlark Island where they are unconformably overlain by Middle Miocene volcanics (Trail, 1967). Rock types include pillow lava, agglomerate, tuff and fine-grained sediments.

Lower and Middle Oligocene

No Lower or Middle Oligocene sediments have been positively identified in eastern Papua. The Dokuna Tuff at Port Moresby has been described as Middle Oligocene (Glaessner, 1952) but recent work indicates that it is probably Upper Oligocene with derived Eocene and Middle Oligocene foraminifera (Yates & de Ferranti, 1967).

Upper Oligocene to Lower Miocene (Tertiary e stage)

The Tertiary e stage of the Indonesian letter classification was previously thought to be Lower Miocene but is now equated with Upper Oligocene to Lower Miocene. The Tertiary f_{1-2} or Lower f stage was also previously thought to be Lower Miocene but is now equated with the Middle Miocene, 12.5 - 15 m.y. (Turner, 1969; Page & McDougall, 1970) or lower Middle Miocene (Clarke & Blow, 1969). These revisions are summarized below:

Previous usage (e.g. Paterson & Kicinski, 1956; Australasian Petroleum Company, 1961)

Indonesian letter stage	Lyellian	Papuan Stage	Eurpoean Stage
h	Plio		
g	U. Mio	Muruan	Sarmatian
f_3	M. Mio	Ivorian	Vindobonian
f_{1-2}	L. Mio	Taurian	Burdigalian
e	L. Mio	Kereruan	Aquitanian

Current usage (Clarke & Blow, 1969; Page & McDougall, 1970)

Indonesian letter stage	Lyellian		Papuan stage (Clarke & Blow)		Age, m.y.
	(Clarke & Blow)	(Adopted in this report)			
h	Plio	Plio	U. Muruan		-5.5
g	U. Mio	U. Mio	L. Muruan		5.5-9
f_3	u. M. Mio	l. U. Mio	Ivorian	Kikorian	9-12.5
f_{1-2}	l. M. Mio	M. Mio	Taurian		12.5-15
e	U.Olig.-L.Mio	U.Olig-L.Mio	Kereruan		15-22.5-30(?)

Upper Oligocene to Lower Miocene clastic sediments are exposed in the westernmost part of Plate 1 (Aure Trough, 146°E) and scattered volcanics and limestone of this age occur elsewhere in eastern Papua. Limestone has been found south and east of Tapini (Macnab, 1969; Davies, in prep.) and in the western islands of the Calvados Chain, 11°05'S, 152°20'E (Smith & Pieters, 1969). Limestone and volcanics occur in the Port Moresby area (Yates & de Ferranti, 1967) and volcanolithic sediments and tuff on the Cape Vogel peninsula and southwest of Milne Bay. Tuff on Cape Vogel peninsula contains e stage foraminifera (Davies and others, 1968) and nearby submarine basalt, which includes some devitrified glass, has a K-Ar age of 28 ± m.y. Some of the basalt contains clinoenstatite (Dallwitz and others, 1966; Dallwitz, 1968). The volcanolithic sediments southwest of Milne Bay include sandstone, limestone and pebble conglomerate with benthonic foraminifera, and turbidites with planktonic foraminifera.

Gabbro and dolerite which intrude Eocene sediments in the Port Moresby area (Sadowa Gabbro) are thought to be Oligocene (Yates & de Ferranti, 1967) and gabbroic and monzonitic and syenitic intrusives in the southeastern mainland are probably Oligocene or Miocene.

Aure Trough. The following information is from the Australasian Petroleum Company (1961). The Aure Trough is the north-south trending eastern part of what has been termed the Papuan Geosyncline. The axis of the trough is between 145 and 146°E and there is a hinge line marked by limestone reefs at 146°E (the western edge of Plate 1). Sedimentation began in the Tertiary e stage and continued through Middle and Upper Miocene and Pliocene. Maximum thickness of sediments is 11,000-12,000 m.y. comprising at least 4500 m of Tertiary e and f_{1-2} stages, 1500-1800 m of f_3 stage, 2500-3000 m of g stage and up to 2500 m of Pliocene. Sediments in the axis of the trough are mainly alternations of mudstone and greywacke and were probably deposited by turbidity currents. Diagnostic larger foraminifera are rare. The greywacke is a poorly sorted lithic labile sandstone which includes material from contemporary volcanism and clasts of reef limestone, schist and strained quartz. Samples of Upper Miocene mudstone and greywacke examined by Edwards (1950) had chemical compositions equivalent to andesite lava and consisted largely of clasts of plagioclase, hornblende, pyroxene and andesite lava.

Middle Miocene (Tertiary f_{1-2} stage)

The Middle Miocene was a time of continued rapid sedimentation in the Aure Trough and of reef growth and probably volcanism on its eastern margin. Shallow-water limestones up to 1000 m thick are exposed in the Tauri and Kapau Rivers at about 146°E. About 3000 m of volcanics on the Tapini-Woitape area (Talama Volcanics; Macnab, 1969) is thought to be Middle Miocene but without direct fossil evidence. Middle Miocene conglomerate in the Oroi petroleum exploration well, southeast of Yule Island, consists of clasts of phyllite, schist, quartz, greenstone and chert and thus was probably derived from the Mesozoic metamorphics of what is now the main range.

