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PREVIEW REPORT FOR THE MARINE GEOPHYSICAL SURVEY OF THE GULF OF PAPUA AND THE BISMARCK SEA, 1970

by

J.B. Willcox

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CONTENTS

TABLES

2

CONTENTS (Cont'd)

PLATES

SUMMARY

During 1970, Compagnie General de Geophysique (C.G.G.) will carry out an offshore seismic, gravity, and magnetic survey around Papua New Guinea, including the Bismarck Archipelago, for the Bureau of Mineral Resources, Geology & Geophysics (BMR). A coverage of 30 000 kilometres (i.e. 16 000 nautical miles) is envisaged during a period of about 70 days at sea. The operation will be divided into:

(i) Coverage of the continental shelf using a line separation of 10 minutes of latitude (about 19 kilometres)

(ii) Regional traverses across the Bismarck, Solomon, and Coral Seas.

To permit 24 hour-a-day operation, navigation will be by a synthesis of satellite doppler and sonar doppler systems but will incorporate references to frequency stabilized v.l.f. stations around the world. This will circumvent the problems of range, and sky-wave interference at night, associated with the more conventional radio navigation aids.

Digital outputs from the gravity meter, magnetometer, and navigation systems will be fed via an HP2116B computer to magnetic tape storage. Filtered analogue outputs will be displayed on 12-channel analogue recorders. A time series comparison of the digital outputs and cross-comparison of some of the analogue and digital outputs will be made in the computer to test the reliability of the data. Seismic data will be processed digitally and recorded in analogue on magnetic tape: a second HP2116B computer will be used for on-board common depth point (CDP) stacking and mixing of the seismic traces.

In order to make maximum use of calm sea conditions the survey should commence in the Bismarck Sea about mid-September and terminate in the Gulf of Papua by mid-December.

1. INTRODUCTION

The Bureau of Mineral Resources has now made three large-scale marine geophysical surveys, the first two in the Joseph Bonaparte Gulf/Timor Sea area, and the last over the northwest continental shelf. These have been done to extend regional gravity coverage of Australia onto the continental shelf, and in so doing have gradually incorporated other geophysical methods for relatively small additional costs. Feasibility tests of geophysical methods not previously used on surveys in Australia and experience with advanced navigational techniques - viz. the V.L.F. (and OMEGA) location method making reference to frequency-stabilized v.l.f. transmissions, and sonar doppler and satellite doppler methods - have made a large contribution to the methods of operation and to the geophysical coverage of offshore Australia.

The Timor Sea/Joseph Bonaparte Gulf marine gravity and seismic "Spark-array" survey (Smith, 1966; G.A.I., 1966) was done during 1965. Navigation was by the Toran hyperbolic radio location system which, though accurate, is expensive to install and operates satisfactorily only during daylight hours. The seismic reflection system used a spark-array energy source of 14 000 joules. A LaCoste & Romberg gimbal-mounted surface gravity meter was installed on the ship and gave a standard deviation of 3 milligals for the gravity difference at line intersections.

In the Timor Sea survey (Jones, 1969) the Toran navigation system was replaced by the V.L.F.-OMEGA system which, although of lower accuracy, permitted 24 hour-a-day operation. The gravity meter used was an Askania marine type mounted on a gyro-stabilized platform. Despite the reduced navigational accuracy the gravity observations had mean misclosures of only 2.5 milligals at line intersections, with 2.8 milligals standard deviation. Continuous magnetic profiling was introduced, using a Varian proton-precession magnetometer, with the sensor towed about 200 metres behind the ship. Magnetic diurnal variation was monitored on shore at Darwin. In order to increase depth of penetration of seismic energy, the power of the spark-array energy source was increased to 21 000 joules.

The survey of the northwest continental shelf (Whitworth, 1969) was made during 1968. Further improvement in accuracy of gravity data was attempted by navigating with a satellite-doppler navigation system, giving position fixes believed to be accurate to 200 metres once every two or three hours, and a pulsed continuous-wave sonar-doppler unit, expected to provide ship's velocity accurate to 0.1 knot in shallow water, but of lower accuracy when operating off water backscatter in deep water. (To achieve an accuracy of 1 milligal in gravity results, position must be known to 1 minute of latitude and velocity to 0.1 knot). The V.L.F. navigation system was thought to give position fixes to an accuracy of half a mile when tied to satellite-doppler fixes.

The seismic equipment was basically the same as in 1967; a 21 000 joule sparker energy source, a six-channel cable, and a single-channel high-resolution cable. Recording was on magnetic tape in analogue form, with visual monitoring on two facsimile recorders, which displayed the outputs from the high-resolution cable and the six-channel cable. Refraction shooting was added in the hope of correlating refractors with known onshore geological horizons. This utilized air-gun energy sources for high penetration, and sonobuoys dropped at suitable times to 'relay' refracted seismic energy back to the ship.

A LaCoste & Romberg surface marine gravity meter, mounted on a gyro-stabilized platform, was supplied by the contractor. Corrections for cross-coupling errors were made by a simple analogue computer. Recording was by strip-chart pen recorder and a digital magnetic-tape system, which was also used to record magnetic observations and ship's speed and heading.

A Varian proton-precession magnetometer, with sensor towed 600 feet (200 metres) behind the ship, gave direct read-out in gammas. A magnetic station at Broome, for monitoring diurnal variations, failed to function during most of the survey.

The marine geophysical survey of Papua New Guinea (1970) will be carried out under contract by Compagnie Generale de Geophysique (C.G.G.). About 70 days at sea will be available for the work. It is anticipated that about 30 000 kilometres of traversing can be surveyed in this period.

The survey consists of two stages:

(i) Geophysical coverage of the continental shelf with west-east traverses spaced at 10 minutes of latitude (about 19 kilometres) and with more widely spaced tie-lines.

(ii) Regional traverses across the Bismarck, Solomon, and Coral Seas for crustal studies.

As the survey area comes under the influence of the northwest monsoon and southeast trade winds, which cause large seasonal variations in sea conditions, it is desirable to commence work in the Bismarck Sea during the winter months and gradually progress southwards as conditions deteriorate (Appendix 1).

The survey area is shown in Plate 1. This covers coastal waters around Papua New Guinea and the adjacent islands, out to the 1 000-metre isobath. In the Gulf of Papua its western boundary is roughly north-south along latitude 143°E. The area covers the Gulf of Papua; the southeast Papuan coast encircling the Louisiade Archipelago, D'Entrecasteaux Islands, and Trobriand Islands; the Vitiaz Strait, and a 60-km wide strip along the northern New Guinea coast, including the coastal volcanic islands. A similar strip covers the inner crescent of New Britain and New Ireland, and surrounds the Admiralty Islands group. The bathymetry is poorly defined, and in some instances (see Krause, 1965) the survey area probably lies beyond the 1000-metre limit; the boundaries having been chosen to encircle features of interest.

Areas of thick sediments, volcanic piles, ultrabasic intrusives, and a metamorphic belt are thought to be present in the survey area. Sedimentary basins have been confirmed in the Gulf of Papua and Cape Vogel areas, and possibly exist off Wewak. Other areas of thick sediments in Dyke Ackland Bay and east of Madang are inferred from gravity observations. Except in the Gulf of Papua, where extensive seismic exploration has been undertaken by Phillips Petroleum, Tenneco, and B.O.C., the area is poorly surveyed. Sparse bathymetric data, a few gravity observations, and widely spaced aeromagnetic traverses constitute the surveying to date.

The gravity meter to be used will be a LaCoste & Romberg, mounted on a gyrostabilized platform, with an analogue computer to make cross-coupling corrections.

A Varian proton-precession magnetometer will again be in use. A second Varian magnetometer will be placed at Port Moresby or Madang to monitor diurnal changes in the Earth's field.

Seismic equipment will consist of a 21 000 joule 'spark-array' source, a 6-channel streamer cable, a reserve 3-channel cable, and a single-channel high-resolution cable. Refraction profiles will be recorded with a sonobuoy system as used in 1968 and probably an explosive energy source (?Flexotir or Aquaflex). In addition to FM magnetic tape recordings, digital processing and on-board trace stacking will be carried out in the HP2116B computer. Five facsimile displays will allow continual checking of the data quality:

(i) A trace from the deep reflection recordings.

(ii) A stacked trace from the computer.

(iii) A 'spit-out' from the computer.

(iv) The recorded trace from the computer.

(v) The recorded trace from the pinger.

(vi) The trace from the shallow reflection recording (Plate 23).

The navigation system will include:

(i) V.L.F.

(ii) Sonar-doppler.

(iii) Satellite-doppler.

(iv) Compass.

(v) Electromagnetic log.

(vi) Engine revs.

Digital outputs from these sources and the gravity meter, magnetometer, fathometer, and anemometer will be interfaced with a second HP2116B. This computer will be programmed to assess continuity of data, and to compare filtered analogue outputs (via analogue to digital conversion) with the digital values. A printout of diagnostics will be given on a teleprinter. Analogue outputs will be displayed on a 12-channel facsimile recorder. (Plate 24).

2. GEOLOGY

The geological complexity of Papua New Guinea can be attributed to successive waves of 'geosynclinal' deposition and tectonism along the northern edge of the Australian craton (Crook, 1969). The Australian Plate has been moving northwards relative to Antarctica (Heirtzler, 1968) since the Upper Cretaceous, and subduction appears to have taken place along a series of island arcs. Subduction has terminated when the underthrusting plate reached continental crust, and new zones have developed farther north or polarity reversals have taken place (Davis & Smith, 1970). Orogenesis and probably shearing have occurred throughout the Tertiary.

The geology of the Bismarck Sea is unknown apart from deductions made from the bathymetry (Krause, 1965). However, in the Gulf of Papua seismic exploration and subsequent drilling have enabled the structural divisions of the Papuan Basin to be traced offshore.

The locations of places referred to in the text are shown in Plate 25.

STRATIGRAPHIC EVOLUTION OF THE NEW GUINEA REGION

Harrison (Continental, 1969) has conveniently summarized the stratigraphic history of the region:

'Sediments of Cambrian to Cretaceous ages were deposited beyond an ever northward moving stable platform which formed part of the Australian Continent. At the end of Mesozoic the southern sediment supply ceased and from this time onward the rising land masses of New Guinea supplied the material deposited in subsequent basins. Eocene and Oligocene were times of carbonate deposition over the whole of New Guinea. Orogenesis at the end of the Oligocene produced land masses along the spine of the island which contributed clastics to basins formed on either side in Lower Miocene times. That in Northern New Guinea was a classical geosyncline with eugeosynclinal and miogeosynclinal sides. Clastic sedimentation in deep trough areas of these basins was more or less continuous throughout Miocene while on the stable shelf area of West Papua and southern West Irian carbonates were laid down. By Pliocene the Papuan geosyncline had contracted to three small basins receiving mainly continental sediments. Vigorous deposition continued in Pliocene mainly in the North New Guinea Basin. Pleistocene times saw the basins finally filled although deposition is still active today in the delta area of Papua.'

STRUCTURAL UNITS

The region is divided into six structural units similar to those of Denham (1969) (Plate 2).

(i) Stable Continental Shelf

(ii) Aure Trough

(iii) Orogenic and Metamorphic Belt

(iv) North Coast Orogenic Belt and the New Britain Arc

(v) Papuan Ultramafic Belt

(vi) West Melanesian Arc

(i) Stable Continental Shelf. This area lies in southwest Papua and is essentially a stable platform extending from continental Australia. In the south, granitic basement crops out near Daru and dips gently to the north beneath thin Miocene sediments. These sediments reach eastwards into the Aure Trough, where they thicken rapidly. In the southwest folding is very broad and dislocation has occurred by normal faulting. However, to the northeast, as the Miocene reef front is approached folding intensifies and thrust faulting is developed.

This shelf area occupies a small portion in the west of the Gulf of Papua near the western boundary of the survey area.

(ii) Aure Trough. This is an area of thick Cainozoic sediments (10 000 metres) occupying the portion of central Papua between the stable shelf and the 'spinal ranges'. The Aure Trough covers the Gulf of Papua and possibly sweeps into the Coral Sea. Its northeastern boundary lies close to the Port Moresby coast. The sediments consist of an alternating greywacke/ mudstone sequence probably derived during the elevation of the Owen Stanley Ranges in the north. A narrow shelf zone is developed in the northeast, containing localized reefs and limestone lenses, and coarse clastics derived from basic and andesitic volcanism in the north and northeast.

The region is characterized by tight folding with thrusting at the fold crests and diapirs produced by the less competent mudstones. Major strikeslip faulting, probably with considerable horizontal and vertical displacement, is also present. This is generally a region of slow subsidence - 'slow enough for sedimentation to keep the offshore shelf sea shallow, and for the deltas to advance, but fast enough to keep the countless anastomosing reticulating channels of the (Fly/Strickland) delta open and deep' (Carey, 1938).

The stable shelf, the Aure Trough, and the narrow shelf to the northeast form the Tertiary Papuan Basin. Thompson (1967) considers that 'the broad morphology of the Papuan Basin throughout Miocene time is mainly characteristic of a miogeosyncline......' but Harrison (op. cit.) appears to separate the Basin into a eugeosyncline, the Aure Trough, with a miogeosyncline on the west of the Erave-Wana Swell (Plate 2).

(iii) Orogenic and Metamorphic Belt. This belt constitutes the 'spine' of the island, including the Central Highlands and the Morobe Arc. It is made up of mid-Tertiary volcanic and metamorphic rocks, with a core of Cretaceous and probably older metasediments. In southeastern Papua the sialic core of the Highlands is separated from the volcanics on its northeast side by the Papuan Ultramafic Belt, which is a discontinuous string of Cretaceous gabbros and peridotites. Low-grade metamorphic rocks are believed to terminate at 148°E, but they are again found draped about the granitic cores of the D'Entrecasteaux

Islands. In the Louisiade Archipelago and non-crystalline rocks are low-grade metamorphics similar to those of the Owen Stanley Ranges (Davies, 1959). It is suggested that the metamorphic belt is offset to the northeast by transcurrent faulting in the vicinity of longitude 148°E and recontinues on Goodenough Island, along a similar trend.

The Owen Stanley Ranges were elevated in lower Miocene times, but development of the Central Highlands spread from the southeast in the middle Miocene. Denham (op. cit.) considers the New Guinea Highlands to represent a fossil island arc, associated with the northeasterly moving Australian continent and the westerly spreading of the Pacific Ocean. Cainozoic volcanics extending from Mount Lamington to Sanoroa Island, off the east coast of Fergusson Island, are considered (Ruxton, 1967) to be a true volcanic arc marking a single major tectonic feature. Volcanism has been largely basaltic, but more recently andesitic lavas have been produced.

(iv) <u>The North Coast Orogenic Belt and the New Britain Arc</u>. New Britain is a natural extension of the north New Guinea coastal ranges and the Finisterre/Saruwaged Ranges of the Huon Peninsula. The uplifted sediments throughout this region lie on Tertiary volcanic 'basement' and, in general, are folded into antiform structures. Together these ranges constitute a province of active mountain building, indicated by the elevation by up to 250 m of Miocene reefs in the coastal area. The northern portion of New Britain and the offshore islands of New Guinea form an active volcanic chain stretching westwards to Bam in the Schouten Islands, where activity abruptly terminates. Marchant has pointed out that volcanism is absent between Bam and Ternate, 2000 km to the west. The lavas of the New Britain/northern New Guinea chain are a complex assortment of andesite and tholeiitic basalts. From the orientation of the New Britain arc - that is, concave towards the Bismarck Sea and Pacific Ocean - and the location of the foredeep on the southern side of New Britain, it appears that the arc is associated with underthrusting of the Solomon Sea. The disposition of earthquake epicentres also indicates the presence of a thrust plane dipping towards the Bismarck Sea, in accord with classical island-arc development.

The central spine of New Guinea and the northwesterly trending sedimentary basins in the north coastal region have been described as the New Guinea Mobile Belt (Dow et al., 1968, after Badgley, 1965). Visser & Hermes (1962) recognize the 'Northern Province' as typically eugeosynclinal and the 'Central Province' as the fringing miogeosyncline.

In the northern areas of New Guinea, faulting is undoubtedly predominant over folding. However, there is a general controversy as to the nature of the faulting and the type of mechanism that produced it. Krause (1965) has followed Carey (op. cit.) in contending that 'large horizontal left-lateral movements characterize northern New Guinea'. In his 1938 Ph.D. thesis Carey postulated that New Guinea has been sheared westwards under a system of rotational stresses for which he coins the term 'The Melanesian Shear System'; however, he later modified this to a system of combined left-lateral and right-lateral shears, squeezing the islands of southeast Asia westwards and leaving Australia and New Guinea in their present position (Carey, 1958). Carey's hypothesis also includes sinistral rotation of the island from a position east of Queensland. However, there is no evidence of a shear zone between Australia and Papua, as required for the westward movement of Papua New Guinea. On the available bathymetric evidence Marchant (1968) finds nothing to support the worldwide shear system and rotation of New Guinea proposed by Carey, and treats northern New Guinea under a system of localized pure shear. Dow (op.cit.) considers that some faults 'can be traced with reasonable certainty for a total distance of 500 miles.....straight traces all indicate a predominant transcurrent displacement, but only rarely has evidence of horizontal movement been proved'. The faults tend to be concentrated in zones and are often marked by intense shearing and mylonitization. Faulting is usually subparallel to the New Guinea coast, with a west to west-northwest trend. The northwesterly 'Solomons trend' is clearly present in large faults on the Gazelle Peninsula and in New Ireland, and may be the result of a more recent episode of shearing.

It has been suggested that the axis of deposition of the coastal basins lies offshore, but this is not clearly indicated by the gravity and magnetic data. Although structural lineations are largely subparallel to the coast it is possible that some of these, such as the Ramu Fault, extend onto the continental shelf.

(v) The Papuan Ultramafic Belt. As mentioned above this is a narrow discontinuous band of ultrabasic intrusions separating the metamorphic Owen Stanley Ranges from the volcanics on their northeast flank. The belt continues for an uncertain distance out to sea but possibly includes large bodies of ultramafic rocks on Normanby Island. It has been postulated by Thompson & Fisher (1965) that the ultrabasic belt is derived from an upthrust wedge of oceanic floor and subjacent mantle over the acidic Owen Stanley metamorphics. In his thesis St John (1967) derives a similar model from the observed gravity data. A northeasterly dip of 60^{o} to 70^{o} for the ultramafics is also consistant with Milsom's (in prep.) gravity interpretation of southeast Papua. A northeasterly dip was modelled on an ultrabasic body southeast of Sewa Bay on Normanby Island, and the ultrabasic belt seemed to extend through Cape Vogel.

(vi) The West Melanesian Arc. This term is applied to the arc stretching from New Ireland, through the St Matthias/Admiralty Islands group, with a possible projection onto the West Irian/Papua New Guinea border (Denham, op. cit.). It is associated with a shallow but well defined trench, 6000 metres deep and about 200-300 kilometres north of the islands. With the exception of Feni Volcano east of New Ireland and Tuluman Volcano in the Admiralty Islands, the belt is largely inactive and is almost aseismic.

New Ireland consists of 2300 metres of marine sediments and volcanics draped over a small area of rising basement. The sequence consists of Lower Oligocene beds with predominant limestones, middle and upper Oligocene volcanics of both acidic and basic affinity, and lower Miocene and Pliocene limestones (French, 1966). Crumpling and folding of the sedimentary pile has taken place, especially towards its margins. Two large ?transcurrent faults, the Weitin River and Sapon Faults, of northwest (Solomons) trend, occur in the south of New Ireland.

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In his report on the geology of Manus Island, Thompson (1952) concludes....'Manus Island has an igneous core composed of a medium-acid plutonic complex about which Tertiary limestones and massive tuffaceous sediments have been deposited. Volcanic flows, essentially basaltic, and tuffs unconformably overlie these sediments and possibly the igneous basement. This volcanism is thought to be of Pleistocene age'. However, Reynolds' (1958) study of the recent (1955-1957) activity of Tuluman Volcano showed that the lavas are acidic, in fact almost exclusively rhyolite.

In general the islands of the West Melanesian Arc consist of a complex pile of volcanics and limestones of Upper Tertiary and Quaternary age. These appear to rest on an acidic basement. Volcanic activity is a curious mixture of acidic and basic types, possibly indicating a complex relation between 'Oceanic' and 'Continental' crust. It has been suggested that islets of sialic material ('sialets' of Thompson) have been dislodged from the Australian craton and are 'floating' on Oceanic crust.

The extent of sedimentation between islands is unknown but the bathymetric charts show that they are connected by relatively shallow (1000+ metres) waters, and that the sedimentary section may extend between New Hanover and Manus Island. Krause (op. cit.) implies that an extension of arc to the New Guinea/West Irian border is unlikely.

It is possible that the 1970 survey could reveal several guyots in this region. It is noted (Denham, op. cit.) that a line of earthquake epicentres lies between Wewak on the New Guinea coast and New Hanover.

SEDIMENTARY BASINS

Northern New Guinea Basin

The area of Miocene and Plio-Pleistocene sedimentation extending with northwesterly trend from the Huon Peninsula to West Irian, and between the Highlands and the coast, has been termed the Northern New Guinea Basin (Osborne, 1956). The southern edge of the basin may be regarded as the boundary with the Highlands, with which it appears to be in faulted contact (e.g. along the Ramu-Markham Fault). Thompson (1965) considers the axis of deposition to lie offshore but as noted by Watts (1969) 'the abrupt nearshore bathymetry, including a plunge of 1000 fathoms 16 miles off Wewak (Krause, 1965, Plate 1,...), does not support this hypothesis.'