On the northern side of the main range several thousand metres of basaltic pyroclastic shallow marine sediments were laid down in the Cape Ward Hunt area (Iauga Formation; Paterson and Kicinski, 1956). Andesitic volcanic sediments and minor limestone were also laid down in Sewa Bay on Normanby Island (Davies, 1969), on the north coast of Misima Island (de Keyser, 1961), and on Woodlark Island (Trail, 1967). The Woodlark Island section is of particular interest because it is mineralized and intruded by penecontemporaneous biotite tonalite. It consists of a sequence of limestone, tuff, agglomerate and fine-grained sediments which includes an unconformity (Trail, 1967). There is some Middle Miocene limestone in the Port Moresby area (Yates and de Ferranti, 1967) and Middle Miocene reef limestone in the Adau River headwaters at 148°50'E, and on Cape Vogel peninsula (149°50'E).

The Morobe Granodiorite which intrudes sialic metamorphics northeast of Wau (7°20'S, 146°40'E) has a K-Ar age of 12-15 m.y. (Page, 1971). Other granitic rocks and andesitic porphyries which intrude the metamorphics are probably younger.

Cape Vogel Basin. This name has previously been applied to almost the entire length of the north coast of eastern Papua (Paterson and Kicinski, 1956) but is here restricted to sediments exposed on the Cape Vogel peninsula. The oldest rocks on the peninsula are Upper Oligocene lavas and tuffs exposed in an east-west fault bounded ridge. Clastic sedimentation began in the Middle Miocene (one sample of lithic sandstone with plant remains contains diagnotic Middle Miocene foraminifera) but most of the clastic sediments are thought to be Upper Miocene and Pliocene. Papp and Nason-Jones (1930) estimated a total thickness of 4200 m of lithic sandstone and siltstone, polymict conglomerate, marl and tuff. The east-west ridge of Upper Oligocene lavas separates gently folded mainly clastic sediments on the south side from steeply dipping finer-grained and more calcareous sediments on the north. The clastic sediments consist of predominantly basaltic detritus derived from the main range to south.

Upper Miocene and younger

Clastic sediments. In the Upper Miocene and Pliocene, clastic sediments were deposited in the Aure Trough and Cape Vogel Basin. Pliocene sediments in the eastern part of the Aure Trough are continental sandstone and conglomerate derived from contemporary volcanism. In the Musa Valley (148°40'E) up to 1000 m of continental sediments and volcanics were laid down in an intermontane basin in the Plio-Pleistocene. Other Plio-Pleistocene sediments include cross-bedded deltaic deposits, more than 1000 m thick, exposed immediately south and southwest of Cape Vogel and discontinuously along the coast east of Rabaraba.

Volcanics. Pliocene(?) volcanics cover large areas south of Tapini and Woitape (Mount Davidson Volcanics; Macnab, 1969) and east of Port Moresby (Astrolabe Agglomerate; Yales & de Ferranti, 1967), and are exposed along the south coast near Cloudy Bay and near Mullins Harbour. Pliocene volcanics form the southeastern part of the Mount Lamington - Managalase volcanic province (Ruxton, 1966), and some of the volcanics on Normanby and Fergusson Island are probably Pliocene. Volcanics in the Lusancay Islands (8°30'S, 150°30'E), Egum Atoll (9°30'S, 152°E) and on islands in the western Calvados Chain (11°S, 152°30'E) are also probably Pliocene (Smith & Pieters, 1969; current work by I.E.S.).

Quaternary volcanics are grouped around the active cones Mount Lamington (Taylor, 1958) and Mount Victory (Smith, 1969) on the mainland, and Lamonai, Oiau and Dobu in the D'Entrecasteaux Islands. The Mount Lamington area includes the Hydrographers Range and the Managalase Plateau (Ruxton, 1966). The Mount Victory area includes the deeply eroded Mount Trafalgar cone which with Victory forms the Cape Nelson peninsula, and the separate eruptive centre Goropu or Waiowa (Baker, 1946) to the south. The D'Entrecasteaux volcanics include many well preserved small cones, craters, and lava domes on Goodenough and Fergusson Islands. Mount Victory erupted in the 1890's, Goropu in 1943-4 and Mount Lamington in 1951.

The Pliocene and Quaternary volcanics range from basaltic to rhyolitic and include some alkali-rich types. Lavas from Mount Lamington, Hydrographers Range and the Cape Nelson centres are calc-alkaline andesites with minor basalt and dacite (Jakes and Smith, 1970). High-potash basic and intermediate lavas are known from the Managalase Plateau (Ruxton, 1966) and from the volcanics on the south coast of the mainland. The active centres in the D'Entrecasteaux Islands have yielded predominantly rhyolitic material but basaltic and andesitic lavas are also known (Davies and Ives, 1965; Morgan, 1966).

Raised coral. The islands of the Trobriand, Marshall Bennett, Conflict and Engineer groups are entirely raised coral. Woodlark Island is mostly covered with raised coral, and the Lusancay Islands consist of coral platforms with rare volcanic outcrop. There are prominent benches of raised coral in the islands of the Louisiade Archipelago, particularly on the south coast of Misima Island, and there are lower benches and stacks around the D'Entrecasteaux Islands, along the north coast of the eastern mainland (Cape Vogel and eastwards), and in Milne Bay.

GEOLOGICAL HISTORY

1. Jurassic-Cretaceous: Oceanic crust of gabbro and basalt developed at a spreading centre somewhere in the Pacific, possibly at the East Pacific Rise. At the same time 10,000-20,000 m of sediments were being deposited on or near the northeastern margin of the Australian continent. The sediments were partly volcanogenic and their overall chemical composition was sialic, though with some limestone and basalt.

2. At the end of the Cretaceous or in Palaeocene or early Eocene time Jurassic-Cretaceous oceanic crust rode over the sialic sediments on a low-angle fault. The sialic sediments were metamorphosed. If this event was late Cretaceous or Palaeocene it was not accompanied by the emergence of any land mass. If it was Eocene then it probably was accompanied by an arching (cf. Thompson, 1967) which caused local emergence. The only Palaeocene rocks recorded in eastern Papua are deep water sediments with little or no terrigenous component. Eocene rocks on the other hand include both deep and shallow water sediments (e.g. in the Port Moresby area) and fine clastic near-shore sediments.

3. Other Eocene events included

(a) tonalite intrusion and probably contemporaneous dacitic volcanism and pelagic limestone deposition, in the northern part of the Papuan Ultramafic Belt,

(b) extrusion of great volumes of basalt on to the deep ocean floor (southeastern mainland), and

(c) explosive volcanism in the Woodlark Island area. (This might have begun in either the Eocene or Oligocene).

4. There is no record of Lower and Middle Oligocene rocks in eastern Papua, except perhaps the Dokuna Tuff at Port Moresby. This lack has previously been taken to indicate general emergence (e.g. Australasian Petroleum Company, 1961; Thompson, 1967) but we suggest that it might be better explained by continued submergence, slow sedimentation, and subsequent erosion of, or failure to recognize, the sedimentary record. If there was a newly emergent landmass in Lower and Middle Oligocene we would expect to find some evidence of rapid clastic sedimentation. None has been found. (By way of contrast, emergence in the Middle Miocene resulted in the deposition of large volumes of conglomerate, sandstone and siltstone).

5. In the Upper Oligocene and Lower Miocene (Tertiary e stage) an eastern Papuan landmass began to emerge. Clastic sediments poured into the Aure Trough and were augmented by contemporary andesitic volcanism; limestone reefs developed on the eastern shelf of the trough. There was explosive volcanism in a shallow water environment at Port Moresby, on Cape Vogel, and around Mullins Harbour ($10^{o}30$'S, 150^{o}E). Poorly consolidated Eocene sediments were re-worked near Tapini and Port Moresby, and reef limestone developed on Panasia Island in the Calvados Chain ($11^{o}10$'S, $152^{o}20$'E).

6. Emergence continued in the Middle Miocene (Tertiary f_{1-2} stage) and was accompanied by rapid sedimentation into the Aure Trough and the beginning of clastic sedimentation in the Cape Vogel basin. Reef limestone continued to develop on the eastern margin of the Aure Trough, and other reefs grew at Port Moresby, on the Adau River ($9^{o}50$'S, $148^{o}50$'E), and on Cape Vogel. There was explosive volcanism in a shallow water environment on Cape Ward Hunt, and on Normanby, Woodlark and Misima Islands.

7. Emergence continued in the Upper Miocene and Pliocene by block faulting. Coarse clastic sediments were deposited on both sides of the main range (Aure Trough and Cape Vogel basin) and the present cycle of volcanism began (mainland, Lusancay, Trobriand(?) and Egum Islands, parts of the D'Entrecasteaux Islands and western Calvados Chain).

8. Emergence by block faulting continued into the Quaternary, accompanied by rapid sedimentation into offshore areas, volcanism on the mainland and D'Entrecasteaux Islands, and coral reef growth.

Discussion

Seismic zones (Denham, 1969) indicate that the present contact of the Australian and Pacific lithospheric plates lies along the north coast of New Guinea and the south coasts of New Britain and the Solomon Islands. Lesser seismic zones between New Ireland and the New Guinea mainland and between the Solomon Islands and eastern Papua suggest that the area may be broken into a number of smaller lithospheric plates. Le Pichon (1970) has calculated from spreading rates on the Pacific and Antarctic ridges that the resultant movement between the Australian and Pacific plates at 3°S, 142°E is a compression of 10.7 cm/yr on aximuth 075°. The present response of the New Guinea - Solomons region to this compression is probably (1) left-lateral shear along the line of the Solomon Islands, New Ireland and Manus Islands, coupled with (2) possible rotation of smaller lithospheric plates in the Bismarck and Solomon Seas, (3) sinking of Australian plate into the trench on the southern side of New Britain and the Solomon Islands, and (4) buckling and overthrusting of lithosphere in the central New Guinea highlands.

Interaction between the two plates in the early Tertiary may have led to the emplacement of the Papuan Ultramafic Belt. The Ultramafic Belt is thought to be part of a thrust plate of oceanic mantle and crust which was emplaced on a low angle fault (the Owen Stanley Fault) in the Palaeocene or Eocene. It is suggested that at that time the fracture represented by the Owen Stanley Fault might have been a subduction zone in which the Australian plate was going down. Arrival of Australian continental crust (and marginal sediments) at the subduction zone brought a halt to the process because of the buoyancy of the sialic crust. Presumably the zone became inactive and movement was taken up along the line of the New Guinea-Solomons trench. Sialic crust and sediments remained wedged under oceanic mantle and crust (lithosphere) until the late Oligocene and Miocene when the buoyant sialic crust rose isostatically and tilted the overlying slabs of oceanic lithosphere (sections, Fig. 2, Plate 1).