Several sub-basins have been recognized, notably the Bewani-Torricelli Basin in the northwest, the Sepik River Basin to the south of the coastal ranges, and the Ramu Basin inland from Madang. Aeromagnetic surveying (Aquitaine, 1967; Continental, 1968) outlined further localized areas of thick sediments.

Stratigraphy. Classification of the stratigraphy in the Northern New Guinea Basin is discussed by Marchant (op. cit. page 8, plate 22). In some instances (e.g. APC geologists) sections have been correlated by detailed palaeontological methods, but because of the broad requirements of this survey the generalized stratigraphy given by Thompson, and the units defined in West Irian by Visser & Hermes (op. cit.) appear most applicable (Table 1).

12

TABLE 1

Generalized Stratigraphy of the Northern New Guinea Basin

AGE	VISSER & HERMES (WEST IRIAN)		THOMPSON (NEW GUINEA)		
	UNIT	THICKNESS	NORTH-WESTERN PART (N. Bewani & Torricelli Mtns)	CENTRAL PART (Lower Sepik R.)	SOUTH-EASTERN PART (Madang Basin)
PLIOCENE	MAMBERAMO FM.	1300-23 000 ft.	Basal marine mudstone and sandstone to upper non-marine conglomerate and mudstone with coal 12 000-17 000 ft.	Section thins, volcanic component decreases and shelf facies developed.	Section similar to that in northwestern part but Pliocene thinner and volcanic component increases eastward throughout section. Section in Finisterre and Saruwaged Ranges is dominantly volcanic.
MIOCENE: UPPER - MIDDLE - LOWER	MAKATS FM.	6500 ft.	Interbedded volcanics, limestone, greywacke and mudstone 16 000-29 000 ft. uppermost 1000-4000 ft. mainly globigerinal marl with volcanics.		
PALEOCENE	AUWEWA FM.	13 000+ ft.	Scattered erosional remnants of Eocene Limestone		
UPPER CRETACEOUS			Metasediments, granite-granodiorite, diorite, gabbro, peridotite.		
PRE-UPPER CRETACEOUS			Crystalline rocks of unknown ages.		

In the north of West Irian and in eastern New Guinea basement consists of ultramafic rocks, which in the north have the form of a buried ridge paralleling the coast and occasionally cropping out. The basement dates as Jurassic-Cretaceous in the Sepik district and Oligocene-Miocene north of the Prince Alexander Mountains. Visser & Hermes (op. cit.) have suggested that these rocks are 'tectonically emplaced fragments of peridotite mantle' but the Sepik River Helicopter Gravity Survey (Watts, op. cit.)shows only minor Bouguer anomaly highs in this area.

The earliest sediments appear to be a sequence of mafic volcanics and limestone of Late Cretaceous and/or Palaeogene ages, totalling about 4000 metres (the Auwewa Formation of Visser & Hermes). The limestone content gradually increases and becomes predominant at the top.

At about the close of the Mesozoic era the deposition of clastics ceased in central New Guinea, and orogeny producing rising land masses to the south of the present day basin. In the middle Miocene, tuffaceous deposition began. The Auwewa Formation is overlain by several thousand metres of a turbidite sequence (middle and upper Miocene Makats Formation of Visser & Hermes), and this in turn by an increasingly paralic sequence terminating with non-marine conglomerate and coal beds (upper Miocene to Pleistocene Memberamo Formation). The sedimentary pile varies in thickness but reaches 10 500 metres in the region of the Bewani-Torricelli Ranges. Inland from Madang the section thins, the volcanic content decreases, and in general the facies is more representative of shelf environment.

Tectonics. Late Tertiary orogeny produced the coastal ranges with their cores of granite, diorite, and upfaulted mafic(?) basement and tight folding on their northern slopes. Folding tends to be broader in the Madang area, but in the rugged Saruwaged and Finisterre mountains a predominantly volcanic Miocene sequence has been uplifted, folded, and faulted. Aquitaine (op. cit.) have described the Bewani, Torricelli, and Prince Alexander Mountains as '.... a highly faulted northward overthrusting dorsal or geanticline...', flanked to the north and south by a series of sub-basins. Four predominant structural trends are defined:

(i) West-east, Bewani-Torricelli trend.

(ii) Northwest-southeast, Prince Alexander trend.

(iii) North-south, Maimai-Makafin trend.

(iv) Northeast-southwest, Vanimo trend.

Thinning of sediments over ridges indicates that trends (i) and (ii) have been active since middle Miocene, whereas trend (iii) may be related to deep-seated transcurrent faulting in the basement.

There is little doubt that the structure of the New Guinea Mobile Belt is dominated by faulting, but opinions differ widely as to its nature. Dow et al. (1968) have considerable evidence in favour of a complex system of faults, many of a transcurrent nature. Marchant, on the other hand, in an interpretation which he warns may be subjective, maintains that high-angled thrusting, trending 300° to 310°, is the principal structural feature.

Cape Vogel Basin

The following summary relies largely on information presented by Thompson (1965). Table 2 shows Thompson's generalized stratigraphy for this basin.

TABLE 2.

General Stratigraphy - Cape Vogel Basin (after Thompson)

	AGE	APPROX. THICKNESS	SEDIMENTS	IGNEOUS ROCKS
CAPE VOGEL BASIN SEDIMENTS	PLEISTOCENE & RECENT	300'	Alluvium and coral reef at or near sea level; raised reef up to 400 feet a.s.l., tilted but not noticeably folded.	Extensive and shallow intrusive igneous rocks of andesitic to basic composition. Includes (1) Pleistocene to Recent volcanics of Cape Nelson and their apron deposits; (2) basic tuffs, lapilli beds, and explosion breccias within the sedimentary succession exposed on Cape Vogel; and (3) basic intrusive rocks which have intruded and domed the Neogene sediments at Cape Vogel.
		Slight	Unconformity	
	PLIO-PLEISTOCENE	1000'	Interbedded poorly sorted conglomerate & greywacke tuff and white marl, mainly non-marine. Gently folded.	
		Slight	Unconformity	
	PLIOCENE (h stage)	1200'	Light grey & buff coloured marine marl with h stage Foraminifera. Medium dips. Exposed on both north and south flank of Cape Vogel.	
		Slight	Unconformity	
	MIO-PLIOCENE	10 000'	Interbedded brown greywacke & carbonaceous mudstone containing Foraminifera. Moderately folded. Dips steep and sediments indurated adjoining volcanics and shallow intrusives on Cape Vogel.	
	MIDDLE MIOCENE	400'	Reef limestone & calcarenite on Castle Hill.	
			MAJOR UNCONFORMITY	
	PALEOCENE	+200'	Limestone, marl, conglomerate.	Basic submarine lavas. Ultramafic & basic plutonic rocks.
			MAJOR UNCONFORMITY	
BASEMENT	? MESOZOIC	?	Recrystallized limestone & calc-silicate metamorphics on the N. flank of the Owen Stanley Range east of Musa Valley.	
		Unconformity		
	?MESOZOIC-PALAEOZOIC	+10 000' (?)	Phyllite, schist, and metavolcanics of Mount Dayman and the Goropu Mountains.	

The Cape Vogel Basin includes a thick middle Miocene to Recent sedimentary sequence forming Cape Vogel, and possibly extending to the northwest below the coastal plain alluvium and volcanics, and to the southeast across Goodenough Bay. The offshore limits are unknown at present. Gravity data from the East Papuan Survey (Milsom, op. cit.) suggests the presence of another coastal basin to the northwest of Dyke Ackland Bay.

The principal fold on Cape Vogel has an exposed core of basic submarine lava of probable early Tertiary age which has been intruded by Pliocene or younger basalt. A veneer of Paleogene limestone, marl, and conglomerate overlies 'basement'. An upper Miocene and Pliocene sequence of sandstone, conglomerate, and marl, totalling about 4000 metres, was deposited under paralic conditions. It is bounded by an active fault block of low-grade metasediments and basic to ultrabasic intrusives.

Papuan Basin

The most useful regional geological summaries for the area around the Gulf of Papua are given by Thompson (1965, 1967) and Phillips Petroleum (well completion reports, 1967-1969). Although not specifically referred to in the text the following summary leans heavily on these sources. Phillips has drilled in five widely spaced locations (Plate 3) in the Gulf and has carried out extensive seismic surveying in the north and northwest. Tenneco has conducted seismic surveying and drilled Anchor Cay No. 1 Well, southeast of Daru.

Geological history. The Papuan Basin is a composite basin covering about 200 000 square kilometres in central Papua and the Gulf of Papua. It contains a thick Tertiary succession of marine and paralic sediments overlying, with degrees of unconformity, a Cretaceous and Jurassic succession. Upper Mesozoic sandstone, siltstone, mudstone, and minor coal seams overlie igneous basement rocks on the Oriomo Shelf. A similar relation is seen in outcrop on Cape York Peninsula. Seismic interpretation indicates that Mesozoic sediments, penetrated in a few wells, are continuous throughout the western portion of the basin.

Over most of the Basin a major break occurred between the deposition of the Lower Cretaceous and the Miocene. With the exception of the eastern portion, where deposition of Palaeogene limestone, chert, and arenaceous sediments have been recorded (Glaessner, 1952), the Upper Cretaceous/Lower Tertiary was a period of widespread emergence, and eastward tilting about the stable shelf. Thin Eocene limestones, representing a temporary marine transgression, have been encountered in wells in western Papua. Following Eocene time, broad folding developed about east-west axes in the 'slope province' (see Phillips zone 2, Plate 3 of this report).

Development of the Aure Trough (Plates 2 and 3) in the lower Miocene accelerated the easterly tilting of the shelf areas and provided an environment for limestone deposition, formation of a barrier reef, and formation of platform reefs in structurally high areas. In the east, towards the depositional axis, limestones grade into mudstone, greywacke, and volcanics.

Pliocene sediments are generally not as folded as the Miocene. At the close of Miocene time broad synclines linked by sharp anticlinal crests evolved, causing the later Pliocene sediments to exhibit a catenary effect. In some instances there was no deposition on the crests of the anticlines.

After lower Miocene time, uplift occurred in the north and west, subjecting the western edge of the basin to erosion and initiating a prograding depositional system in the western portion. From that time to the present, clastic deposition throughout the basin has dominated in response to accelerated tectonic movements.

Stratigraphic/structural divisions. Phillips divides the Papuan Basin into six stratigraphic/structural zones, on the basis of seismic information (Phillips, 1965) (Plate 3).

Zone 1: Western stable shelf with relatively thin Tertiary section dipping eastwards. Structurally disturbed. Miocene reef development is suggested on the basinward edge.

Zone 1A: A Miocene limestone shelf area in Deception Bay. Eocene block uplift and a Miocene reef development are indicated.

Zone 2: West slope of the basin in which the Tertiary dips more steeply, and rapidly thickens, towards the east. Tertiary/Mesozoic unconformity is evident and the Mesozoic is locally folded and faulted.

Zone 3: An undeformed belt occupying the western part of the mobile Tertiary basin. Sediments dip steeply to the east. Local faulted structures are recognized in the older rocks on the eastern edge of this zone. Gentle folding is present in strata tentatively identified as upper Miocene and Pliocene.

Zone 4: Seaward extension of the Aure Trough, a complex fold belt characterized by gentle synclines separated by tight anticlines. Crests of the anticlines tend to be thrust-faulted, and diapirs have developed in the anticlinal cores by flowage of incompetent mudstones. Regional dip is to the west.

Zone 5: A mobile eastern shelf and slope province where there is good evidence of thrust-faulting associated with the eastern shelf of the Aure Trough.

Stratigraphy. Thompson's generalized stratigraphy of the Papuan Basin is shown in Table 3. This gives details of lithologies and sedimentary thicknesses found in the southwest, the trough, and the northeast of the basin.

Table 4 indicates the broad lithologies and age-depth determination from four of Phillips's wells in the Gulf of Papua: Borabi No. 1, Pasca No. 1, Orokolo No. 1, and Maiva No. 1, chosen to give a representative cross-section of the Gulf. The wells are located in zones 1, 2, 3 and 5, respectively, as shown in Plate 3.

TABLE 3

GENERALIZED STRATIGRAPHY OF THE PAPUAN*BASIN (after Thompson)

AGE	S.W. FLANK (Wide, shallow shelf)	TROUGH (Miogeosynclinal, from Lower Miocene to Recent; Jurassic to Aptian environment not known).	N.E. FLANK (Narrow, steep, local and intermittent shelves during Tertiary; Mesozoic sediments slightly metamorphosed).
RECENT	100 ft; flood plain and delta unconsol. clastics	200 ft; flood plain and delta unconsol. clastics	50ft; alluvium.
PLEISTOCENE	300 ft; Fly River delta and flood plain deposits. Basaltic volcanics and piedmont fans.	800 ft; Kikori-Purari delta and flood plain. Local reefs raised to 500 ft. a.s.l. Basalt plugs, cones and apron deposits.	Sub-basaltic agglomerate sheets up to 2000 ft thick; raised limestone to 50 ft. thick; dissected piedmont deposits 300 ft.
PLIOCENE	0-1000 ft; deltaic clastics	8000-10000 ft. Trough divided into two subsiding depositional basins by transverse emergent area. Deltaic deposits - greywacke and mudstone with coal measures in lower half of sequence.	1000-5000 ft medium to coarse clastics: greywacke, with notable tuffaceous content: local raised reef limestone to 300 ft. thick. Basaltic volcanic plugs, flows, apron deposits to 3000 ft thick.
	SLIGHT REGIONAL UNCONFORMITY		ANGULAR UNCONFORMITY
NEOCENE Miocene "g", "f" "e" stages.	500 - 3,500 ft; algal-bryozoal reef and shoal limestone. 11,000 ft locally in Omati Trough, including 6000 ft Miocene "e-stage" basinal limestone.	30,000 - 35,000ft marine and deltaic deep-water muddy clastics; mudstone and greywacke. Interbeds of basinal ('puri-type') limestone.	Up to 10,000 ft medium to coarse tuffaceous clastics: intruding localized reefs to 500 ft thick. Basaltic volcanics.
	MAJOR REGIONAL LOW ANGLED UNCONFORMITY		
PALAEOGENE (Eocene, Oligocene)	Reef and shoal limestone, local erosional remnants of Eocene to 200 ft. thick. Oligocene missing.	Eocene shoal and basinal limestone and coarse clastics to 2000 ft. Oligocene missing.	Up to 5000 ft limestone, chert, submarine volcanics complexly folded.
UPPER CRETACEOUS (Cenomanian) (Turonian) (Senonian)	REGIONAL LOW ANGLED UNCONFORMITY	10,000 ft; Greywacke and mudstone, some local limestone. Exposed only in central highlands.	+4000 ft clastics and some limestone, completely folded and partly metamorphosed; true thickness indeterminate.
LOWER CRETACEOUS	0-3000 ft; fine clastics, some quartz sand in west.	+6000 ft fine clastics; mudstone, glauconitic greywacke and red shale.	Not recognised, possibly because of metamorphism.
JURASSIC	0-6000 ft; clastics, mudstone and greywacke, some coal measures, quartzose and arkosic sandstone and conglomerate near base.	10,000 ft black mudstone, in trough in Western Highlands. (Not exposed in Aure Trough).	Not recognised, probably metamorphosed.
TRIASSIC	Possible 650 ft arkosic sandstone at Barikewa.	Possible 2000 -3000 ft coarse to fine arkosic clastic sediments in central highlands.	Not recognised (?metamorphosed).
PERMIAN	800 ft; arkosic limestone, limestone and submarine volcanics in central highlands.	Not recognised.	Not recognised.
BASEMENT	(?) Permo-Carb. granite.	Probable Palaeozoic metamorphics.	Cretaceous and older metamorphics.

* (The Papuan Basin is strictly a late Tertiary basin - the extent and pattern of early Tertiary and Mesozoic sedimentation in Papua has not yet been unravelled).

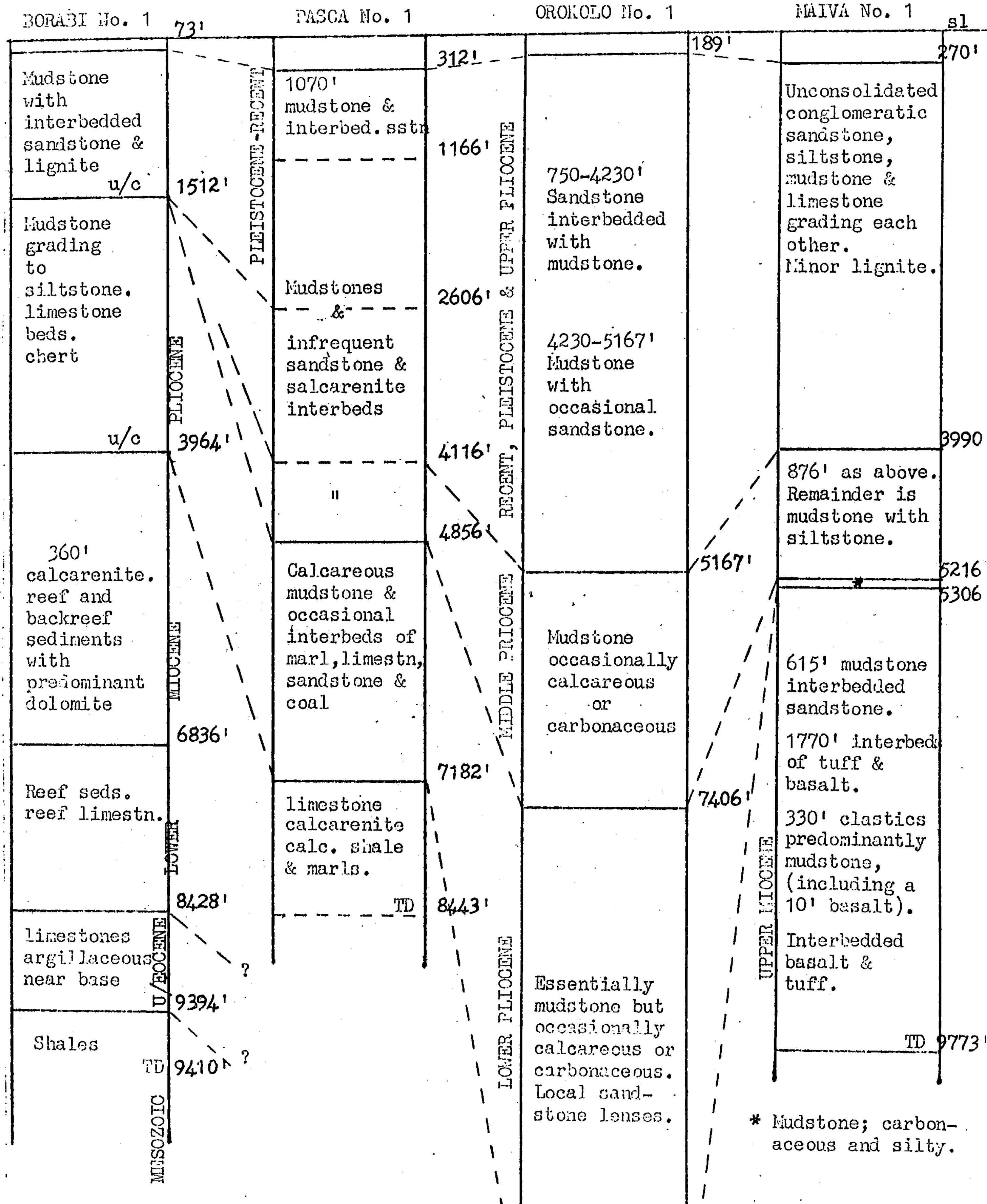

TABLE 4: LITHOLOGIES ENCOUNTERED IN PHILLIPS WELLS LOCATED IN ZONES 1, 2, 3 & 5, GULF OF PAPUA.

3. PREVIOUS GEOPHYSICS

AEROMAGNETIC SURVEYS

Plates 4, 5, and 6 show the areas covered by aeromagnetic surveys around New Guinea, the magnetic intensities, and a basement contour map, respectively. The International Geomagnetic Reference Field (IGRF) has been used for regional corrections to ensure compatability between results from different surveys.

Northern New Guinea

Young (1963) records the results of some widely spaced groups of reconnaissance traverses across the Northern New Guinea Basin. North-south traverses across the Bewani Geosyncline and northeast-southwest traverses across the Finisterre Ranges terminate at the coast, but those across the Prince Alexander Mountains extend to Kairiru Island, about 10 miles offshore. In the vicinity of the coast, the Finisterre traverses are interpreted as showing basement dipping seaward at about 250 metres per kilometre. The other areas have been duplicated in a more recent survey (Aquitaine, 1967) and are discussed below.

The Sepik Aeromagnetic Survey was carried out by Geophysical Associates for Australian Aquitaine in 1967, within Permit P45. This covers an area north of the Sepik River. In the Wewak and Aitape districts traverses extend by up to 60 km beyond the coast. Line spacing is approximately 20 km.

Between Vanimo and Aitape a possible basin is delinated by magnetic basement contours. Basement dips north-northeast at about 150 metres per kilometre, reaching a depth of 3000+ metres at the coast. Around Wewak, depth to basement ranges from +8 m on Kairiru Island, to -350 m in areas 8 km to the east. Both basinal structures form part of a broader seaward dip along this portion of the New Guinea coast. Geophysical Associates draw the conclusions that the sedimentary sections indicated between Vanimo and Aitape, and east of Kairiru and Mushu Islands, form prospective basins both onshore and offshore. It must, however, be pointed out that along the coastal strip the interpretation relies largely on inferences drawn from data recorded inland.

The four structural trends discussed above are all indicated, to a greater or lesser extent, on the magnetic basement contour map. The predominant anticlinal and synclinal trends are subparallel to the coastline. Near Vanimo, the anticlinal feature marking the Bewani-Torricelli-Prince Alexander ranges is displaced (either north or south), possibly indicating the presence of a major transcurrent fault.

The Madang Aeromagnetic Survey was carried out in 1968 by Compagnie Generale de Geophysique (C.G.G.), for Continental Oil, in Permit P41. The region around the Ramu River was flown using a 2-km grid with 8-km tie-line spacing. The flight-lines have negligible seaward extent, but data obtained in the 'Sepik/Ramu delta' are of interest. Four magnetic markers were envisaged:

Basic plutonic rocks of the basement
Volcanics in the sedimentary section
Metamorphic rocks of the primary basement
A weak marker due to basic Cretaceous dykes

The anomalies recorded vary in both amplitude and width. The appropriate magnetic marker is identified on the basis of computed depth and the degree of continuity with depths computed for adjacent anomalies.

The basement contour map indicates a major character change on each side of a line along the north-south-trending lower reaches of the Ramu River. East of this line, the basement contours indicate a northwest-trending basin, with depths to 4000 m, disturbed by predominantly north-south faulting. This magnetic basement depression parallels the Ramu Gravity Low but is slightly offset to the southwest. West of the Ramu the magnetic basement depth estimates vary from 500 m to about 4000 m, with a number of subparallel northwest-trending structures. An extension or offshoot of the Ramu-Markham Fault towards the coast, and possibly beyond, could be responsible for this change in magnetic character.

Papua

The Papuan Basin and Basic Belt Aeromagnetic Survey (1967) was flown by C.G.G. for BMR during 1967. The survey area lies between latitudes 7°S and 9°15'S and the meridians 143°15'E and 148°30'E, forming a strip across the northern portion of the Gulf of Papua and across New Guinea between Lae and Port Moresby. About 32 000 line kilometres were flown; in the eastern highland area at an elevation of 4500 metres on a 4.8 kilometre by 9.6 kilometre grid, and in the western (Papua Basin) area at an elevation of 1200 metres on a 9.6 kilometre by 19.2 kilometre grid.

The following deductions were made in the eastern area:

(i) The Owen Stanley Metamorphics produce a low-intensity anomalies decreasing to the southwest.

(ii) Anomalies of 200-400 gammas were detected over basic igneous bodies in the Mount Victoria area.

(iii) The Ultramafic Belt is associated with anomalies of 20 gammas closure, with northwesterly and westerly trends. The anomaly pattern is consistent with a northeast dip for the ultrabasics.

(iv) The trends of the Owen Stanley and Timeno Faults are clearly visible.

(v) Cainozoic sediments and volcanics northeast of the Ultramafic Belt are interpreted as being about 1700 m thick.

(vi) Granodiorites are associated with intense anomalies.

21

(vii) West-east profiles across the Huon Gulf indicate a northeast-dipping basement to 3000 metres with only thin sedimentary cover.

In the western area two zones were clearly defined:

(i) A zone between Port Moresby and Kerewa, extending 500 km inland, characterized by intricate anomalies with trends from 340° to 040°.

(ii) The remaining portion of the Papuan Basin, associated with broad anomalies.

A brief summary of the Basins's structure is given by C.G.G.:

> The Papua Basin was clearly outlined by the airborne survey, with the exception of its eastern boundary which still remains unknown. The intermediate anomalies due to the complex tectonics and volcanics conceal the basement anomalies in this eastern zone, preventing from finding out whether the basement rises to the east up to the Owen Stanley range or if it still deepens.
>
> With the exception of this eastern zone, the Basin appears to be nearly symmetrical, with the maximum depth a little to the south of the point of co-ordinate 144°30' East - 8° South. From this point the basement rises sharply to the north, up to the latitude 7°30'S, and then slightly deepens further north.
>
> Westward and southward the basement rises in a similar manner. To the south the basement rises from depth 25 000 - 30 000 feet to the depth 14 000 feet on latitude 9°15'. This southern area is the most interesting since it is the only one where a closed structure (A4) and a possible other one (A3) could be mapped.

The Eastern Papua Aeromagnetic Survey is at present being carried out for the BMR. This will complete the aeromagnetic coverage of Papua, and the adjacent islands, east of meridian 144°.

The Fly River Aeromagnetic Survey (1968) was flown by Aero Service Corporation for American Overseas Petroleum, in the region of the Fly River delta. There is an absence of predominant trends, and nearly all the magnetic values fall within a 300-gamma range. Lack of correlation with known geological trends is taken to indicate that the anomalies are due to minor changes of magnetic susceptability within the basement. Three magnetic horizons appear to be present:

(i) Shallow horizon - 300 to 600 m - (?) base of recent alluvium.

(ii) Intermediate horizon - 2000 to 3000 m - intrabasement structure.

A comparatively thin sedimentary cover is consistent with a location on the 'shelf province' of the Papuan Basin. Similar conditions are to be expected in the west of the Gulf.

Aeromagnetic Survey, P51 Papua (1968), for Union Oil, was located in the 'slope province'. Correlation of magnetic data with gravity observations and geologically mapped surface features is evident. Sedimentary depositional thicknesses outlined by the survey show deep troughs of sediments along the northern border of P51, and in the northeast where the Omati Trough is known. Magnetic basement contours show the Komewu Fault and a shelf area shallowing to about 2000 m in the southwest corner of the permit.

Carrington - Ka Aeromagnetic Survey (1968) was undertaken for British Petroleum in an area adjacent to and northeast of permit P51. As may be expected, depth to basement of 4000+ m are indicated. Anomalies due to interbedded volcanics within folded sediments obscure basement anomalies over much of the area.

Australasian Petroleum, Marathon, and Delhi have made aeromagnetic surveys west of the areas discussed above, but these are considered to have little bearing on marine work in the Gulf.

Additional Magnetic Data

The U.S. Naval Oceanographic Office track chart for Project MAGNET, shows a loose network of flight paths across the Bismarck Sea, and also isolated paths across the Solomon and Coral Seas. Relevant data will be compiled before commencement of the marine survey.

Scattered magnetic observations should be available from the tracks of the Shoup (1963-64) and the Umitaka-maru (1964) (Tomoda et al., 1968).

GRAVITY SURVEYS

A composite gravity anomaly map for Papua New Guinea, the surrounding islands, and portions of the Bismarck, Solomon, and Coral Seas is presented in Plate 7. Bouguer anomalies were computed on land and for short traverses off the coast between Aitape and Madang (see Watts below). The marine data are presented as free-air anomalies, and are essentially gravity on the spheroid, corrected for ship's movements. Bouguer anomalies and marine free-air anomalies are equivalent along the shoreline.

Between 1963 and 1967, scattered gravity observations were made throughout Papua New Guinea by Shirley (1964) and St John (op. cit.). A base station network was set up in Papua New Guinea and Bougainville, superseding lower-accuracy airport stations established by the University of Wisconsin in 1961. These base station values are in close agreement with those of the BMR Isogal network installed by Milsom (1967).

From these regional gravity observations St John has computed crustal models to fit some of the major anomalies; for example, that due to the Papuan Ultramafic Belt. In an interpretation of the gravity profiles he concluded that it was not possible to differentiate between a continental basement in Papua and an oceanic basement north of the Highlands. 'Gravity gradients on the north coast indicate that the crust thins rapidly towards the true oceanic crust. Preliminary results from Royleigh wave dispersion studies by J.A. Brooks....indicate a crust of continental thickness throughout the inland areas of northern New Guinea'.

Satellite perturbation studies (Schwiderski, 1967) have shown the mantle density to be anomalously high under the Bismarck Sea region. A geoidal bulge has been detected over the Solomon Islands region, and gravity anomalies southeast of New Britain and between Bougainville and New Guinea appear to be excessively positive by more than 100 milligals.

Marine Gravity Data

Extensive cruises were carried out by the U.S.S. Shoup in 1963-64 in the New Guinea region. Surface gravity meter readings are available in the form of free-air anomalies, but positioning was only by dead reckoning. Apparently the vessel's depth sounder was inoperative for the duration of the cruise, and Bouguer anomalies were obtained using depths scaled off Admiralty charts. Near the northern New Guinea coast, better bathymetry is provided by Krause (op. cit.) (Plate 9) and this has been used by Watts to compute offshore Bouguer anomalies shown in Plate 7.

Several marine gravity and magnetic observations have been made aboard British and U.S. hydrographic vessels, the most notable being due to Rose et al. (1965) aboard H.M.S. Dampier, as part of a survey of the Solomon Islands.

A Bouguer anomaly map collated by Rose, Wollard & Malahoff of the Hawaii Institute of Geophysics, from data gathered on board the ships Dampier and Baird, covers the areas southeast of New Britain and east of New Ireland.

The Japanese vessel Umitaka-maru took scattered gravity and magnetic readings along its track through St Georges Channel and the Solomon Sea during 1964.

Land Gravity Surveys around the Bismarck Sea

During the Sepik River Helicopter Gravity Survey (Watts, 1969) 1300 stations were read using a 4-mile grid in an area bounded by the coast, between Aitape and Madang, and the main cordillera. An offshore basin northwest of Wewak is indicated by aeromagnetic data and a poorly defined gravity depression. Other coastal basins may exist west of Dagua. A further gravity low of 20-30 milligals closure is located off Madang, and possibly indicates an area of thick Pleistocene sediments.

A regional gradient, reaching a maximum of 2-3 milligals per kilometre in the BOGIA Sheet area, extends across the survey area, with Bouguer anomalies increasing to about +200 milligals in the centre of the Bismarck Sea. This is in accord with St John's data (op. cit.).

Laudon (1968) carried out land gravity surveys of the Solomon and Bismarck Islands. In general, the islands are characterized by large positive free-air and Bouguer anomalies with extremely steep gradients. The Bouguer anomalies are related to the near-surface geological features, the highs being an expression of basement ridges and Quaternary volcanics, and the lows an expression of Tertiary sedimentary basins. Anomaly closures often in excess of 50 milligals, and gradients among the steepest in the world, probably result from contrasts between ultrabasic basement complexes in the uplifted cores of the islands and Upper Tertiary sediments on their flanks. In the Rabaul area of New Britain the apex of the steepsided, V-shaped anomaly lies close to the volcanic craters. Laudon concluded that...'present volcanic activity may be associated with intersecting fracture zones that are filled with crystalline material or perhaps, at depth, with molten material within the lighter predominantly pyroclastic sequence of which the terrain around Rabaul is composed.'

On a regional scale, the data are interpreted as indicating that the Solomon Islands area is isostatically compensated, but that individual islands and their Quaternary volcanic piles are supported by the crust.

The Helicopter Gravity Survey of New Britain and New Ireland was carried out by Harrison during 1969 (Harrison, in prep.). A preliminary interpretation indicated that the gravity field of the area, taken with values from the Planet Deep and the Bismarck Sea, is in accord with a reversed island arc structure. Localized positive Bouguer anomalies correlate with intrusive and volcanic vents. The northwest faults in the Gazelle Peninsula are evident from the gravity field.

Eastern Papua

The Regional Gravity Survey of Eastern Papua was undertaken by Milsom between 1966 and 1968 (Milsom, in prep.). Except in the Owen Stanley Ranges, the area is marked by positive Bouguer anomalies, with steep gradients over all known outcrops of ultramafic rocks. In some areas steep gradients are found where such rocks are unknown. Several small gravity lows were detected and probably result from areas of thick sediments.

Gulf of Papua

The only marine gravity data in the Gulf of Papua were collected by Williams in 1958 and 1959. Six short (16 km) traverses perpendicular to the shoreline, and one traverse parallel to the shore, were surveyed in Redscar and Kerema Bays. In general, the anomalies decrease towards the coast, that is approximately to the northeast, probably as a result of crustal thickening beneath Papua New Guinea.

Local gravity surveys have been made near the head of the Gulf by Papuan Apinaipi Petroleum (1960), Union Oil (1967), and Australasian Petroleum Company (1959 etc.). These all indicate regional northeast dips, but correlation with known geology tends to be poor. Gravity observations made along seismic lines during the Puri Seismic Survey (A.P.C., op. cit.) showed some correlation between the gravity gradient and deep seismic horizons.

SEISMIC SURVEYS

The only portion of the 1970 marine survey area covered by previous seismic exploration is the Gulf of Papua. Exploration by the Australasian Petroleum Company previous to 1961 in onshore Papua is recorded in the Geological Society of Australia, Volume 8, Part 1. Numerous small onshore surveys are of little significance to a regional survey in the Gulf. A location map of the principal surveys is presented in Plate 8.

Gulf of Papua

A marine seismic survey of the Goaribari Prospect was conducted for Burmah Oil Company during 1961. This indicated the presence of an ancient shelf in the western portion of the Gulf of Papua. A marine seismic reconnaissance carried out for Phillips in 1965 outlined a number of structural and stratigraphic leads, and defined distinct structural zones across the Gulf.

The four surveys listed below are considered in some detail as these appear to be particularly relevent to the forthcoming BMR survey.

The Papuan Marine Seismic Survey, Gulf of Papua P39 (Phillips, 1968). On the basis of this survey it was found that the Gulf of Papua could be divided into six structural/stratigraphic zones. These have been detailed in Chapter 2, under the summary of the Papuan Basin.

The survey used a combination of AM, FM, and digital recording techniques, with AVC and filter passbands of 10-50 Hz, 6.5-62 Hz, and 8.5-62 Hz. The recording boat 'backed up' before each shot, and a second vessel was used for positioning the 20-kg charges. The analogue tapes have been six-fold stacked and filtered, and the final sections are presented as variable-area and variable-density displays. The data are generally of good quality.

Dynamic corrections in the Deception Bay area were based on velocities from Iviri No. 1 well and in the remaining areas the corrections were determined by T - delta T analysis. Velocity uncertainties produce considerable variations in the pre-Miocene structure. Time-depth plots are available with the survey report.

In the shelf and western slope areas (Zones 1 & 2) three horizons were mapped:

(i) Top of the Miocene limestone horizon - a composite of the middle Miocene to the west and the lower Miocene in the east. The middle Miocene horizon is a strong reflector showing a gentle easterly dip and terminating abruptly eastwards from the edge of the shelf. The lower Miocene horizon is of outstanding character and ties to the lower Miocene limestone in Iviri No. 1.

(ii) Cretaceous/Tertiary Unconformity is marked by a seismic energy band correlated with the base of the Eocene limestone. Wide variation in the thickness of the overlying limestones gives the mapped two-way times little structural value. Reflections below this horizon are weak and are thought to represent a predominantly shale section.

(iii) Horizon near the base of the Mesozoic shows as a strong reflection in the Deception Bay area but deteriorates to the west and south. Faulted Mesozoic basement can be inferred from this event.

In the Orokolo Bay area (Zone 3) two horizons were mapped:

(i) Pliocene horizon. A low-energy band in the lower part of the Pliocene section. Phillips interprets small closed structures as obscured flowage or thrusting in Miocene mudstones.

(ii) Top of lower Miocene limestone and ?Eocene limestone. A strong reflection near the base of a large interval of weak energy is ascribed to the Eocene limestone, estimated to be 6000 metres below sea level. This horizon is equivalent to the lower Miocene reflection as mapped in the Deception Bay area.

In the eastern portion of the Gulf, in the shelf and slope province (Zone 5) reflection quality is poor, and only one horizon was mapped:

(i) Top Middle (?)Miocene horizon is tentatively correlated with the upper limestone/middle Miocene limestone interface. The horizon deteriorates to the west and is not mapped south of Yule Island.

The Marine Seismic Survey, Gulf of Papua, 1968 was made in permit P42; that is, in the central area of the Gulf of Papua, with Phillips Petroleum as operator. The objective was to locate reef structures within the permit and to provide connecting control into permit 39.

A neutrally buoyant cable was used. Initially the seismic source used was dynamite, but after successful tests with the Aquapulse system, a change was made. Both the recording and shooting boats were equipped with the Raydist navigation system. Digital recording with binary gain amplifiers was used. The record filters were out-64 Hz and 5-64 Hz passbands.

Stacked records were prepared using both variable-area and variable-density displays.

It is noted that although the survey was conducted between November and March unfavourable weather was experienced for much of this time. Locally, strong currents created cable drifts of up to 15 degrees. Floating debris from the rivers was also considered to be a major hazard.

The principal feature in the survey area is interpreted as a broad pre-Miocene arch extending across the entire length of the permit, in a southwest direction. Biohermal reefs appear to be developed on a structural high on the northeastern tip of this arch. The principal reef varies in thickness from 1000 to 3000 metres and is covered by 2000 to 3000 metres of upper middle Miocene to Recent sediments.

The Seismic and Magnetic Survey of the Northern Great Barrier Reef (Tenneco, 1967) in Area 88PA, Qld. The objectives were to confirm and delineate the extent and thickness of the sedimentary section and to map details of the structural framework of the area.

A neutrally buoyant cable, explosive seismic source, and digital recording were used. Charges were of 15 kg. The filter passband was 12-92 Hz.

The ?Mesozoic horizon (0.770 to 1.700 seconds) shows general easterly dips. There is evidence for two east-trending faults that are downthrown to the north. Two nose-like structures trending from the south to the north and from the south to the northeast have associated local closures. The faulting trends generally northwest and is downthrown to the northeast.

The Tertiary horizon again shows an easterly dip. Three anticlinal closures are in evidence. In the southwest of the area an anticlinal structure associated with a north-trending fault is indicated.

The Bligh Entrance Marine Seismic Survey (Phillips, 1969) was made in the northwest Gulf of Papua, with Phillips Petroleum as the operator. The survey was designed to provide further details over anomalies outlined in the previous work and to extend reconnaissance surveying farther to the west and southwest. The Aquapulse technique was similar to that used in the previous seismic survey. Velocity control was based on dynamic correlation techniques, but some problems arose from rapid variations in the thickness of limestone horizons. After applying velocity corrections, however, the western continental slope was considered to reveal valid structures of Eocene and older ages. The following horizons were mapped:

A horizon within the Pliocene
Top of the lower Miocene limestone
(?) Top of the Eocene
(?) Top of the Mesozoic
Two horizons from within the Mesozoic

The Pliocene horizon can be traced to the Orokolo No. 1 well to the north. It illustrates the folding attributable to flow in the late Tertiary to Recent mudstone-silt section. The lower Miocene limestone reflection shows a northeast-dipping fold plunging from the broad arch that underlies the Pasca area. North and east of Pasca (see Plate 3) the reflection time configuration is affected by the low-velocity overburden. The unidentified top of Eocene horizon is persistent and covers the entire area to the south of Pasca. The (?) top of Mesozoic reflector dips from 1.5 seconds in the southwest, on the continental shelf, to below 6.5 seconds in the basin, northeast of Pasca. It is the only horizon that could be traced across the entire area. The upper of the two Mesozoic horizons shows thinning of the Mesozoic section to the north of the structural arch, and eventual truncation at the Mesozoic/Tertiary unconformity.

BATHYMETRY

Two bathymetric studies by Krause (1965, 1967) deserve special mention, as these attempt to correlate the bathymetric data along the northern New Guinea coast, and in the northern Coral Sea and Solomon Sea, with the known onshore geology of New Guinea. Sources of information include, the Recorder expedition, soundings by H.M.S. Cook, the Netherlands Hydrographic Office, and the U.S. Naval Oceanographic Office. Soundings were also available from the Snellius Expedition and the E.S. Vitiaz. Bathymetry along the north New Guinea strip, between 141°E and 146°E, and in the Solomon-Coral Seas area is reproduced in Plates 9 and 10.

Northern New Guinea

The principal bathymetric features outlined by Krause are:

(i) A southern active (Bam-Umboi) volcanic group trending into New Britain, and a northern inactive (Wuvulu) group, largely submarine and considered to trend into the Admiralty Islands.

(ii) A remnant volcano in the middle of Vitiaz Strait.

(iii) A scarp of 300+ metres and 38° slope, east of Madang.

(iv) To the west of Bam and Blupblup, a trough occurs at the foot of the 'continental slope'. The Sepik River appears to have built its delta to the edge of the shelf, and may have filled the eastern end of this trough.

(v) On the north coast near the West Irian/Papua New Guinea border, there is a northeasterly structural trend correlating in space with structures associated with the Wuvulu volcanoes.

(vi) The trend of the Bewani-Torricelli Mountains continues to the east on the sea-floor.

It is of interest that the scarp east of Madang may correspond to the edge of the thick sedimentary pile indicated by both gravity and magnetic data. The seaward extension of the Bewani-Torricelli trend lies close to a chain of earthquake epicentres plotted by Denham. Hence, the trend appears to be tectonically active, either as a volcanic or as a fault zone.