Metamorphism of the Mesozoic sialic sediments is thought to be directly related to the emplacement of the Ultramafic Belt. The occurrence of lawsonite immediately west and southwest of the Owen Stanley Fault is compatible with this. Lawsonite develops under conditions of high pressure relative to temperature, such as might be caused by high fluid pressure under the thrust plate (cf. Brothers, 1970) or by submergence to depths of several tens of kilometres in the subduction zone (cf. Ernst, 1970).

The time of thrusting and metamorphism was probably Palaeocene or early Eocene. The occurrence of schist clasts in Eocene sediments near Tapini is evidence that the event was pre-Eocene, probably Palaeocene. On the other hand the early Eocene (50-55 m.y.) tonalite intrusions and associated(?) dacitic volcanics of the northern Ultramafic Belt might be interpreted as evidence of island arc type volcanism associated with a subduction zone which was active into the early Eocene. JOIDES drilling has shown that the Pacific plate has probably been moving westward since the Jurassic (Fisher and others, 1970), and magnetic lineations south of Australia indicate that the Australian plate has been moving north away from Antarctica since the early Eocene, 55 m.y. ago (Ringis, 1970). Perhaps the beginning of northward movement of the Australian plate is in some way related to the emplacement of the Ultramafic Belt, for the two events may have been contemporaneous.

In the past it has been suggested that the eastern Papuan peninsula has drifted from an initial position close to the Australian continent (Carey, 1958; Rod, 1966; Coleman, 1967) and some confirmatory evidence has come from recent oceanographic work in the Coral Sea (Falvey and Talwani, 1969; J. Ewing and others, 1970; Gardner, 1970). Gardner has deduced that the Coral Sea opened by rifting over a period of about 11 m.y. in the late Eocene - early Oligocene. Gardner's calculation of the age of the Coral Sea Basin is based on the average thickness of sediments (1.5 km) and the present day sedimentation rate (3.6 cm/1000 yr), from which he arrives at an age of 42 m.y. We suggest that the sedimentation rate might have been much lower before the general emergence of a New Guinea landmass, and that consequently the Coral Sea Basin may in fact be older than Upper Eocene. It might seem improbable that rifting could take place in what otherwise would appear to be a compressional environment. However there are present day parallels in the apparent zones of extension behind the Tonga - Kermadec Trench (Karig, 1970) and in the Philippine Sea and the Sea of Japan (Fisher and others, 1970; Packham and Falvey, in press). In order to make the early Tertiary situation strictly comparable with these present day examples it would be necessary to postulate that the early Tertiary (late Eocene - early Oligocene?) subduction zone somewhere east or northeast of the Coral Sea dipped west and was consuming the Pacific rather than the Australian plate.

In the onshore geology of eastern Papua there is some evidence to support opening of the Coral Sea by rifting. Firstly this would explain the existence in eastern Papua of an isolated belt of sialic metamorphics, 900 km long and 60 km wide, surrounded on three sides by oceanic crust (Rose and others, 1968; M. Ewing and others, 1970): the sialic rocks would formerly have been part of the margin or marginal sediments of the Australian continent. Secondly, if the Papuan peninsula were bent in the course of rifting, as Gardner has proposed, this would explain the apparent change in dip of the Ultramafic Belt thrust sheet from easterly at one end to northerly at the other (sections, Plate 1). Thirdly the presence of deep water Eocene basalts on the southeast Papuan mainland is evidence of submarine volcanism and possibly of the generation of new oceanic crust at about the time when rifting is postulated to have taken place. Subsidiary rifting may also explain the separation of the sialic metamorphics of the D'Entrecasteaux Islands from those of the mainland, as was proposed on other grounds by Davies and Ives (1965). If the sialic metamorphics were not rifted away from the Australian continent then the initial sediments must have developed in situ, presumably by (island arc type) intermediate and acid volcanism.

To summarize, the concepts of plate tectonics and the opening up of the Coral Sea basin may be incorporated into the geological history of the area as follows (Fig. 2):

1) Deposition of sediments along the Australian continental margin (Cretaceous)

2) The Australian continental crust and marginal sediments entered a subduction zone along the line of the present Owen Stanley Fault and the marginal sediments were metamorphosed (Palaeocene, or early Eocene)

3) The subduction zone became inactive and movement was taken up elsewhere, e.g. in the New Britain - Solomon Islands region. Parts of the metamorphics were exposed to erosion (Eocene).

4) The former subduction zone and a slice of the metamorphosed Mesozoic sediments moved away from the Australian continent as the Coral Sea opened by rifting (Eocene, possibly Lower Oligocene).

5) The metamorphosed Mesozoic sediments rose isostatically and the partly overlying plate of oceanic lithosphere was tilted as a result. Erosion of the metamorphics began (Upper Oligocene - Lower Miocene).

6) Uplift and rapid erosion continued and were accompanied by volcanism (Middle and Upper Miocene, Pliocene and Quaternary).