Marchant (op. cit.) is apparently very critical of Krause's interpretation; and indeed it is true that it includes several sweeping statements. Krause considers that 'the sea floor must have a history similar to that of northern New Guinea, because in part Northern New Guinea was sea floor during Cretaceous and Tertiary time, and a continuity of geological structure exists between northern New Guinea and the sea floor to a degree found in very few places in the world'. As Marchant points out, this is not necessarily the case if bodily shifting of New Guinea has taken place and if extensive transcurrent faulting exists along the coast. The structural features of New Guinea are predominantly

29

parallel and subparallel to the coast, and hence seaward continuity is difficult to ascertain. However, the postulated extension of the Bewani-Torricelli trend onto the continental shelf is probably valid.

Two interesting structural hypotheses presented by Marchant are that:

(i) West of meridian 144°E volcanic activity ceases and the sea-floor descends gently from about 1000 metres to depths of 3000-4000 metres with a relief of 1000 metres. It is suggested that the inactive Wuvulu volcanic group is disassociated from the Admiralty Islands volcanic arc, and in fact lies on the Pacific floor, in an 'oceanic province'.

(ii) Extensive faulting inferred to be present in the Ramu Valley may extend northwest, passing between the Schouten Islands and Kairiru and into the offshore trench. A similar hypothesis has been advanced from the gravity data (Watts, pers. comm.). This possibly places a major structural feature between the active and inactive volcanic groups.

Northern Coral Sea - Southern Solomon Sea (extract from Krause, 1967; See Plate 10 of this report)

'The outer edge of the continental shelf off southeastern New Guinea is usually marked by reefs. The shelf near Port Moresby is very narrow with a minimum width of 3 n.m. and broadens to the southeast to 5-10 n.m. Near Tagula Island, the eastern extension of the Papua Peninsula forms a flat-topped underwater ridge with a reef complex almost awash over most of its 23 n.m.-wide top.

The upper continental slope near Port Moresby is very irregular, being extensively cut by sub-marine canyons. Much of the Papuan slope is not mapped, but, off the eastern end of the Peninsula, the slope is much smoother and gentler. At 151°E long. it merges with the lower continental slope. Two shallow depths recorded on this upper slope may be errors of observation (11°S, 150°17'E and 11°S, 150°30'E).

A large plateau (here named the Papua Plateau) exists between the upper and lower continental slopes off Papua with minimum depth of about 1200 fm. A large submarine channel crosses the plateau at 147°30'E long. after trending southeast along the foot of the upper slope. Any sediment flowing over the shelf to as far east as 148°30'E long. would be collected into this channel.

The lower continental slope trends east-west between approximate depths of 1200 to 2400 fm. with a general slope of 1 in 30. A cross fracture trending parallel to the Papua Peninsula modifies the slope near 150°30'E long. A local trough at 12°S, 149°30'E, appears to be a structural depression or else a region with a lower rate of sediment deposition than the surrounding region. From 147°-149°E long. a bulging of the contours between 2000-2400 fm. appears to be a large sub-marine fan built out from the mouth of the large channel.

East of 151°E long., the upper and lower continental slopes merge at 153°E long., the slope is very steep being an overall 1 in 8. This slope is composed of two very steep segments: 0-500 fm and 1500-2100 fm. The upper segment is formed from coral reefs while the lower must be a result of faulting.

To the east of Tagula Island the slope becomes very complex. The very complex floor of the southern Solomon Sea is poorly charted except for certain areas in the Louisiade Archipelago and near Woodlark Island which rests on Woodlark Ridge. The deep Woodlark Basin (new name) between these two ridges was uncharted before the Expedition surveys (Chart 3).

The Louisiade Archipelago rests on the eastward extension of the Papua Peninsula which there becomes a region of parallel structural ridges, troughs and closed basins. Tagula Island, Rossel Island and Pocklington Reef rest on a series of en echelon ridges.

The sea floor of the Woodlark Basin between Pocklington Reef and the Woodlark Ridge is very irregular and is a great contrast to the sea floor south of 12°S lat. The basin floor is cut into a chaotic arrangement of hills, ridges, and irregular depressions. The hills are generally 100-200 fm high and 1-10 n.m. apart, lying at between 1700-2300 fm depth. However, the hills seem to have a general alignment east-west although escarpments cut through the region in various directions. On the average, the basin becomes deeper to the east. Most, if not all, of this sea floor is composed of soft sediments, red clay and globigerina ooze with some interbedded lava flows (see below).

Woodlark Ridge is irregular and seems to be broken by a left-lateral fault (here named the Laughland Fault) at $8^{\circ}50'$S lat. which is a continuation of a structural depression trending ESE out of the northern part of the Solomon Sea. Just north of the Laughland Fault on the Woodlark Ridge lies a high peak, probably a volcano which is flat-topped at 406 fm.

The sea floor to the north of the Woodlark Ridge is again a complete contrast to the basin south of the ridge. The slopes are gentle and covered with extremely fluid fine silt (see below).

The structural rift of the flat-floored Pocklington Trough separates two extremely different areas. The chaotic nature of the area to the north has been described above. The area to the south is a gently undulating plateau of ancient aspect. The trough to the north-east abuts on a very irregular area of east-west-trending structures.'

CRUSTAL SURVEYS

Seismic refraction work was carried out by BMR in 1967 and 1969 in New Britain and the southern part of New Ireland to examine deep crustal structure (Brooks et al., in prep.). This work has indicated higher than normal crustal velocities over most of the area and crustal thicknesses of about 32 kilometres under the Gazelle Peninsula and about 20 kilometres under the Bismarck Sea.

3. OBJECTIVES

The major objective of the survey is to continue geophysical reconnaissance on the continental shelf around Australia. During 1965, when coverage of the shelf commenced, the survey was directed largely at extending regional gravity coverage of Australia into offshore areas. Since that stage other geophysical methods for exploration at sea have become available to BMR, and the equipment and complexity of the operations have greatly increased. The proposed survey provides for continuous gravity, magnetic, bathymetric, and seismic reflection profiling. In addition, seismic refraction profiles will again be included, to permit correlation with onshore refractors and to give additional velocity information. Sonobuoys will be used to 'relay' the refracted energy to the recording vessel.

The geophysical results are of little value unless adequate navigation is available, but this must naturally be a compromise between cost and the desired accuracy of the survey. The V.L.F. navigation system is believed to provide sufficiently accurate positions when tied to satellite-doppler fixes at regular (2-3 hour) intervals (Whitworth, op. cit.). A sonar-doppler system is required to limit errors to ± 0.1 knot, giving corresponding errors of ± 1 milligal in the gravity values.

Geological Objectives

(i) To map the structure of the Papuan Basin, particularly in the south and east, and to correlate seismic reflectors with horizons determined in wells, and with horizons from seismic surveys interpreted by Phillips, Tenneco, and B.O.C.

(ii) To relate gravity and magnetic observations to the structural provinces of the Papuan Basin and to determine the offshore extent of the Basin.

(iii) To determine the seaward extent of the Papuan metamorphic belt and the presence of any transcurrent faulting associated with the apparent offset of its mainland trend onto Goodenough Island.

(iv) To determine the extent of the Papuan Ultramafic Belt, its three-dimensional configuration, and the nature of the faulting along its southern edge.

(v) To determine the locations and thicknesses of sediments around the D'Entrecasteaux Islands, in Dyke Ackland Bay, and in the Cape Vogel Basin.

(vi) To investigate a Bouguer anomaly low and magnetic basement depression northeast of Madang, suggesting the existence of a thick sedimentary sequence.

(vii) To find if the main axis of deposition of the northern New Guinea Basin lies offshore, as suggested by Thompson et al. To delineate the offshore extent of this basin and the thickness of sediments within it.

(viii) To investigate sub-basins, as suggested from aeromagnetic interpretation, between Vanimo and Aitape and northeast of Wewak.

(ix) To locate a possible extension of the Ramu Fault between Kairiru Island and the Schouten Islands, in the area of the trough discussed by Krause. To outline any other major (? transcurrent) fault zones north of New Guinea.

(x) To trace faults of the Solomon Islands trend beyond the Gazelle Peninsula and southern New Ireland.

(xi) To locate further guyots, and investigate the trend of major groups of volcanoes. For example, Krause has suggested that the Wuvulu group trends into the Admiralty Islands.

(xii) To outline further bathymetric features on the continental shelf and to interpret the general morphology in terms of geological structure. The structure of the Papuan Plateau could be of particular interest as this is neither true continental shelf nor abyssal plain. The edge of this plateau may be traversed in eastern Gulf of Papua.

Technical Objectives and Assessment of Equipment Performance

(i) To continue assessing the performance of the V.L.F. navigation system (Ingham, 1968). Satellite fixes and line intersections will be used in the final reduction to determine the overall accuracy of the system. The independent fixes at roughly two-hourly intervals will permit a check on the reliability of the diurnal corrections obtained at the shore station.

(ii) To assess the performance and reliability of the Marquadt pulsed sonar-doppler system.

(iii) To further assess the performance and reliability of the I.T.T. satellite-doppler system. Accuracy when under way is lower than when at anchor, and further estimates of the system accuracy when operating at 10 knots are needed.

(iv) To determine the overall accuracy of the gravity data using line intersections. The accuracy of the velocity determinations probably influences the final accuracy more than uncertainties in averaging the drift within the LaCoste & Romberg meter.

(v) To assess the performance and reliability of the gravity-magnetic-navigation data acquisition system. This will incorporate filtered analogue outputs to 12-channel facsimile recorders and digital outputs to an HP2116B computer. Analogue outputs will be passed, via an analogue-to-digital converter, to the computer. Sequential digital values will be given a feasibility check and will be compared with values obtained from the analogue channels. Diagnostics and sample data blocks will be output on a teleprinter.

(vi) To determine the noise characteristics of the 6-channel seismic cable supplied by CGG, and 3-channel and single-channel Chesapeake cables, and the single-channel high-resolution Geotech cable, when operating at speeds up to 10 knots.

(vii) To further test the sonobuoy refraction technique by shooting continuous refraction profiles in areas with flat-bedded rocks.

(viii) To tie into previous seismic surveys allowing co-ordination and compilation of the results.

(ix) To check upon analogue displays from the pinger, a shallow reflection trace and a deep reflection trace, and to assess the performance of the digital seismic system and associated analogue displays.

5. PROGRAM

The program consists of a series of east-west lines spaced 10 minutes at latitude (about 19 km) apart with north-south tie-lines about 100 nautical miles (185 km) apart. This pattern will require some modification for operations in the southeast Papua area, and in areas where narrow strips along the coast are to be surveyed. It should, however, prove practicable in the Gulf of Papua and the Bismarck Sea. The line spacing is compatible with previous BMR marine geophysical surveys, and permits meaningful contouring of gravity data at a 5-milligal interval. The east-west orientation allows a reliable Eotvos correction (see Glicken, 1962) to be computed. The Eotvos correction depends primarily on the easterly component of ship's velocity and thus remains almost constant, despite small changes in heading, if the traversing direction is in the same plane as the Earth's centrifugal effect.

The survey vessel Hamme will be brought to Australia well before the survey commences, to permit fitting of the seismic and navigational equipment. The seismic system will be installed in a deck cabin and can be loaded in bulk. The second HP2116B will be flown direct from the United States and installed, together with the magnetometer and navigational equipment, in Sydney. The gravity meter will be fitted before the vessel sails for Australia.

The survey will depart from Sydney in mid-June, the cruise to New Guinea being regarded as a shake-down for the equipment. Gravity ties will be made at Brisbane, Cairns, and Port Moresby to assess the meter drift. The actual surveying is expected to comprise three cruises of 20-25 days duration, with a few days spent in port (Port Moresby or Madang) between each cruise. In the Bismarck Sea the calmest conditions occur during August and in the Gulf of Papua during January (see Appendix). The survey is expected to commence in the Bismarck Sea during August and to progress southwards into the Solomon Sea and the Gulf of Papua as sea-states improve in the south.

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APPENDIX

WEATHER CONDITIONS IN THE PAPUA NEW GUINEA AREA

A general statement about weather conditions in the Papua New Guinea area is given in the Pacific Pilot, Vol. 1:

> 'Southward of the equator the Southeast trade wind blows from about May to October, and there are periods between October and April with the very humid and oppressive weather of the northwest monsoon, during which exceedingly heavy rain squalls, and occasional northwesterly gales, alternate with comparatively fine periods with little wind.
>
> Tropical revolving storms ('cyclones or typhoons') are to be expected occasionally, except within 5 degrees of the equator.
>
> Fog is virtually unknown at sea but may occur around swamps, lagoons and river estuaries, rarely persisting long after sunrise.'

Winds tend to be controlled by the development of the 'Australian Heat Low', from December to March, and the 'Southwest Pacific High', an almost permanent feature to the east of the Australian continent. Dissipation of the Australian Heat Low and the presence of easterly migrating highs across Australia during the winter period, results in the predominance of east to southeast winds from about May to October.

The Bismarck and Solomon Seas lie off the main shipping routes, and consequently weather observations are restricted to those from a few shore stations. More extensive information is available for the Gulf of Papua largely as a result of records kept for Phillips Petroleum between 1967 and 1969, during seismic surveys and drilling operations with the Glomar Conception.

Definitions

Weather information has been compiled by Glenn & Associates for Phillips Petroleum. They discuss wave conditions in terms of 'significant wave height' (S.W.H.).

Significant wave height is the average height of the highest 33⅓% of waves passing a stationary point in 20 minutes. This approximates to the average wave height as judged by a casual observer, since waves of greater and lesser magnitude tend to be discarded. Statistically, the highest waves are about 150% of S.W.H., but for counts of 1000 waves this figure can reach 186% of S.W.H.

Waves and Swell. The distinction between waves and swell is not clearly defined in the literature available for this study. An unsatisfactory and imprecise definition of swell as 'long period waves' has had to be used. Swell is generated by weather remote from the point of observation and is usually characterized by periods of tens of seconds or more. It generally has little effect on seismic noise levels but can often be critical for surface gravity observations. The reverse is usually true of waves.

In Plate 12, where swell has been described as 'light, moderate or heavy' the middle of the 'moderate range' approximates to the limit of successful operation for the gravity meter. If the critical acceleration acceptable to the gravity meter is taken as 100 gals, sea-state observations in the Gulf of Papua indicate that 100% of gravity data would be recoverable provided wave amplitudes were less than 10 feet with periods of more than 7.5 seconds. Shorter-period waves observed in the 10-15 foot amplitude range would result in a 20% loss of gravity data.

GULF OF PAPUA

Sea conditions

Tables 5-8 show the average percentage frequency of significant wave height and direction at 9°S/145°E, in a water depth of 3240 feet. Each table provides a quarterly summary which is used for the graph in Plate 11. This information is probably representative of sea conditions in exposed waters but would not be expected to apply close to shore or in the lee of coral reefs.

Plate 12 is reproduced from data compiled for the RAAF by the Meteorological Bureau, from monthly meteorological charts of the western Pacific. It shows average swell conditions around Papua New Guinea in four ten-degree squares which slightly overlap. Plate 12C is in general agreement with Plate 11.

Bar charts of maximum wave height and maximum swell have been drawn from daily observations by Phillips, at various locations in the Gulf, for the period October 1967 to June 1969 (Plate 13). Both charts show the broad characteristics of the previous diagrams.

The principal points from the wave/swell statistics are summarized below:

(i) Calmest conditions occur in January, when average S.W.H. is below 6 feet for 96% of the time. This would suggest that maximum wave height could reach about 10 feet.

(ii) During July, the roughest month, S.W.H. is below 6 feet for only 57% of the time.

(iii) Between October 1967 and October 1968 the maximum wave height observed was 12 feet, but the mean value was about 2-3 feet. A swell (long-period waves) of amplitudes up to 18 feet, but on average about 7 feet, was superimposed on the waves. In most instances heavy swell and high waves occurred simultaneously, causing daily maximum to average 9-10 feet but on rare occasions to reach 30 feet. Sea conditions between November and May are notably calmer, the mean (wave and swell) disturbance being about 5 feet.

(iv) The dominant wave direction is from east or southeast and occurs about 75% of the time. This is closely related to the direction of the prevailing wind.

Normal Wind Conditions

As mentioned above, winds are generally controlled by the development of the Australian Heat Low and the Southwest Pacific High. In coastal areas, however, substantial onshore and offshore breezes must also be considered.

Tables 9-12 show the average percentage frequency of occurrence of wind speed and direction. Wind speeds are represented graphically in Plate 13. A barchart (Plate 15) shows Phillip's observations for the period October 1967 to October 1968.

The principal points are listed below:

(i) It is reasonable to assume that the survey would be impaired by winds in excess of force 5 (19-24 m.p.h.)

January	Winds	exceed	force	5	for	1.0%	of	the	time
April	"	"	"	"	"	2.0%	"	"	"
July	"	"	"	"	"	10.0%	"	"	"
October	"	"	"	"	"	2.6%	"	"	"

(ii) For the period October 1967 to October 1968, wind speeds between November and May averaged about 10-12 m.p.h. with occasional peaks of short duration reaching 30 m.p.h. The average for June to October was about 18-20 m.p.h., reaching 25-30 m.p.h. for periods of a few days. The southeasterly trade winds are evident from October to November 1967 and from June to October 1968.

Storm Winds

Cyclonic disturbances can develop in any part of the Gulf of Papua and can blow from any direction. The strong-wind area is normally 100-200 miles in diameter. Cyclones occur principally from November to April but are possible in any month. They are generally less severe than those found farther south. On average cyclones occur less than once per year. Most cyclonic disturbances rarely develop winds of greater than force 7, except in squalls.

Squalls are associated with cumulus or cumulo-nimbus formations and may develop 30-50 m.p.h. winds for short durations. On rare occasions winds may reach 70-80 m.p.h. and the squall may be of longer duration. They are of insufficient duration to develop waves and storm tides. Squalls are most common between April and October.

'Gradient Intensification Storms' occur principally from June to September, pressure gradient intensification causing east-southeast winds over the Gulf. These commonly reach 25-40 m.p.h. and persist for 24-48 hours.

The Northwest Monsoon occurs from October until April. It usually starts with high humidity, banked clouds, and a violent squall from the northwest. The monsoon has, however, been known to begin with a prolonged gale.

Gales	Winds greater than force 7
July-March	1% of the time
April-June	less than 1% of the time

Plates 16-22: Sea and Wind Conditions

Useful reference material is provided in Plates 16-22.

Plate 16: Average interval of occurrence of winds of specified speed and duration.

Plate 17: Average interval of occurrence of specified wave heights.

Plate 18: Mean range of astronomical tides.

Plate 19: Range of spring tides.

Plate 20: Spring tidal currents.

Plate 21: Wind-density currents: Dec-Feb

Plate 22: Wind-density currents: Apr-Oct

BISMARCK SEA

A comprehensive weather study is not available for the Bismarck Sea. Most of the data have been gathered by coastal stations which are strongly influenced by the surrounding terrain. Areas shadowed from seasonal rains and winds are common on the New Guinea coast and in the Bismarck Archipelago.

Wave Conditions

The calmest seas occur during August (Plate 12) but relatively calm conditions can be expected from about May until October. Swells assume the direction of the seasonal winds. It is noted that the calmest conditions in the Gulf of Papua are roughly equivalent to the roughest conditions in the Bismarck Sea.

Normal Winds

The southeast trade wind begins to blow intermittently southward of latitude 10°S in March and April, and spreads to about 5°S in May, and to the vicinity of the equator in June. It is most persistent from July to September, when it often maintains force 5-6 for several days on end over the open sea. It becomes increasingly unsteady northward of latitude 5°S after October. Between October and April the area comes under the influence of the northwest monsoon.

Prevailing winds over this region depend to a large extent on the location of the equatorial front separating the northern and southern tradewinds. The two large islands, New Britain and New Ireland, with their mountain ranges above 4000 feet, interrupt the sweep of the prevailing winds over the ocean surface and in some places completely overshadow or modify the monsoons.

Storm Winds

Most storm winds between the equator and lat. 10°S come from the west-southwest. They are often accompanied by electrical activity and torrential rains.

The Bismarck Sea is free of travelling cyclones.

When gales are monsoonal they persist steadily for some days but when they come from an unseasonal direction their duration is a matter of some 2 to 3 hours. Gales of force 7 and above occur:

November-April	1% of the time
May-October	less than 1% of the time

Squalls may occur, particularly during the northwest monsoon.

SOLOMON SEA

Virtually no data are available in the area of the Solomon Sea to be covered on this survey. A table of wind recordings from Kiriwina Island indicates predominant southeasterlies for most of the year, but a predominant northwesterly during February. In southeast New Guinea and the adjacent islands the trade wind does not often bring heavy rain.

The latitude and proximity to land suggest weather conditions similar to those in the Gulf of Papua, but with greater exposure to southeasterly winds.

CONCLUSION

Within the Bismarck Sea the period May-October is most suitable for survey operations, thus avoiding the months of greatest swell. There is no risk of cyclones, and gales are less frequent during this period.

In the Gulf of Papua the calmest season extends from about mid-November until the end of February. Since waves of about 6 feet and above could seriously impair the progress of the survey it would appear logical to work during this period. Further, winds of above force 5 (probably the critical level for the required control of the ship and stability of the gravity meter), occur on about 10% of the time in July but as little as 1% in January. At this time of the year there is a slightly increased risk of cyclones and gales, but this is thought to be of only marginal significance.

In general, the weather patterns for the Bismarck Sea and Gulf of Papua appear to be antiphase. Assuming the survey to be of about 3 months' duration, the two ideal timetables would be:

Bismarck Sea	mid-Sept to mid-Oct	about May-June
Solomon Sea	mid-Oct to mid-Nov	April-May
Gulf of Papua	mid-Nov to mid-Dec	March-April

AVERAGE PERCENTAGE FREQUENCY OF WAVE HEIGHT - DIRECTION

GROUPS AT 9°S - 145°E (after Glenn and Associates)

TABLE 5: January Summary (Dec., Jan., Feb.)

SIGNIFICANT WAVE HEIGHT (ft.)

	0-1.9	2-3.9	4-5.9	6-7.9	8-9.9	10-15	15+	TOTAL
N	1.3	0.5	0.2	0.0	0.0	0.0	0.0	2.0
NE	2.6	1.1	0.2	0.1	0.0	0.0	0.0	4.0
E	7.2	5.1	2.7	0.8	0.2	0.0	0.0	16.0
SE	4.2	4.2	2.7	0.8	0.1	0.0	0.0	12.0
S	3.5	1.8	0.6	0.1	0.0	0.0	0.0	6.0
SW	2.6	1.1	0.3	0.0	0.0	0.0	0.0	4.0
W	22.8	10.0	3.2	0.6	0.3	0.1	0.0	37.0
NW	11.8	5.1	1.6	0.3	0.1	0.0	0.0	19.0
Total	56.0	28.9	11.5	2.7	0.7	0.2	0.0	100.0

TABLE 6: April Summary (Mar., Apr., May)

N	0.8	0.6	0.5	0.1	0.0	0.0	0.0	2.0
NE	2.7	2.3	1.7	0.3	0.0	0.0	0.0	7.0
E	12.4	13.1	16.6	6.8	1.9	0.2	0.0	51.0
SE	5.4	8.2	10.1	7.1	1.1	0.1	0.0	32.0
S	0.9	0.9	0.8	0.3	0.1	0.0	0.0	3.0
SW	0.5	0.3	0.2	0.0	0.0	0.0	0.0	1.0
W	1.4	0.6	0.0	0.0	0.0	0.0	0.0	2.0
NW	1.4	0.6	0.0	0.0	0.0	0.0	0.0	2.0
Total	25.5	26.6	29.9	14.6	3.1	0.3	0.0	100.0

AVERAGE PERCENTAGE FREQUENCY OF WAVE HEIGHT - DIRECTION GROUPS AT 9° - 145°E (after Glenn and Associates)

TABLE 7: July Summary (Jun., Jul., Aug.)

	SIGNIFICANT WAVE HEIGHT (ft.)							
	0-1.9	2-3.9	4-5.9	6-7.9	8-9.9	10-15	15+	TOTAL
N	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
NE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E	1.1	7.7	13.9	8.9	5.1	0.4	0.4	37.5
SE	1.4	8.3	19.8	19.6	6.7	0.5	0.7	57.0
S	0.6	0.9	0.9	0.6	0.0	0.0	0.0	3.0
SW	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
W	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
NW	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Total	5.6	16.9	34.6	29.1	11.8	0.9	1.1	100.0

TABLE 8: October Summary (Sept., Oct., Nov.)

N	0.7	0.2	0.1	0.0	0.0	0.0	0.0	1.0
NE	0.7	0.8	0.3	0.2	0.0	0.0	0.0	2.0
E	15.6	17.4	16.0	6.0	2.1	0.2	0.2	57.5
SE	7.1	9.8	10.5	5.8	1.1	0.1	0.1	34.5
S	1.4	1.4	0.8	0.3	0.1	0.0	0.0	4.0
SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
NW	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Total	26.5	29.6	27.7	12.3	3.3	0.3	0.3	100.0

AVERAGE PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS SPEED - DIRECTION OVER GULF OF PAPUA (after Glenn & Associates)

TABLE 9: JANUARY SUMMARY (Dec., Jan., Feb.)

WIND SPEED (m.p.h.)

	0-4	5-9	10-14	15-19	20-24	25-29	30-40	40+	TOTAL
N	0.4	0.8	0.5	0.2	0.1	0.0	0.0	0.0	2.0
NE	0.8	1.6	1.1	0.4	0.1	0.0	0.0	0.0	4.0
E	2.8	6.3	4.5	1.8	0.5	0.1	0.0	0.0	16.0
SE	2.3	4.7	3.4	1.3	0.3	0.0	0.0	0.0	12.0
S	1.2	2.3	1.7	0.7	0.1	0.0	0.0	0.0	6.0
SW	0.8	1.6	1.1	0.4	0.1	0.0	0.0	0.0	4.0
W	6.3	14.4	10.4	4.2	1.1	0.4	0.2	0.0	37.0
NW	3.4	7.3	5.3	2.2	0.5	0.2	0.1	0.0	19.0
Total	18.0	39.0	28.0	11.2	2.8	0.7	0.3	0.0	100.0

TABLE 10: APRIL SUMMARY (Mar., Apr., May)

N	0.2	0.5	0.5	0.6	0.2	0.0	0.0	0.0	2.0
NE	0.8	1.5	1.9	2.1	0.6	0.1	0.0	0.0	7.0
E	3.8	12.3	13.4	15.7	4.6	1.0	0.2	0.0	51.0
SE	2.2	8.0	8.5	9.9	2.8	0.5	0.1	0.0	32.0
S	0.1	0.8	0.9	0.3	0.1	0.0	0.0	0.0	3.0
SW	0.1	0.3	0.3	0.3	0.0	0.0	0.0	0.0	1.0
W	0.4	0.8	0.8	0.0	0.0	0.0	0.0	0.0	2.0
NW	0.4	0.8	0.8	0.0	0.0	0.0	0.0	0.0	2.0
Total	8.0	25.0	27.0	29.5	8.5	1.7	0.3	0.0	100.0

AVERAGE PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS SPEED - DIRECTION OVER GULF OF PAPUA (after Glenn & Associates)

TABLE 11: JULY SUMMARY (Jun., Jul., Aug.)

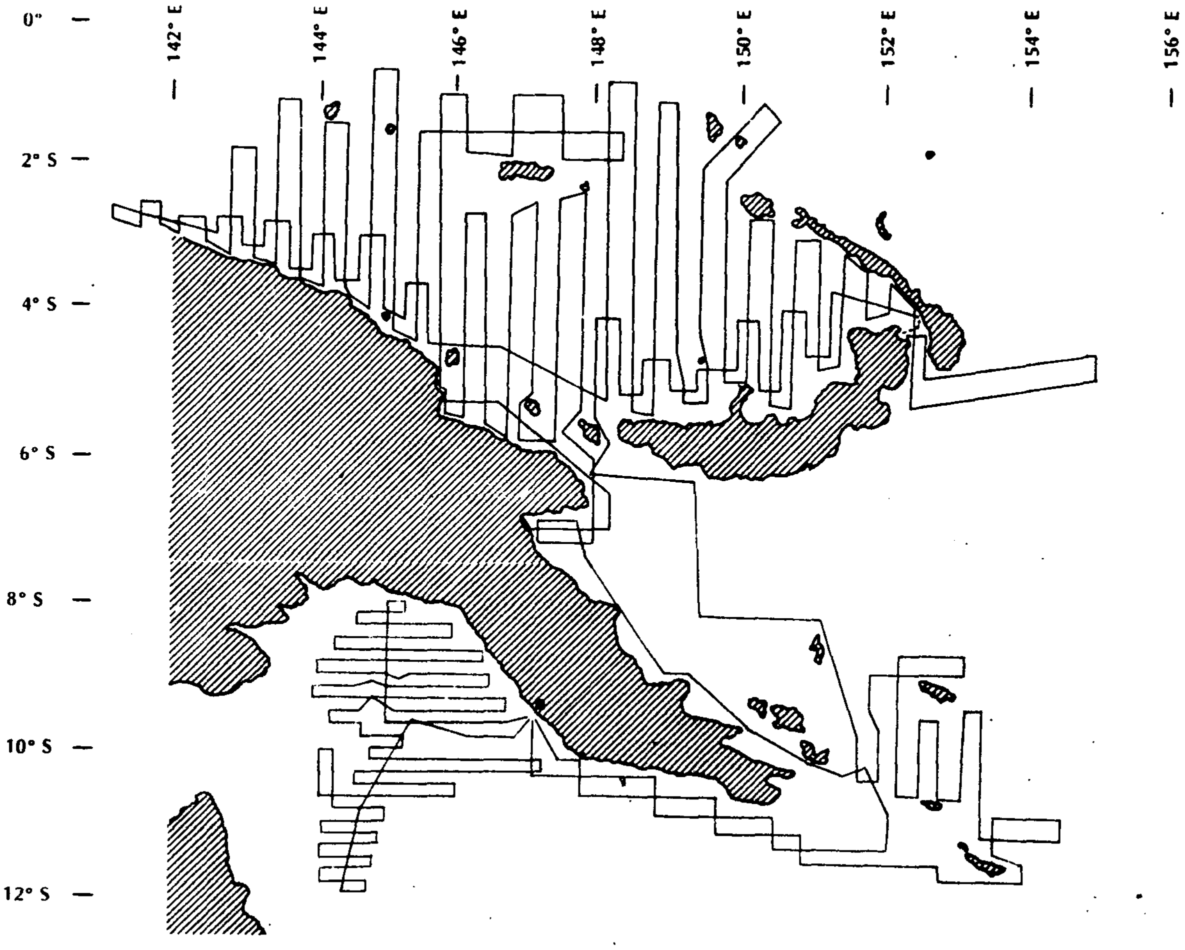
WIND SPEED (m.p.h.)

	0-4	5-9	10-14	15-19	20-24	25-29	30-40	40+	TOTAL
N	0.1	0.9	0.0	0.0	0.0	0.0	0.0	0.0	1.0
NE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E	0.1	1.4	10.4	13.5	7.7	3.6	0.7	0.1	37.5
SE	0.1	3.3	15.8	20.5	11.7	4.4	1.0	0.2	57.0
S	0.1	0.5	0.8	1.0	0.6	0.0	0.0	0.0	3.0
SW	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5
W	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5
NW	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Total	1.0	7.0	27.0	35.0	20.0	8.0	1.7	0.3	100.0

TABLE 12: OCTOBER SUMMARY (Sept., Oct., Nov.)

N	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	1.0
NE	0.1	0.5	0.7	0.4	0.2	0.1	0.0	0.0	2.0
E	5.2	14.8	18.5	13.1	4.3	1.2	0.3	0.1	57.5
SE	3.5	8.9	11.2	7.5	2.6	0.6	0.2	0.0	34.5
S	0.4	1.0	1.3	0.9	0.3	0.1	0.0	0.0	4.0
SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5
NW	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Total	10.0	26.0	32.0	22.0	7.4	2.0	0.5	0.1	100.0

PLATE I



MARINE GEOPHYSICAL SURVEY OF THE GULF OF PAPUA & THE BISMARCK SEA, 1970

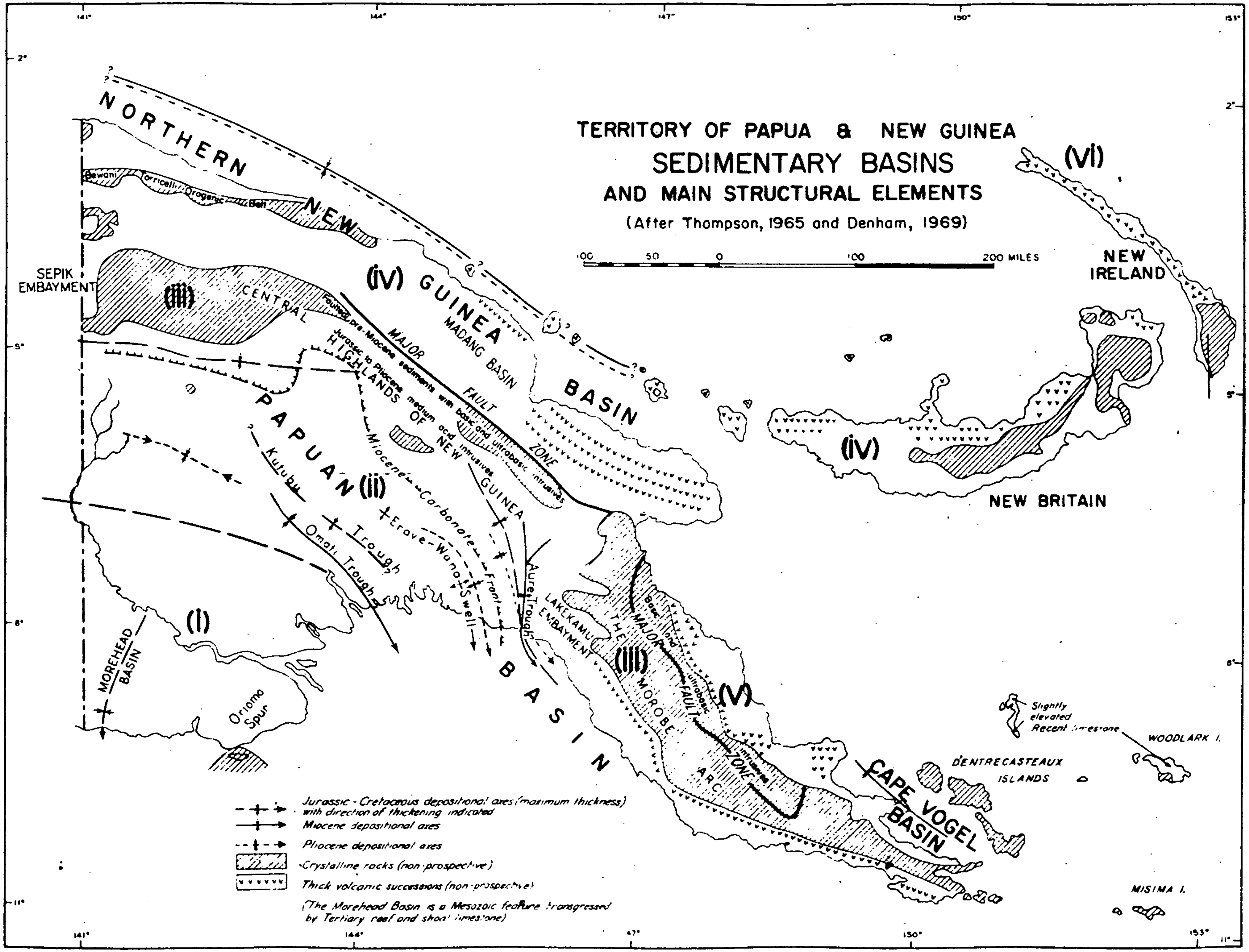
TRAVERSE PLAN

To accompany Record No. 1973/38

PNG/B8-24A

To accompany Record No. 1973/38

PLATE 2



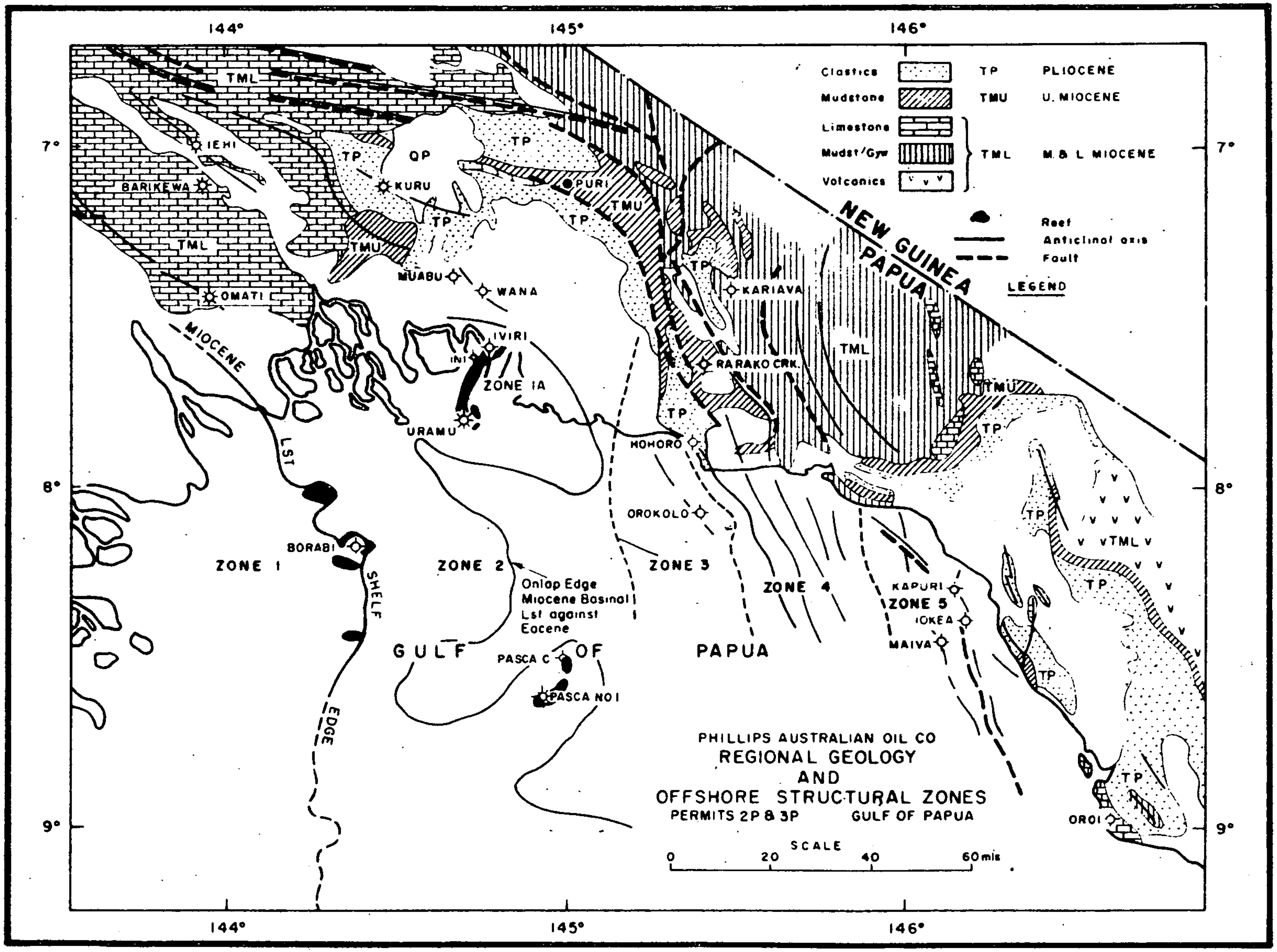
PNG/B2-24-1A

51

To accompany Record No. 1973/38

(After Phillips Australian Oil Co.)