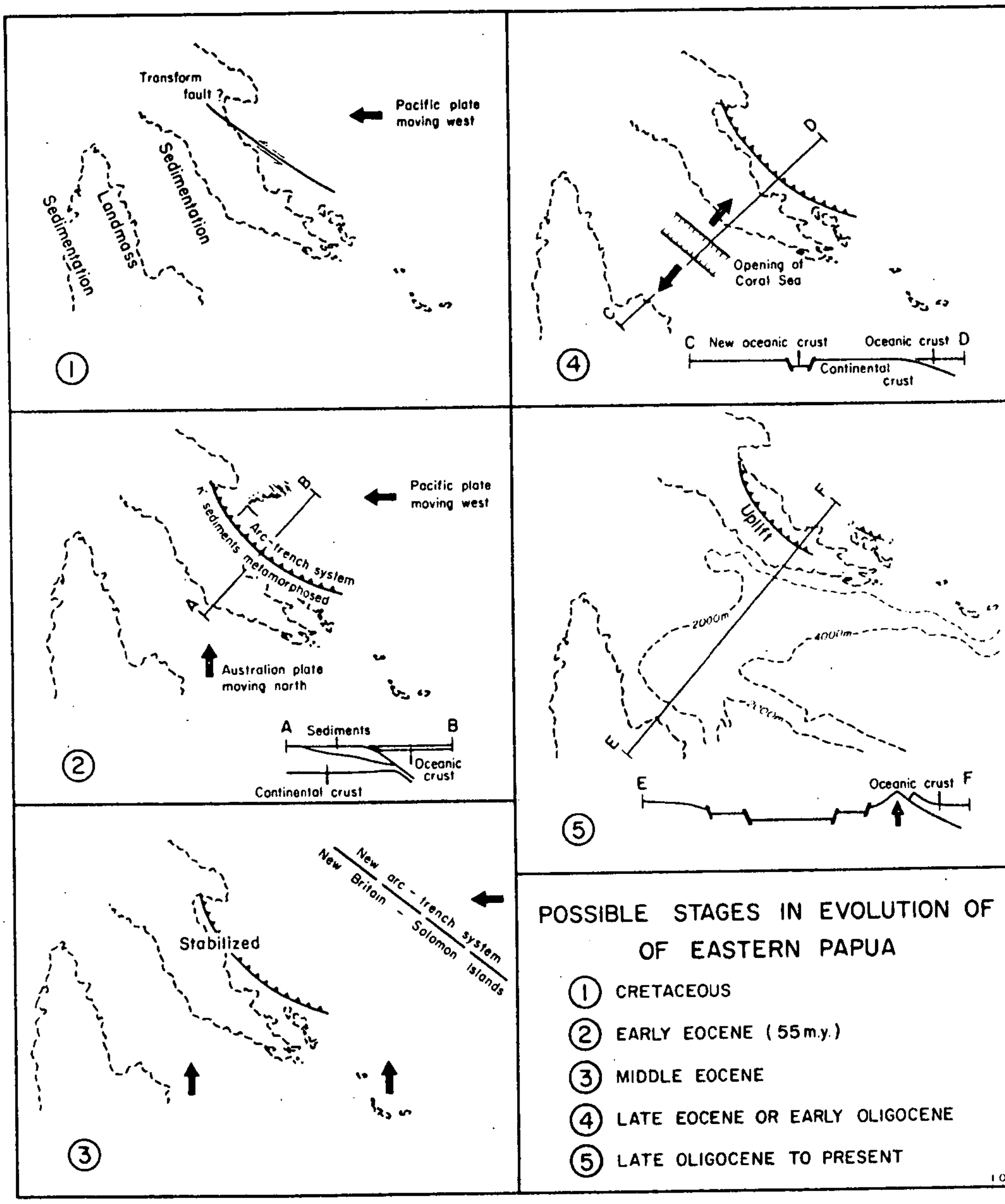
Transform fault ?
Pacific plate moving west
Sedimentation
Landmass
Sedimentation
1
Pacific plate moving west
Arc-trench system
sediments metamorphosed
A
B
Australian plate moving north
A Sediments B
Oceanic crust
Continental crust
2
Stabilized
New arc-trench system
New Britain - Solomon Islands
3
Opening of Coral Sea
C New oceanic crust
Oceanic crust D
Continental crust
4
Uplift
2000m
4000m
E
Oceanic crust F
5
POSSIBLE STAGES IN EVOLUTION OF OF EASTERN PAPUA
1 CRETACEOUS
2 EARLY EOCENE (55m.y.)
3 MIDDLE EOCENE
4 LATE EOCENE OR EARLY OLIGOCENE
5 LATE OLIGOCENE TO PRESENT

Figure 2

REFERENCES

AUSTRALASIAN PETROLEUM COMPANY, 1961 - Geological results of petroleum exploration in Western Papua, 1937-1961. J. Geol. Soc. Aust., 8(1), 133 p.

BAKER, G., 1946 - Preliminary note on volcanic eruptions in the Goropu Mountains, southeastern Papua, during the period December 1943 to August 1944. J. Geol., 54, 19-31.

BELFORD, D.J., 1968 - Palaeocene planktonic foraminifera from Papua and New Guinea, 1-34 in Palaeontological Papers 1966, Bur. Miner. Resour. Aust. Bull. 92.

BROTHERS, R.N., 1970 - Lawsonite-albite schists from northernmost New Caledonia. Contr. Mineral Petrol. 25, 185-202.

CAREY, S.W., 1958 - The tectonic approach to continental drift. Continental Drift - A Symposium, Univ. Tasmania, Hobart.

CLARKE, W.J., and BLOW, W.H., 1969 - The inter-relationships of some late Eocene, Oligocene and Miocene foraminifera and planktonic biostratigraphic indices. Proc. 1st Internat. Conf. Planktonic Microfossils, Geneva, 1967. 2, 82-97.

COLEMAN, P.J., 1967 - A speculative resolution of the Melanesian Re-entrant. in Ringwood, A.E., Editor: Progress Report Upper Mantle Project, Australia.