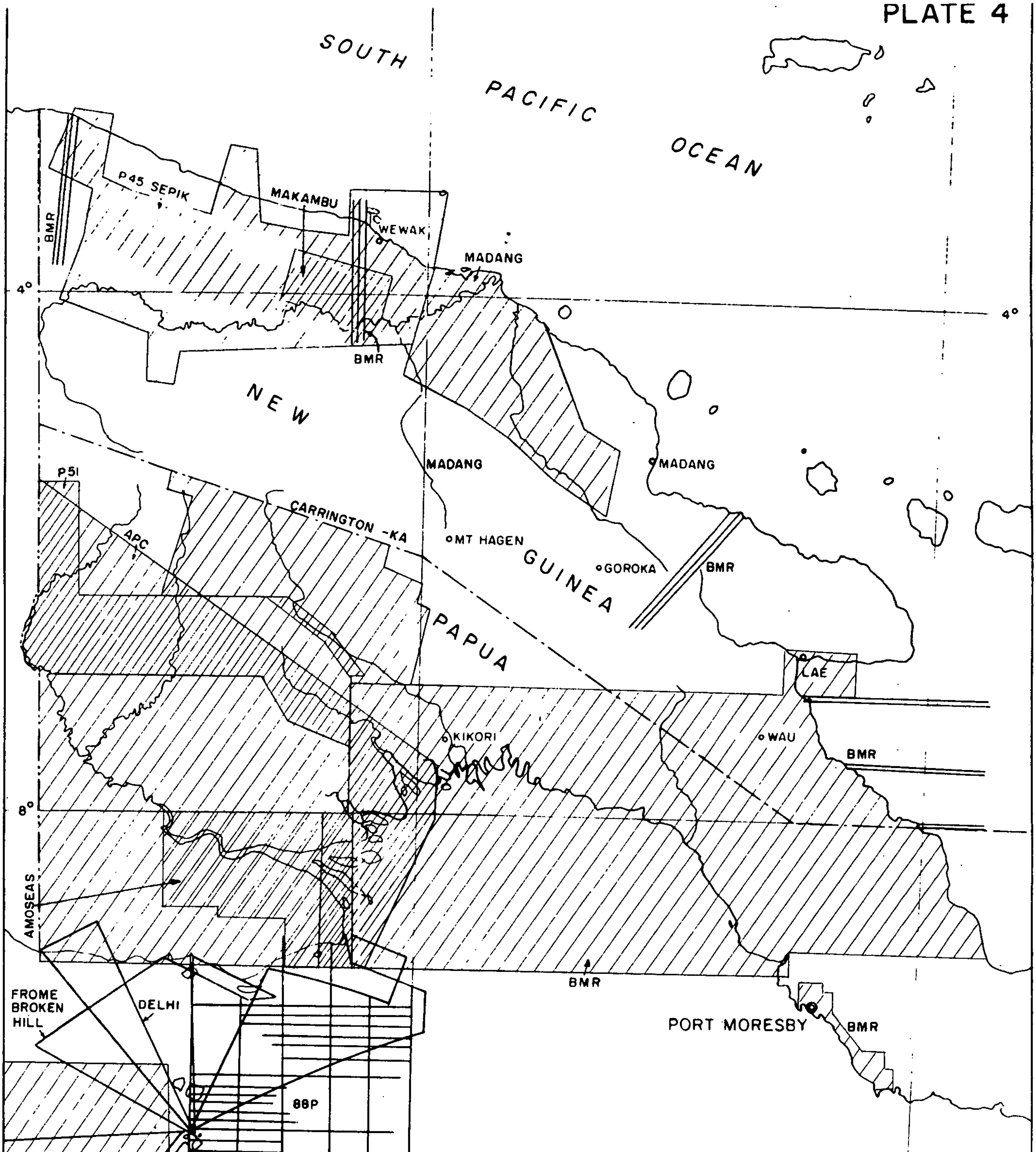
PLATE 3



PNG/B8-69A

52

PLATE 4



AEROMAGNETIC SURVEYS

SCALE 1:5,000,000

50 0 50 100 150 MILES

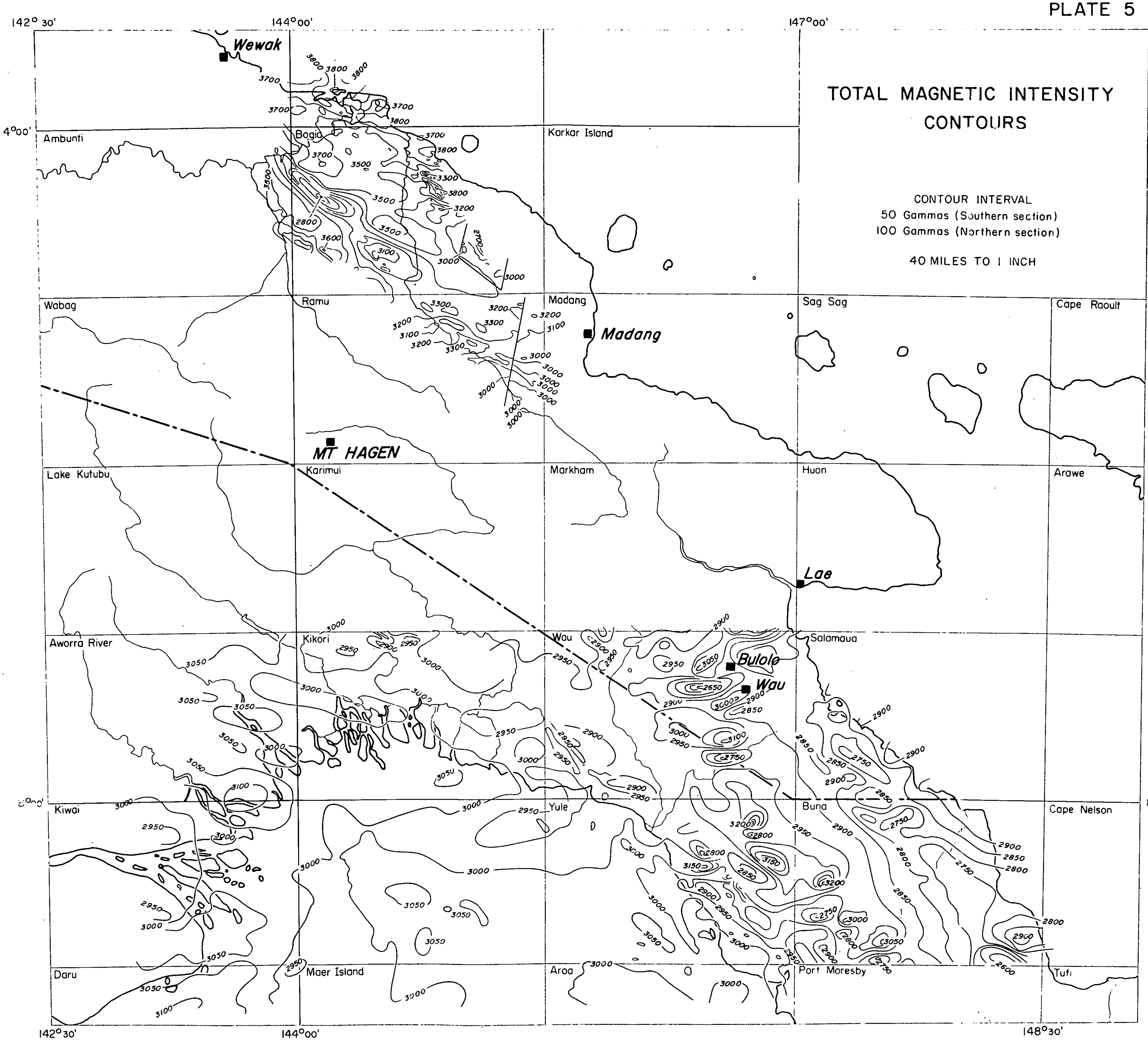
50 0 50 100 150 200 250 KILOMETRES

To accompany Record No. 1973/38

PNG/B1-5A

BASED ON PNG/B0-29A

PLATE 5



To accompany Record No. 1973/38

B55/B2-37

54

PLATE 6

To accompany Record No. 1973/38

PNG/B8-8-1

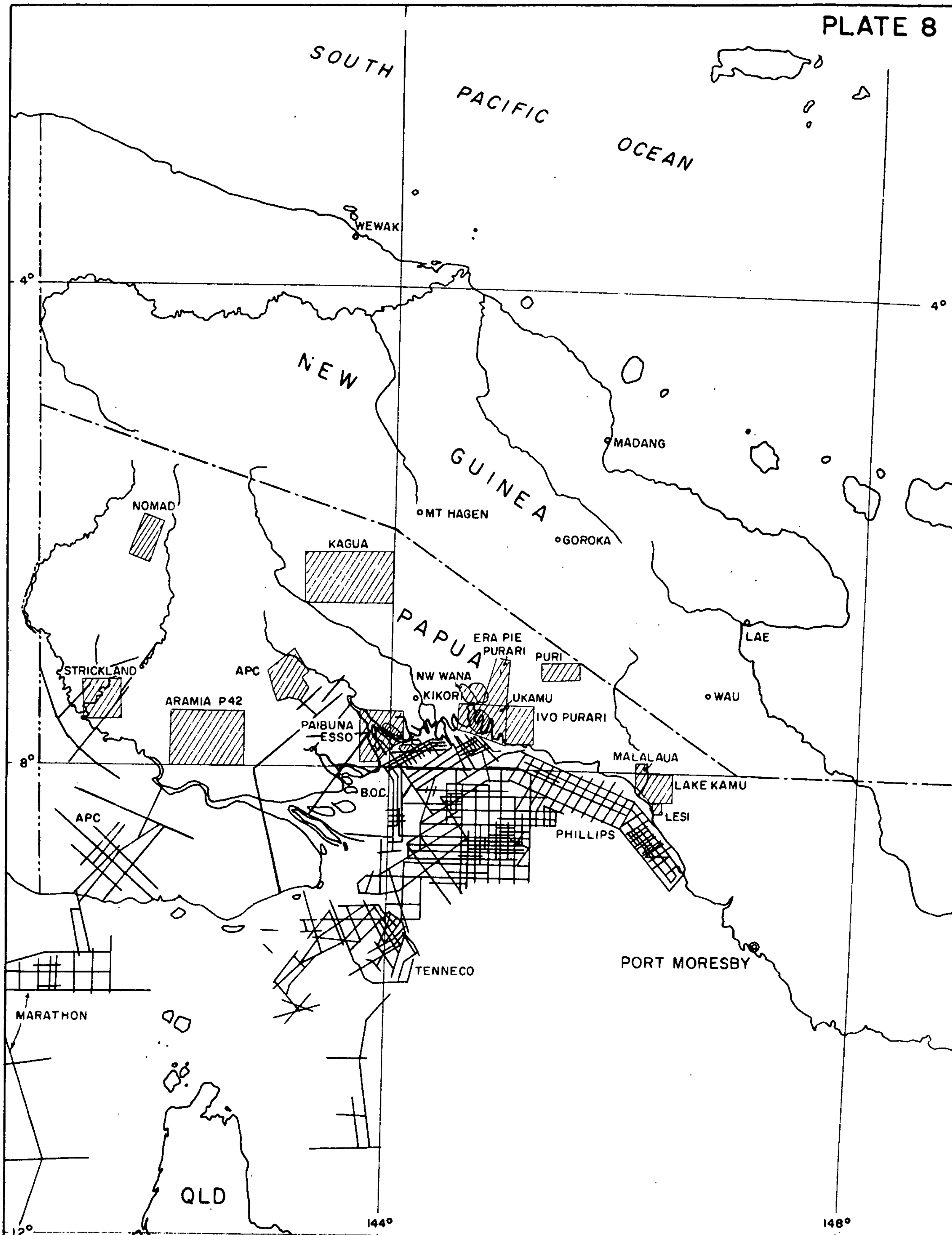
(BASED ON PNG/B0-2)

PLATE 7

(BASED ON PNG/80-2)

PNG/B2-29-2

PLATE 8



SEISMIC SURVEYS

SCALE 1:5,000,000

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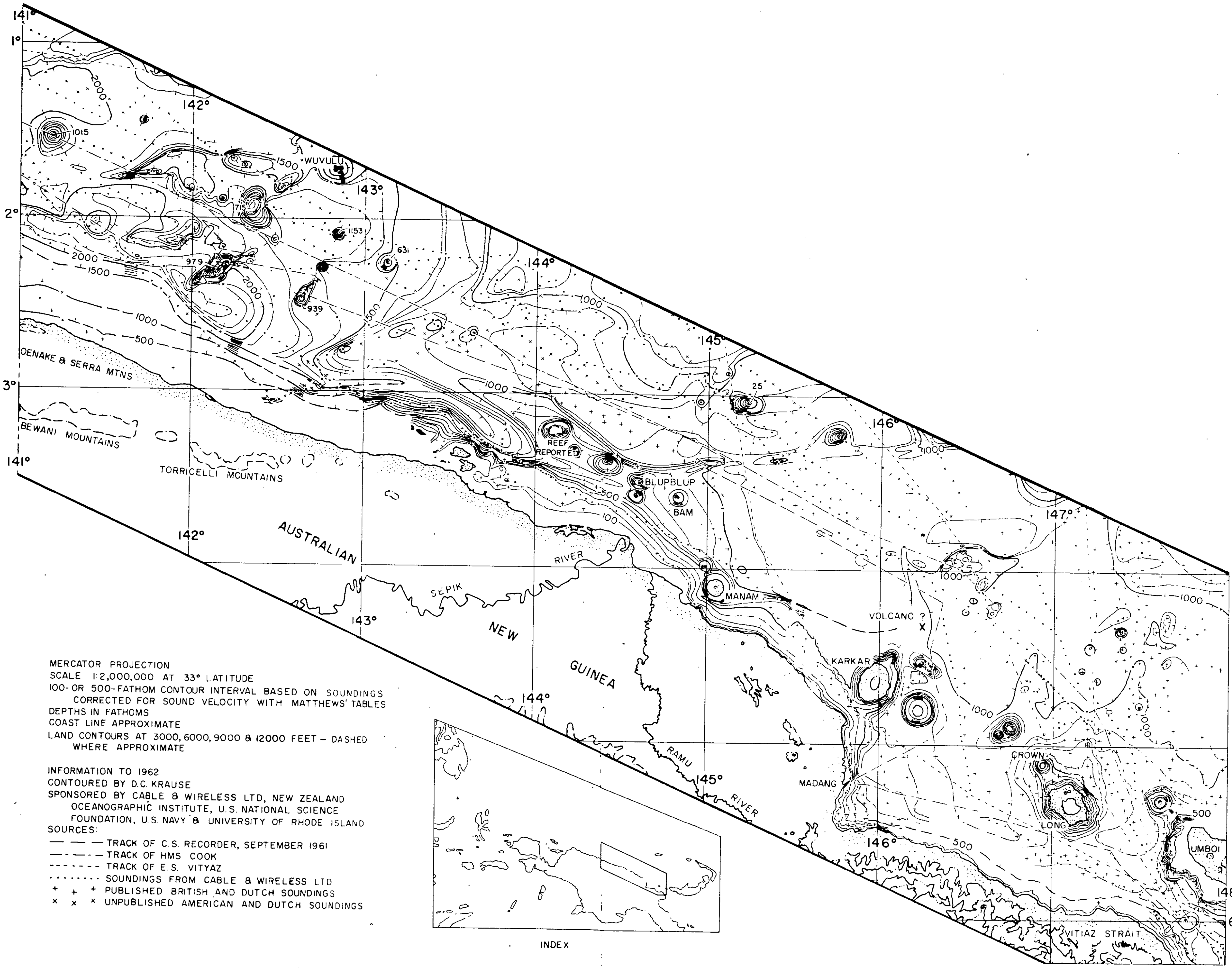
To accompany Record No. 1973/38

PNG/B3-1A 58

BASED ON PNG/80-29A

PLATE 9



MERCATOR PROJECTION
SCALE 1:2,000,000 AT 33° LATITUDE
100- OR 500-FATHOM CONTOUR INTERVAL BASED ON SOUNDINGS CORRECTED FOR SOUND VELOCITY WITH MATTHEWS' TABLES
DEPTHS IN FATHOMS
COAST LINE APPROXIMATE
LAND CONTOURS AT 3000, 6000, 9000 & 12000 FEET – DASHED WHERE APPROXIMATE

INFORMATION TO 1962
CONTOURED BY D.C. KRAUSE
SPONSORED BY CABLE & WIRELESS LTD, NEW ZEALAND OCEANOGRAPHIC INSTITUTE, U.S. NATIONAL SCIENCE FOUNDATION, U.S. NAVY & UNIVERSITY OF RHODE ISLAND

SOURCES:
— — — TRACK OF C.S. RECORDER, SEPTEMBER 1961
— - — - — TRACK OF HMS COOK
- - - - - - - TRACK OF E.S. VITYAZ
. . . . SOUNDINGS FROM CABLE & WIRELESS LTD
+ + + PUBLISHED BRITISH AND DUTCH SOUNDINGS
× × × UNPUBLISHED AMERICAN AND DUTCH SOUNDINGS

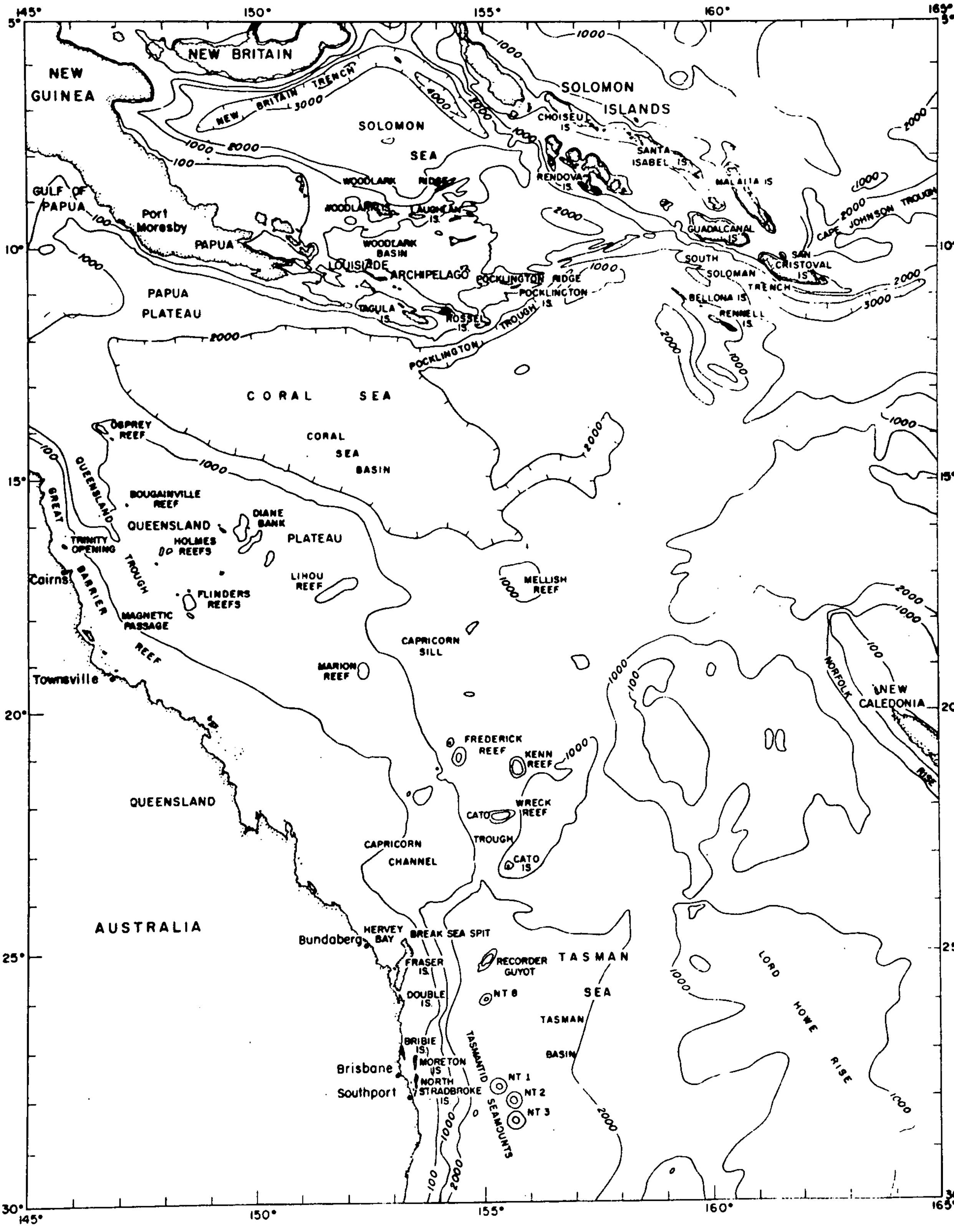
BATHYMETRIC CHART NORTH OF NEW GUINEA

(After Krause, 1965)

To accompany Record No. 1973/38

56

PNG/B8-68



BATHYMETRIC FEATURES OF THE CORAL SEA AND BISMARCK SEA

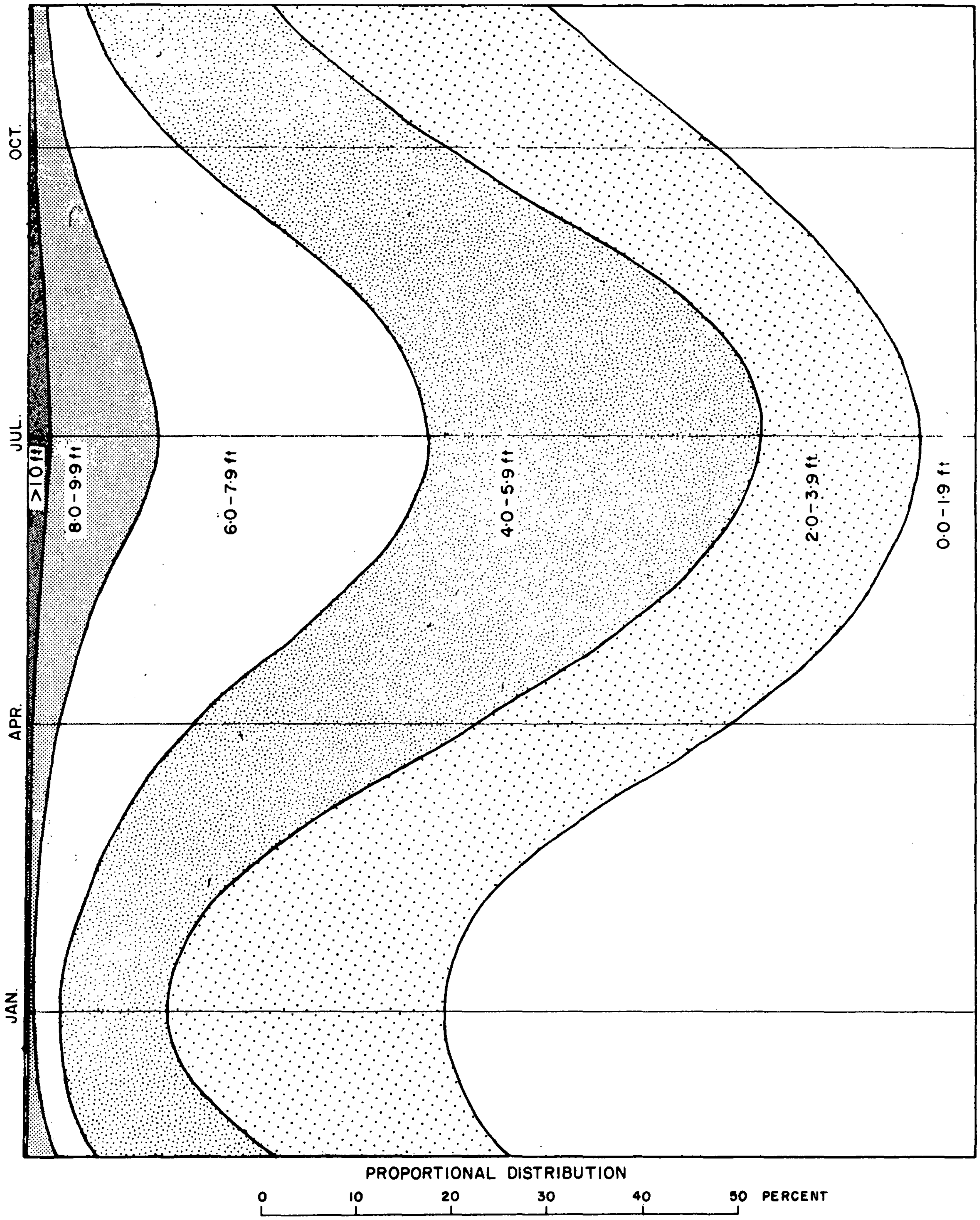
(After Krause, 1967)