COMPAGNIE GENERALE DE GEOPHYSIQUE, 1969 - Papuan Basin and Basic Belt aeromagnetic survey, T.P.N.G. 1967. Bur. Miner. Resour. Aust. Rec. 1969/58 (unpubl.).

DALLWITZ, W.B., 1968 - Chemical composition and genesis of clinoenstatite - bearing volcanic rocks from Cape Vogel, Papua: a discussion. Rep. 23rd Int. Geol. Congr., Prague, 2, 229-242.

DALLWITZ, W.B., GREEN, D.H., and THOMPSON, J.E., 1966 - Clinoenstatite in a volcanic rock from the Cape Vogel area, Papua. J. Petrology, 7(3), 375-403.

DAVIES, H.L., 1968 - Papuan Ultramafic Belt. Rep. 23rd Int. Geol. Congr., Prague, 1, 209-220.

DAVIES, H.L., 1969 - Normanby Island reconnaissance petrography. Bur. Miner. Resour. Aust. Rec. 1969/46 (unpubl.).

DAVIES, H.L., (in press) - Peridotite-gabbro-basalt complex in eastern Papua: an overthrust plate of oceanic mantle and crust. Bur. Miner. Resour. Aust. Bull. 128.

DAVIES, H.L., in prep. - Metamorphic rocks between Garaina and Tapini, T.P.N.G. Bur. Miner. Resour. Aust. Rec. (unpubl.).

DAVIES, H.L., and IVES, D.J., 1965 - The geology of Fergusson and Goodenough Islands, Papua. Bur. Miner. Resour. Aust. Rep. 82.

DAVIES, H.L., SMITH, I.E., CIFALI, G., and BELFORD, D.J., 1968 - Eastern Papua geological reconnaissance. Bur. Miner. Resour. Aust. Rec. 1968/66 (unpubl.).

de KEYSER, F., 1961 - Misima Island - Geology and gold mineralization. Bur. Miner. Resour. Aust. Rep. 57.

de VERTUIL, J.P., and RICKWOOD, F.K., 1946 - Mafulu-Ononge reconnaissance survey. Australasian Petroleum Company (unpubl.).

DENHAM, D., 1969 - Distribution of earthquakes in the New Guinea - Solomon Islands region: J. Geophys. Res., 74, 4290-4299.

DOW, D.B., and DAVIES, H.L., 1964 - The geology of the Bowutu Mountains, New Guinea. Bur. Miner. Resour. Aust. Rep. 75, 31 p.

EDWARDS, A.B., 1950 - The petrology of the Miocene sediments of the Aure Trough, Papua. Proc. Roy. Soc. Vic., 60, 123-148.

ENGLAND, R.N., and DAVIES, H.L., 1970 - Cumulus and noncumulus ultramafic rocks from eastern Papua. Bur. Miner. Resour. Aust. Rec. 1970/66 (unpubl.).

ERNST, W.G., 1970 - Tectonic contact between the Franciscan melange and the Great Valley sequence - crustal expression of a late Mesozoic Benioff zone. J. Geophys. Res., 75, 886-901.

EWING, M., HAWKINS, L.V., and LUDWIG, W.J., 1970 - Crustal structure of the Coral Sea. J. Geophys. Res., 15, 1953-1962.

EWING, J.I., HOUTZ, R.E., and LUDWIG, W.J., 1970 - Sediment distribution in the Coral Sea. J. Geophys. Res., 15, 1963-1972.

FALVEY, D.A., and TALWANI, M., 1969 - Gravity map and tectonic fabric of the Coral Sea (abstr.). Geol. Soc. Amer. Abstracts with programs for 1969, 7, 62.

FISHER, A.G., HEEZEN, B.C., BOYCE, R.E., BUKRY, D., DOUGLAS, R.G., GARRISON, R.E., KLING, S.A., KRASHENINNIKOV, V., LISITZIN, A.P., and PIMM, A.C., 1970 - Geological history of the western North Pacific. Science, 168, 1210-1214.

GARDNER, J.V., 1970 - Submarine geology of the western Coral Sea. Geol. Soc. Amer. Bull., 81, 2599-2614.

GLAESSNER, M.F., 1949 - Mesozoic fossils from the Snake River, Central New Guinea. Mem. Queensland Mus., 12(4), 165-180.

GLAESSNER, M.F., 1950 - Geotectonic position of New Guinea. Bull. Amer. Assoc. Petrol. Geol., 34, 856-81.

GLAESSNER, M.F., 1952 - Geology of Port Moresby, Papua. p.63-86 in Sir Douglas Mawson Anniversary Volume, Univ. Adelaide.

HOHNEN, P.D., 1968 - Geology of the Dilava River area. T.P.N.G. Investigation Note No. 68210(b) (unpubl.).

JAKES, P., and SMITH, I.E., 1970 - High potassium calc-alkaline rocks from Cape Nelson, Eastern Papua. Contr. Mineral. and Petrol., 28, 259-271.

JONGSMA, D., (in press) - Marine geology of Milne Bay, eastern Papua in Bur. Miner. Resour. Aust., Bull. 127.

KARIG, D.E., 1970 - Ridges and basins of the Tonga-Kermadec island arc system. J. Geophys. Res., 75, 239-254.

KHAN, M.A., and WOOLLARD, G.P., 1968 - Methods of analysis and comparison of geophysical data on a plane, with specific application to the Solomon Islands area. Hawaii Inst. Geophys. Rep. HIG-68-17, 79 p.

KRAUSE, D.C., 1965 - Submarine geology north of New Guinea. Bull. Geol. Soc. Amer., 76, 27-42.