57

To accompany Record No. 1973/38

PNG/B8-70A

PLATE II

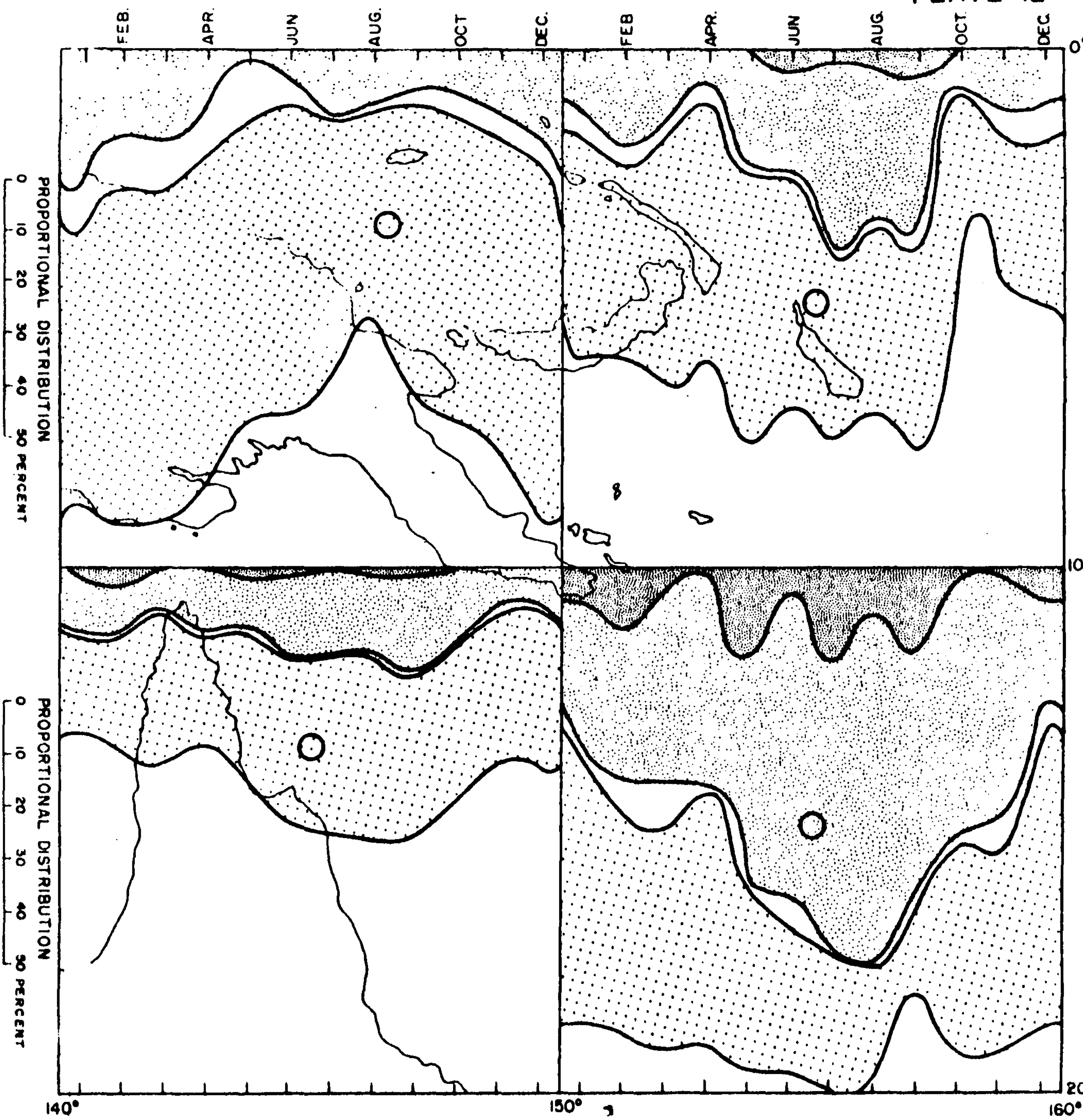


PROPORTIONAL DISTRIBUTION OF 'SIGNIFICANT WAVE HEIGHTS' FOR AN AVERAGE YEAR

(FROM QUARTERLY SUMMARIES COMPILED BY GLENN & ASSOCIATES)

PNG/B8-11A

To accompany Record No. 1973/38



PROPORTIONAL DISTRIBUTION OF SWELL HEIGHTS FOR AN AVERAGE YEAR

(PLOTTED OVER APPROXIMATE LOCATION)

(Compiled by the Meteorological Bureau for RAAF)

SWELL CONDITION

- Heavy
- Moderate
- Confused
- Light
- None
- Centre of 10° area covered
- Coast line

To accompany Record No. 1973/38

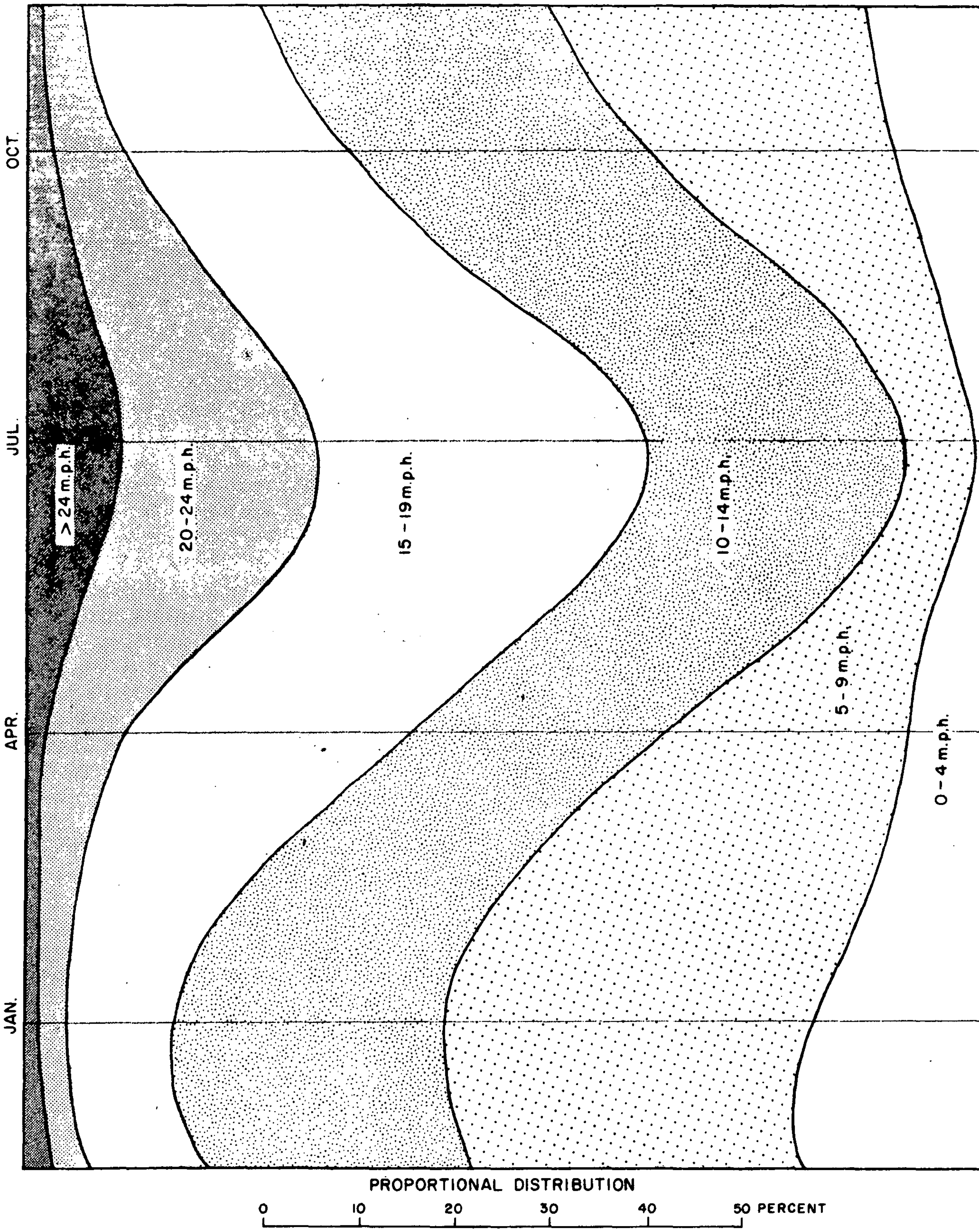
PNG/B8-12A

MAXIMUM DAILY SWELL (FEET) RECORDED ABOARD GLOMAR CONCEPTION AT VARIOUS LOCATIONS IN THE GULF OF PAPUA APRIL 1968 - JUNE 1969

MAXIMUM DAILY WAVE HEIGHT (FEET) RECORDED ABOARD GLOMAR CONCEPTION AT VARIOUS LOCATIONS IN THE GULF OF PAPUA FOR 12 MONTHS COMMENCING OCT. 1967

To accompany Record No 1973/38

PNG / B8 - 13

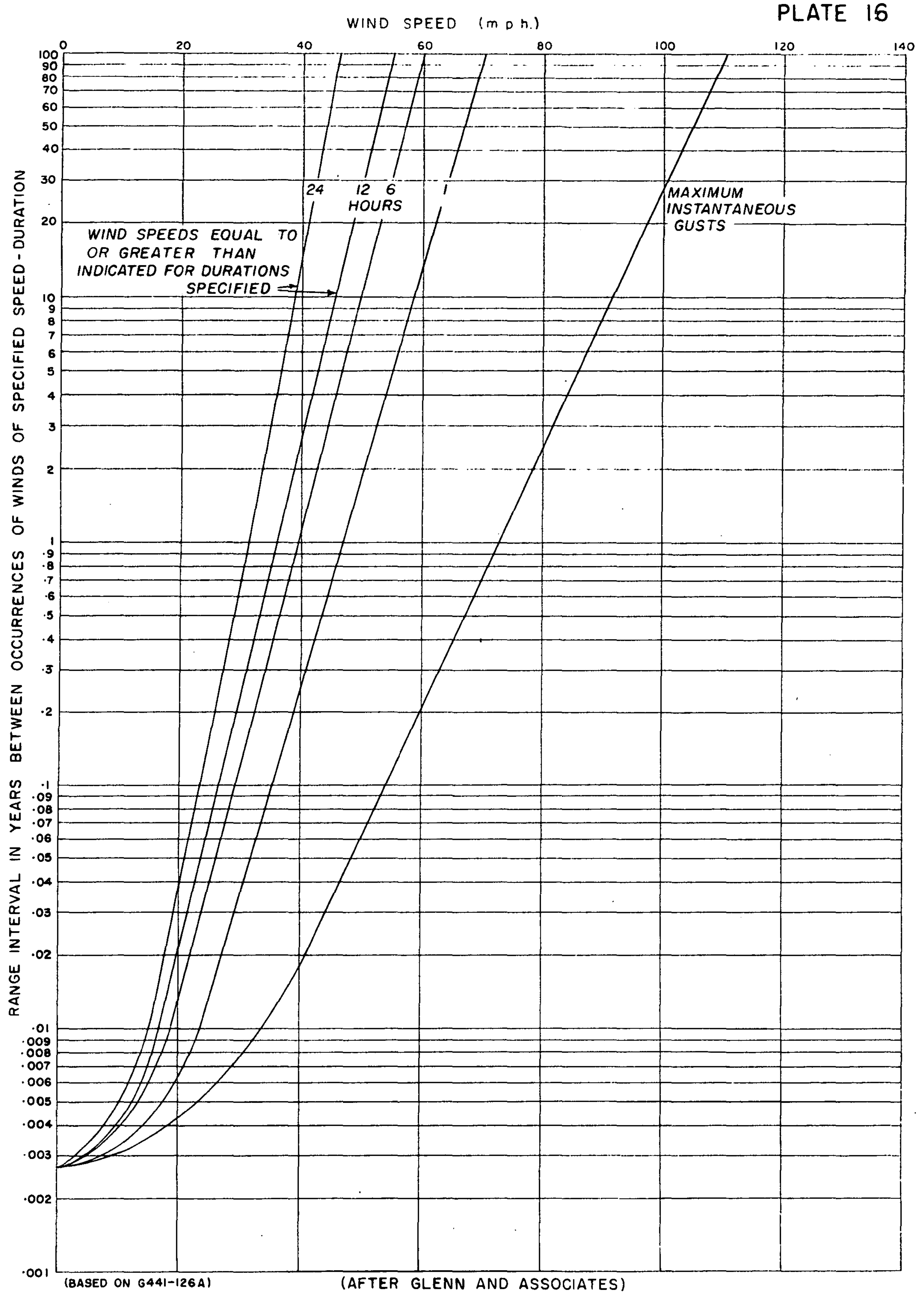


PROPORTIONAL DISTRIBUTION OF WIND VELOCITIES FOR AN AVERAGE YEAR

(FROM QUARTERLY SUMMARIES COMPILED BY GLENN AND ASSOCIATES)

PNG/B8-15A

WIND SPEED (m.p.h.) AND DIRECTION FOR OCT. 1967– OCT. 1968 RECORDED ABOARD GLOMAR CONCEPTION AT VARIOUS LOCATIONS IN THE GULF OF PAPUA



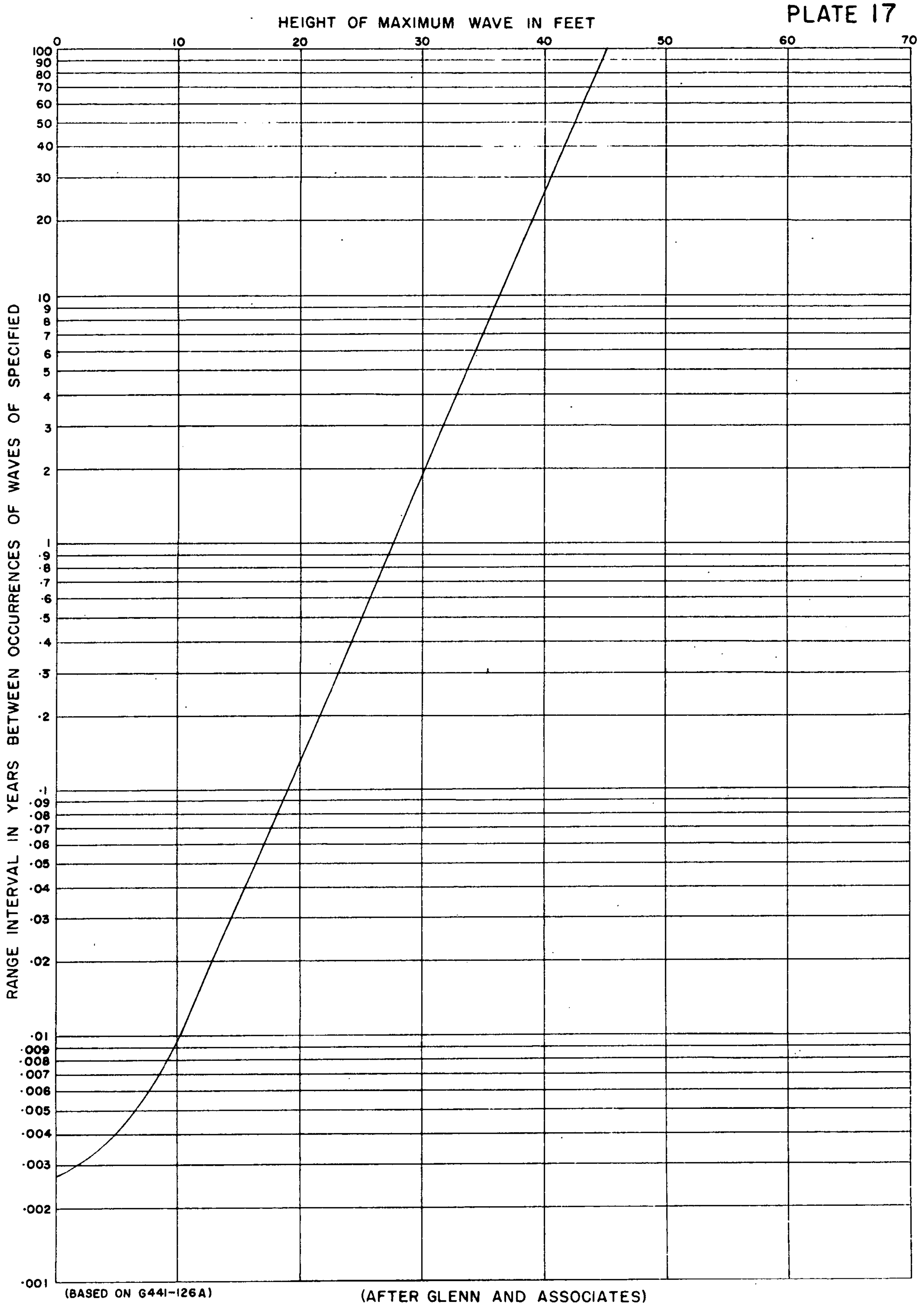
(AFTER GLENN AND ASSOCIATES)

AVERAGE INTERVAL BETWEEN OCCURRENCES OF WINDS OF SPECIFIED SPEED-DURATION

To accompany Record No. 1973/38

61

PNG/B8-17A



(BASED ON G441-126A)

(AFTER GLENN AND ASSOCIATES)

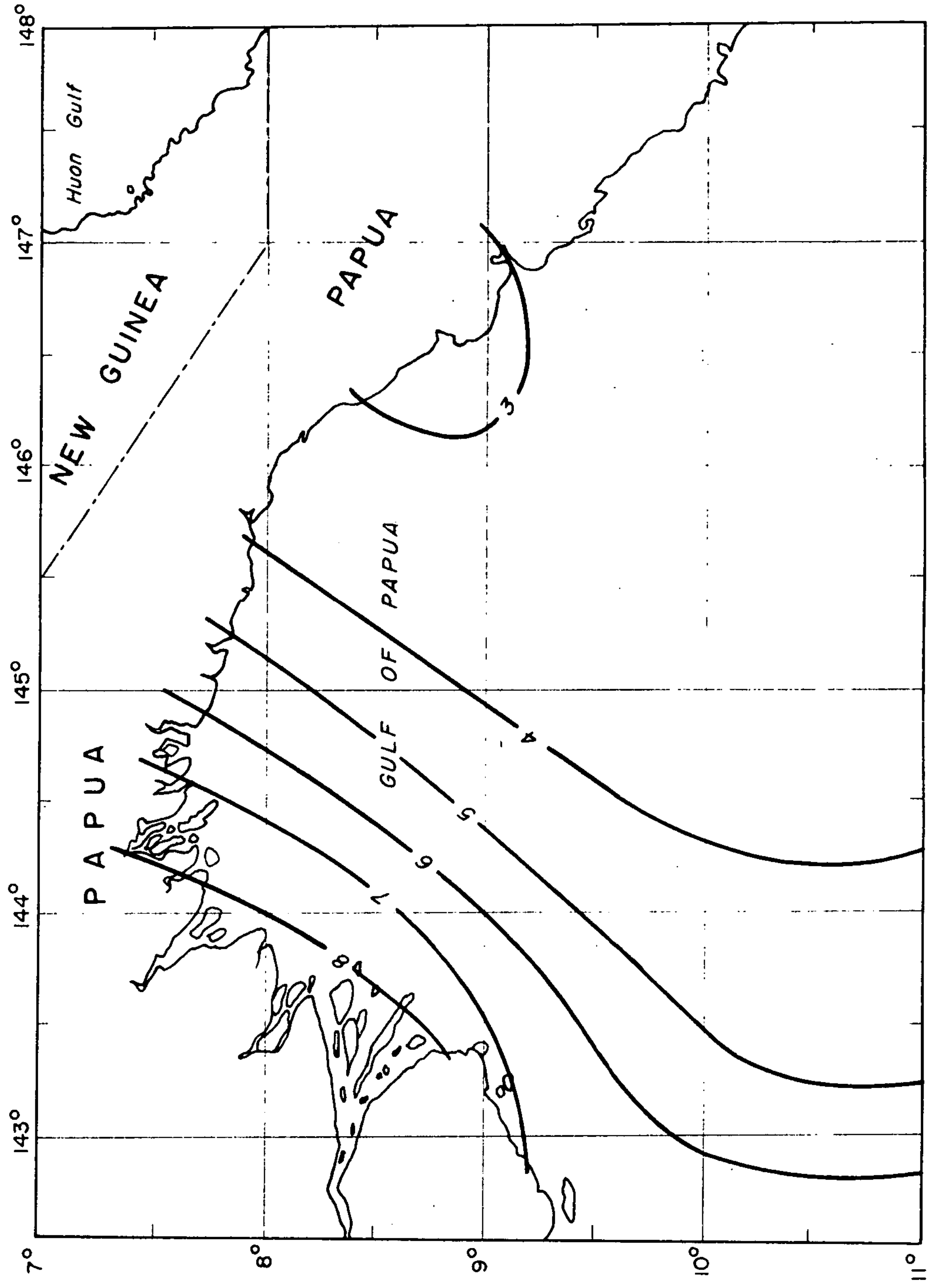
AVERAGE INTERVAL BETWEEN OCCURRENCES OF MAXIMUM WAVE HEIGHTS AT 9°S, 15°E IN THE GULF OF PAPUA