DRAUSE, D.C., 1967 - Bathymetry and geologic structure of the northwestern Tasman Sea - Coral Sea - South Solomon Sea area of the southwestern Pacific Ocean. New Zealand Dep. Sci. Ind. Res. Bull. 183 (N.Z. Oceanogr. Inst. Mem. 41), 48 p.

Le PICHON, X., 1970 - Correction to paper by Xavier Le Pichon "Sea floor spreading and continental drift". J. Geophys. Res., 75, 2793.

MACNAB, R.P., 1967 - Geology of the Keveri area, eastern Papua. Bur. Miner. Resour. Aust. Rec. 1967/98 (unpubl.).

MACNAB, R.P., 1969 - Geology of the Aroa-Upper Dilava-Auga-Middle Angabunga Rivers area, Papua. Bur. Miner. Resour. Aust. Rec. 1969/126 (unpubl.).

MANSER, W., and FREEMAN, C., (in press) - Bibliography of the geology of eastern New Guinea (Papua-New Guinea). Bur. Miner. Resour. Aust. Rep. 141.

MILSOM, J.S., in prep. - Gravity field and evolution of eastern Papua. Imperial Coll., London, Ph.D. Thesis (unpubl.).

MORGAN, W.R., 1966 - A note on the petrology of some lava types from east New Guinea. J. Geol. Soc. Aust., 13(2), 583-591.

PACKHAM, G.H., and FALVEY, D.A., (in press) - Marginal seas as modern geosynclines.

PAGE, R.W., 1971 - The geochronology of igneous rocks in the New Guinea region. Aust. Nat. Univ. Ph.D. Thesis (unpubl.).

PAGE, R.W., and McDOUGALL, I., 1970 - Potassium-argon dating of the Tertiary f_{1-2} stage in New Guinea and its bearing on the geological time scale. Amer. J. Sci. (in press).

PAPP, S., and NASON-JONES, J., 1930 - Geology of part of the Cape Vogel peninsula, in The oil exploration work in Papua and New Guinea conducted by the Anglo-Persian Oil Company on behalf of the Government of the Commonwealth of Australia, 1920-1929, vol. 2, London. Harrison & Sons.

PATERSON, S.J., and KICINSKI, F.M., 1956 - An account of the geology and petroleum prospects of the Cape Vogel Basin, Papua, pp. 47-70 in Papers on Tertiary Micropalaeontology. Bur. Miner. Resour. Aust. Rep. 52.

PITT, R.P.B., 1966 - Tectonics in central Papua and the adjoining part of New Guinea. Univ. Tasmania Ph.D. thesis (unpubl.).

RINGIS, J., 1970 - Magnetic lineations in the Tasman Sea (abstr). Internat. Conf. on Geophysics of the Earth and the Oceans, Univ. of N.S.W., Australia, Jan. 1970.

ROD, E., 1966 - Clues to ancient Australian geosutures. Eclog. Geol. Helv., 59, 848-883.

RICKWOOD, F.K., 1968 - The geology of western Papua. APEA Journal, 8(2), 51-61.

ROSE, J.C., WOOLLARD, G.P., and MALAHOFF, A., 1968 - Marine gravity and magnetic studies of the Solomon Islands, in KNOPOFF, L., DRAKE, C.L., and PEMBROKE, J.H., ed.: The crust and upper mantle of the Pacific area. Amer. Geophys. Union Monograph 12, 379-410.

RUXTON, B.P., 1966 - A late Pleistocene to Recent rhyodacite - trachybasalt - basaltic latite volcanic association in northeastern Papua. Bull. Volcan., 29, 347-374.

SKWARKO, S.K., 1967 - Mesozoic mollusca from Australia and New Guinea. Bur. Miner. Resour. Aust. Bull. 75.

SMIT, J.A.J., in prep. - Wau, T.P.N.G. - 1:250,000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes. SB/55-14.

SMITH, I.E., 1969 - Notes on the volcanoes Mount Bagana and Mount Victory, T.P.N.G. Bur. Miner. Resour. Aust. Rec. 1969/12 (unpubl.).

SMITH, I.E., DAVIES, H.L., and BELFORD, D.J., in prep. - Geology of the southeast Papuan mainland. Bur. Miner. Resour. Aust. Bull.

SMITH, I.E., and PIETERS, P.E., 1969 - The geology of the Louisiade Archipelago, T.P.N.G., exluding Misima Island. Bur. Miner. Resour. Aust. Rec. 1969/93 (unpubl.).

SMITH, J.W., and GREEN, D.H., 1961 - The geology of the Musa River area, Papua. Bur. Miner. Resour. Aust. Rep. 52.

St JOHN, V.P., 1967 - The gravity field of New Guinea. Univ. Tasmania Ph.D. Thesis (unpubl.).

TAYLOR, G.A., 1958 - The 1951 eruption of Mount Lamington, Papua. Bur. Miner. Resour. Aust. Bull. 38.

TERPSTRA, G.J., 1969 - Micropalaeontological examination of outcrop samples from the Kemp Welch River and Tapini areas of the Central District, Papua - New Guinea. Bur. Miner. Resour. Aust. Rec. 1969/68 (unpubl.).

THOMPSON, J.E., 1967 - A geological history of eastern New Guinea. APEA Jour., 83-93.

THOMPSON, J.E., and FISHER, N.H., 1965 - Mineral deposits of New Guinea and Papua and their tectonic setting: Proc. 8th Comm. Min. Metall. Congr., A.N.Z., 6, 115-148.