(DEPTH APPROXIMATELY 350 FEET)

62

To accompany Record No. 1973/38

PNG/B8-18A



MEAN RANGE OF ASTRONOMICAL TIDES

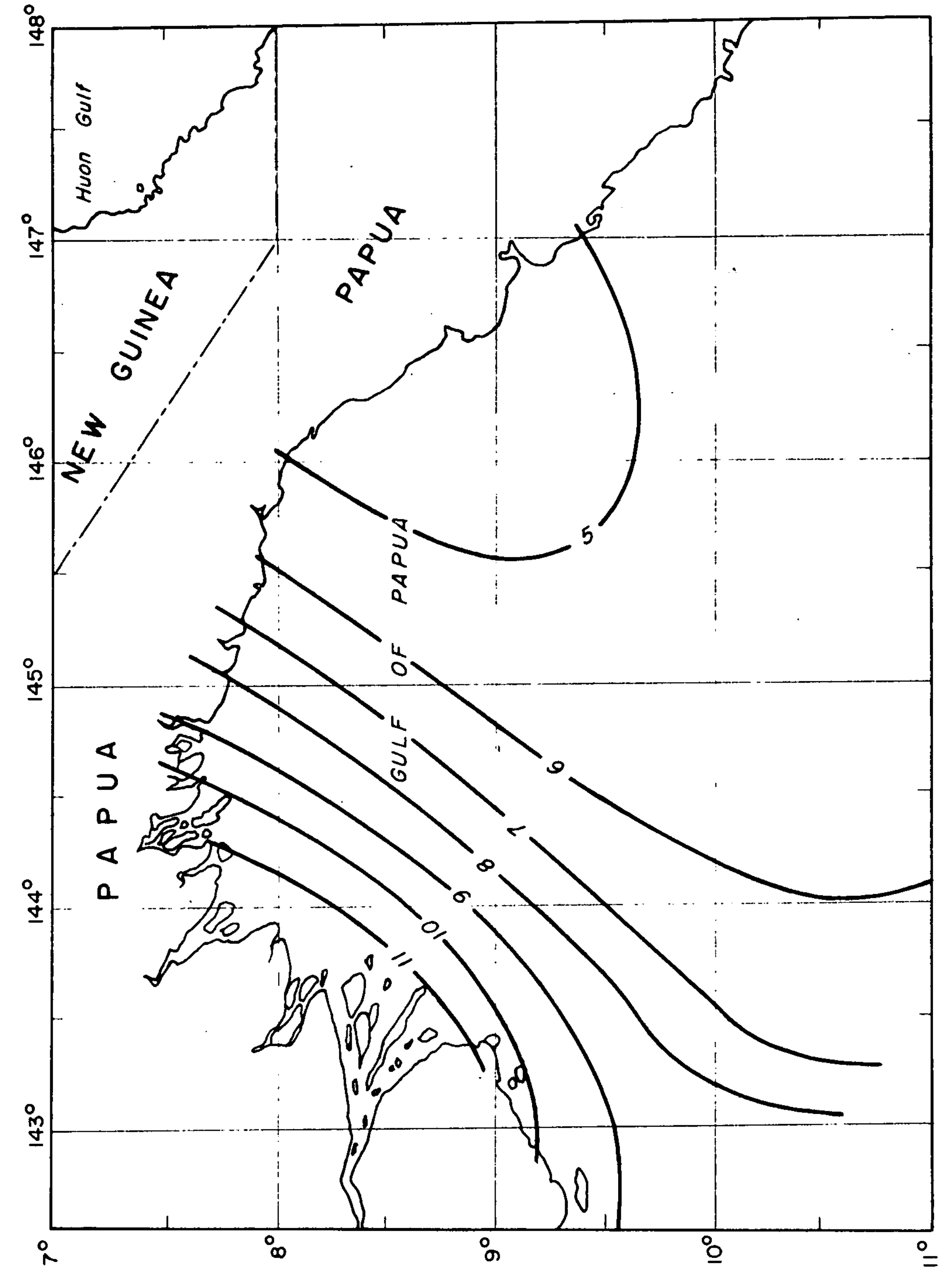
(CONTOURS IN FEET)

SCALES

50 0 50 100 150 MILES

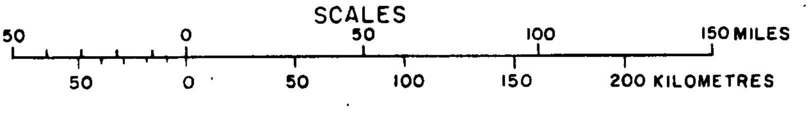
50 0 50 100 150 200 KILOMETRES

63



SPRING RANGE OF ASTRONOMICAL TIDES

(CONTOURS IN FEET)



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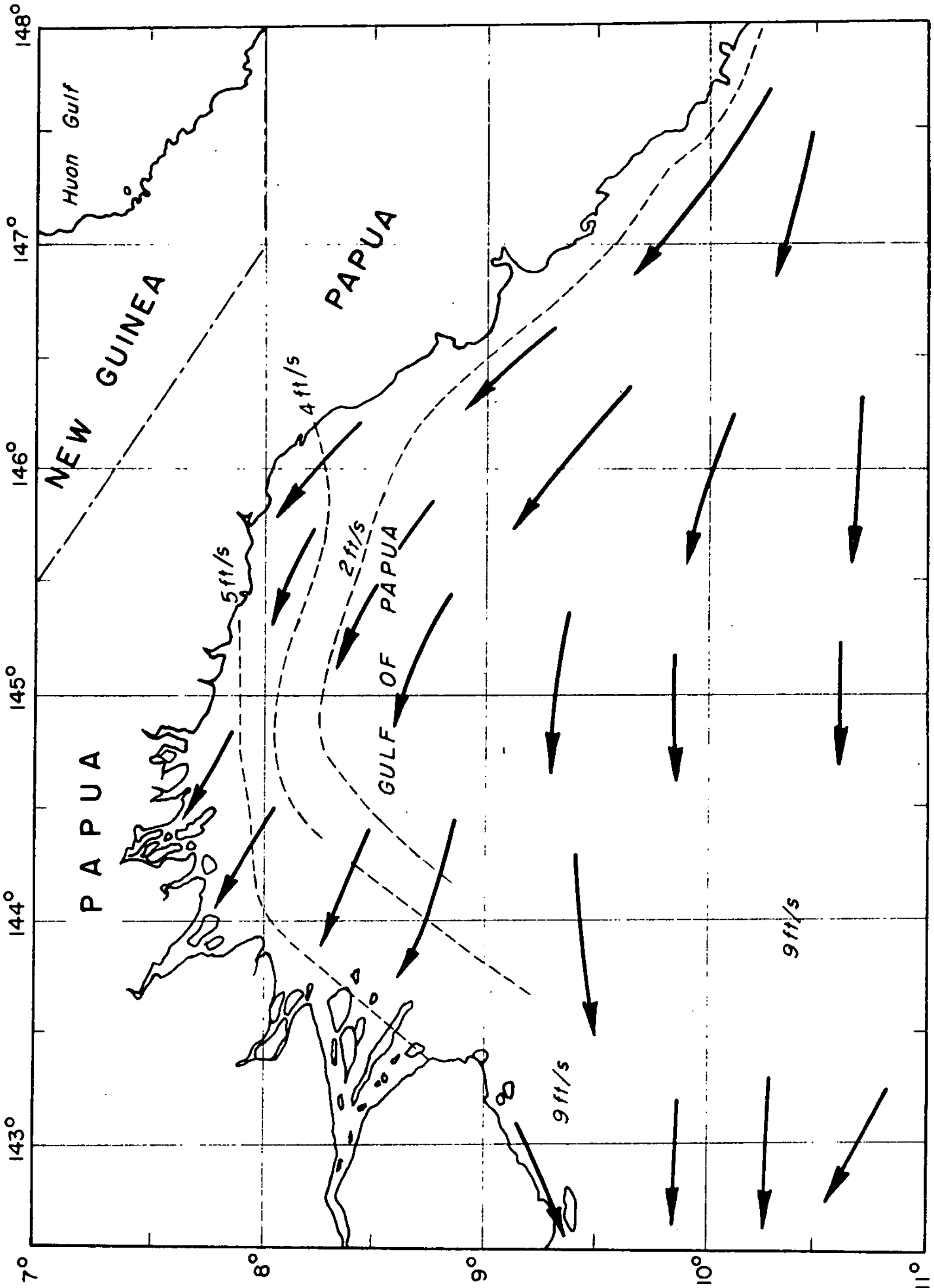
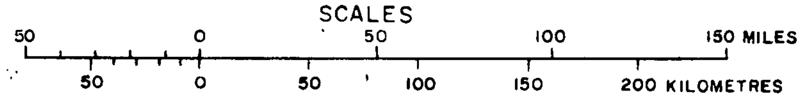
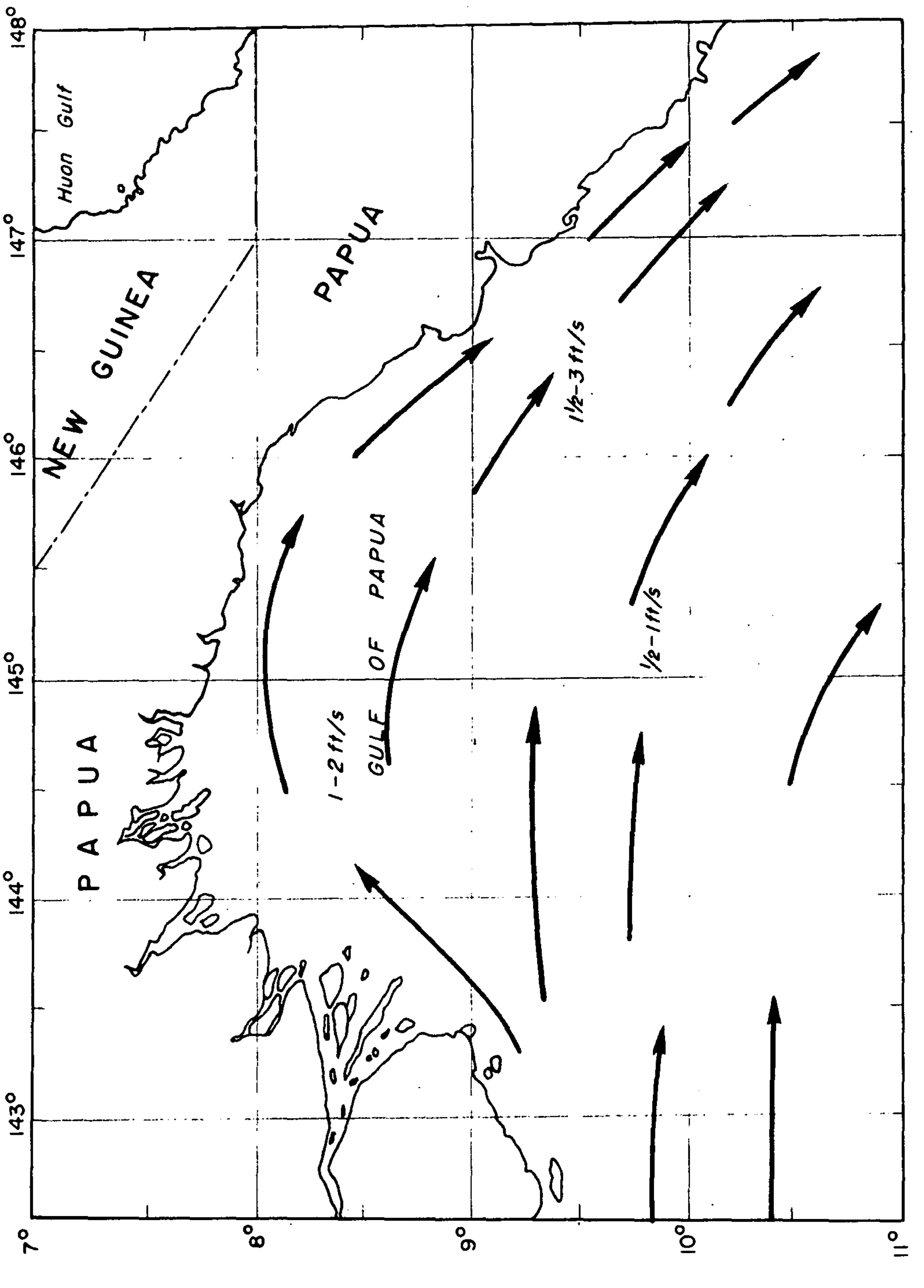


SPRING TIDAL CURRENTS DURING STRENGTH OF FLOOD
(EBB CURRENTS FLOW IN OPPOSITE DIRECTION)

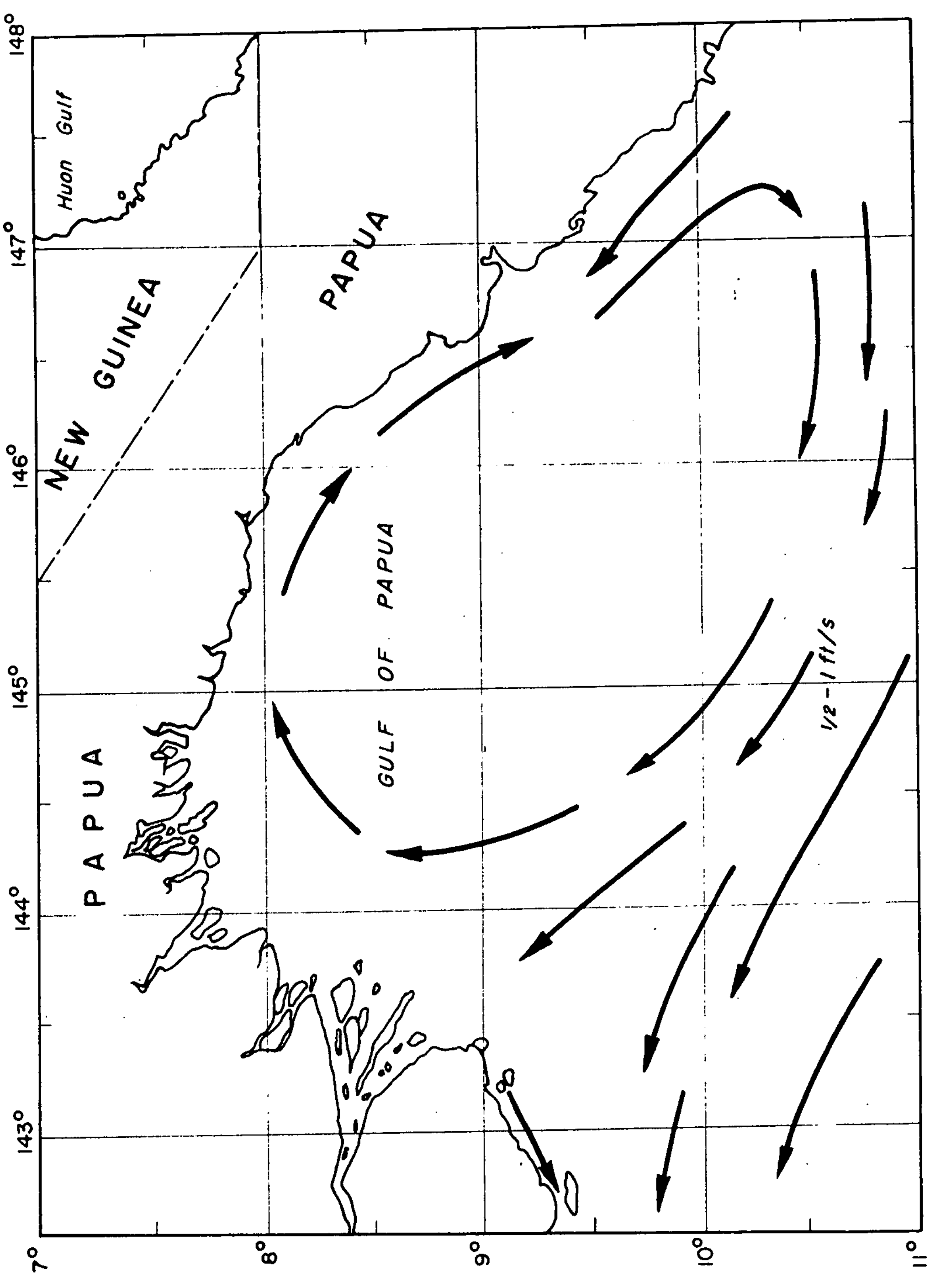




NORMAL WIND-DENSITY CURRENTS
DURING DECEMBER - FEBRUARY PERIOD

SCALES
50 0 50 100 150 MILES
50 0 50 100 150 200 KILOMETRES

To accompany Record No. 1973/38



NORMAL WIND-DENSITY CURRENTS DURING APRIL-OCTOBER PERIOD

SCALES
50 0 50 100 150 MILES
50 0 50 100 150 200 KILOMETRES

MARINE C.D.P. SEISMIC SYSTEM

(BASED ON B.M.R. DRAWING No. SMA SHEET 48)

To accompany Record No. 1973/38

G65-258

DATA AQUISITION AND ANALOGUE RECORDER SIGNALS

BLOCK DIAGRAM

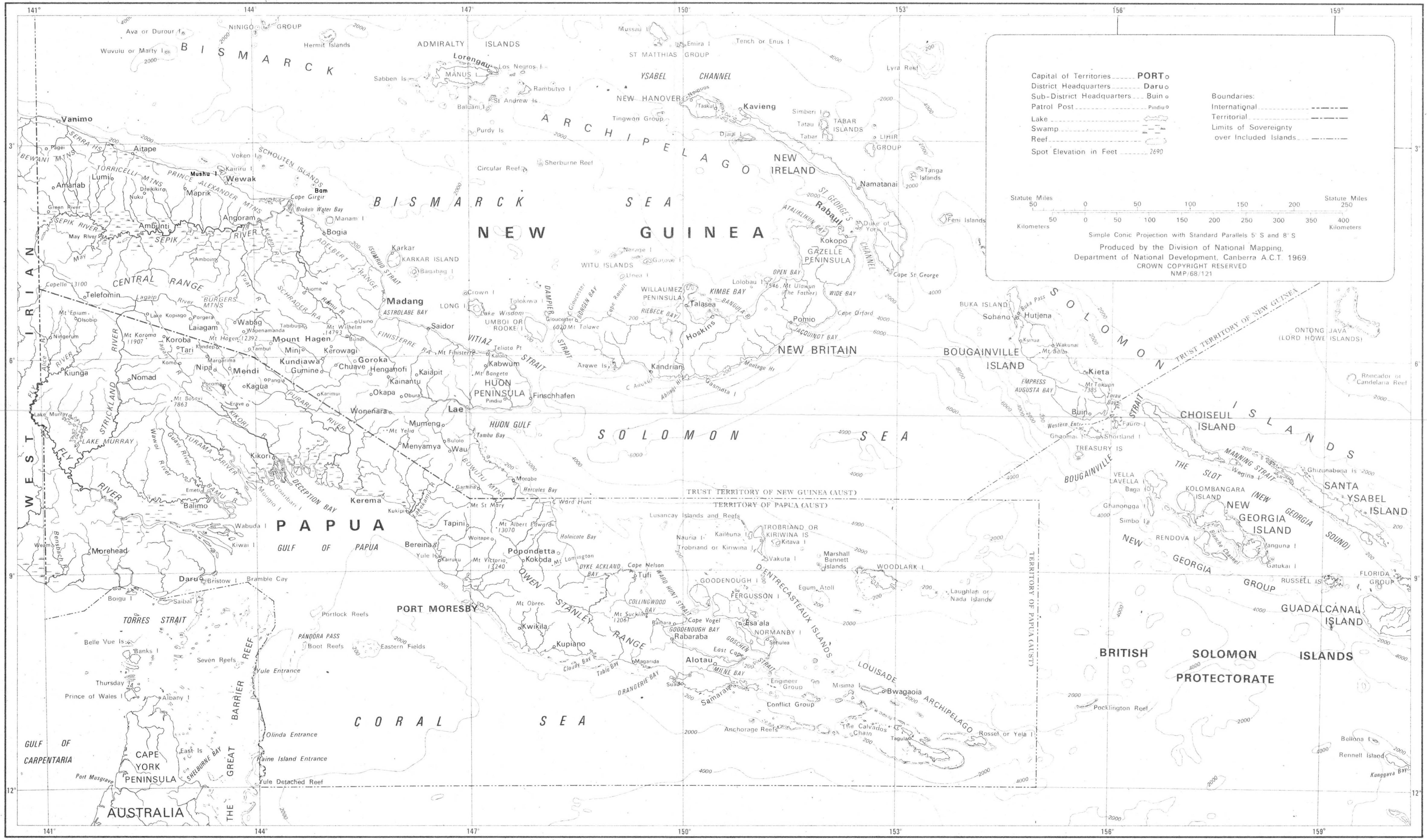
To accompany Record No. 1973/38

(BASED ON B.M.R DRAWING No. 24 SHEET 3)

G65-259

PLATE 25

TERRITORY OF PAPUA AND NEW GUINEA



(Based on PNG/BO-44)

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