TRAIL, D.S., 1967 - Geology of Woodlark Island, Papua. Bur. Miner. Resour. Aust. Rep. 115.

TURNER, D.L., 1969 - Potassium-argon dating of Pacific coast Miocene foraminiferal stages, p.91- 129 in Geol. Soc. Amer. Spec. Paper 124.

von der BORCH, C.C., (in press) - Marine geology of the Huon Gulf region, in Bur. Miner. Resour. Aust. Bull. 127.

YATES, K.R., and de FERRANTI, R.Z., 1967 - The Astrolabe Mineral Field, Papua. Bur. Miner. Resour. Aust. Rep. 105.

PLATE 1 : GEOLOGY OF EASTERN PAPUA

EXPLANATION of letter symbols: K Cretaceous, some probable Jurassic, some possibly older; KE Cretaceous or Eocene; T. Tertiary; E Eocene; O Upper Oligocene; OM Upper Oligocene - Lower Miocene (Tertiary e stage); M Middle Miocene (Tertiary f_{1-2} stage); MP Upper Miocene and Pliocene; Q Quaternary; U ultramafic rocks, Cretaceous and older; gb gabbro; t tonalite; gd granodiorite; gr granite; i intrusives (Mi includes gabbro, monzonite, syenite; Pi includes andesitic porphyry); v volcanics, s sediments, l limestone, c raised coral reef, m metamorphics, p phyllite and low grade metamorphics.

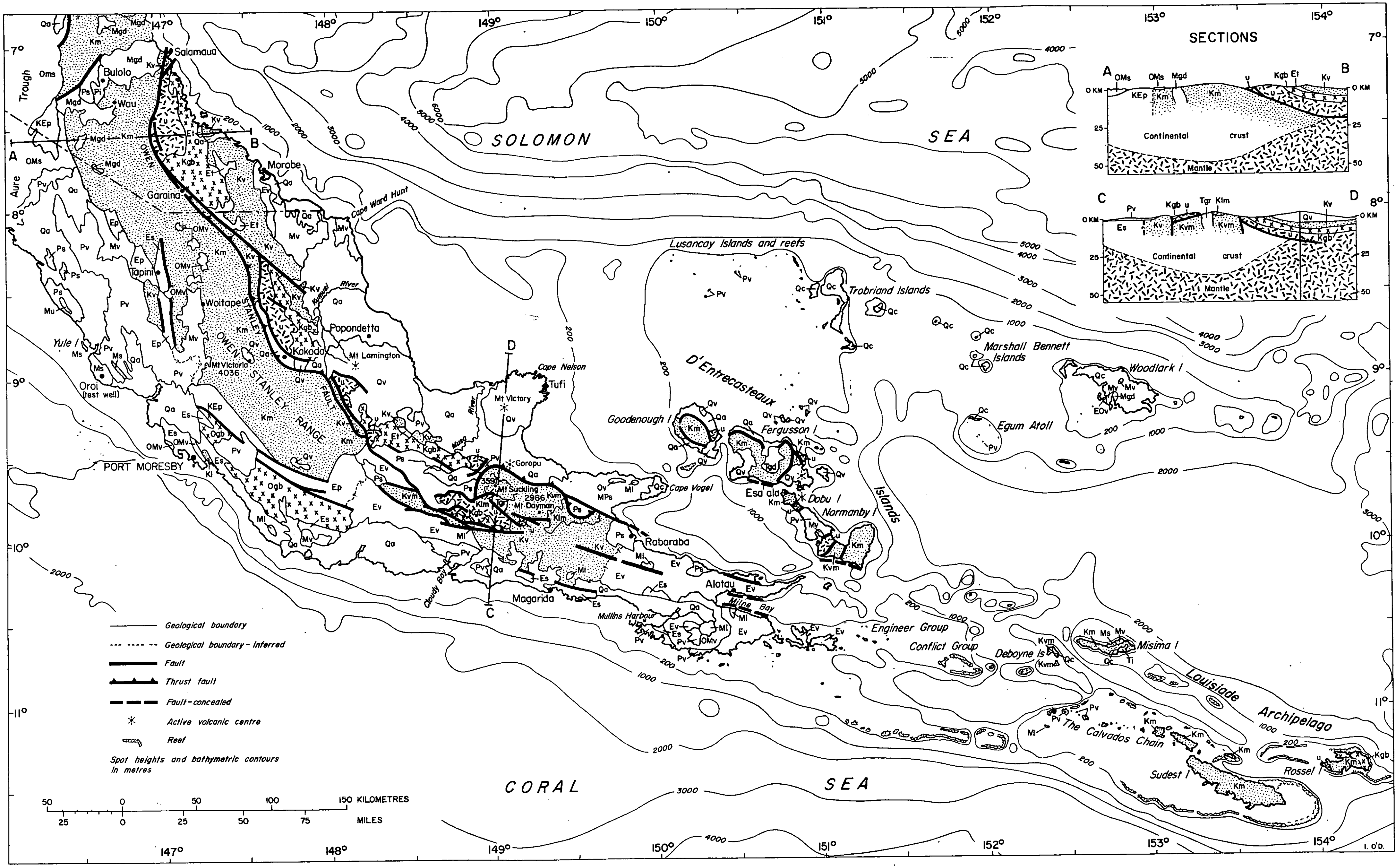

PLATE 1

To accompany Record 1970/116

P/A 334