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REPORT 179

A Structural Analysis of the Gulf of Papua and Northwest Coral Sea Region

J. C. MUTTER

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DEPARTMENT OF MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT 179

A Structural Analysis of the Gulf of Papua and Northwest Coral Sea Region

J. C. MUTTER

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA, 1975

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SUMMARY

A new interpretation of the structure and tectonic history of the Gulf of Papua and northwest Coral Sea has emerged from a study of 9650 km of seismic, gravity, and magnetic data collected by Compagnie Générale de Géophysique in 1970 for the Bureau of Mineral Resources.

Surveying was partly in shallow water, where it supplemented information obtained in previous years by the detailed work of oil companies, but extended into deep water, where oceanic structures were studied. Previous knowledge has also been enhanced by following shallow-water structures into deep water regions.

On the basis of gravity evidence, areas of continental, subcontinental, suboceanic, and oceanic crustal thickness have been outlined. These correspond with the larger physiographic provinces.

Eight physiographic units have been defined. Four new names have been employed to describe features which were defined by far less detailed surveys. In particular, the Pandora Trough is recognized as a basin and the Bligh system is separated into the Osprey Basin and a relatively minor upper crustal feature, the Portlock Trough. The Eastern Plateau is redefined as the Eastern Fields Fan on the basis of both bathymetric and seismic evidence.

The Eastern Fields Fan consists of a superficial wedge of sediments deposited over a dipping surface, named here the 'G' surface. It is underlain by crust of subcontinental thickness. It may be out of isostatic equilibrium and still subsiding towards a compensated state.

Many of the structural features of the Moresby Trough are similar to those characteristic of the Aure Trough. Gravity evidence indicates that it has a thick sediment fill, and folding in the Moresby Trough is very similar to that found in the Aure Trough. It is suggested that the two features are continuous. The crust thins considerably under the Moresby Trough, where the sediment is thickest.

The Pandora Basin has a sediment fill of at least 2.5 km and deposition is continuing. A buried Miocene barrier reef identified by oil company surveys was traced outside oil permit areas and appears to swing east toward Portlock Reef, rather than be continuous with the modern Great Barrier Reef as was previously thought.

Evidence suggests that positive structures on the margin of the continental shelf have controlled the location of reef growth there. No ridge was found beneath the Papuan Plateau, contradicting a supposition by previous workers.

The tectonic events that shaped the region studied are related to large-scale movements outside the immediate area. Plate movements and large-scale events that resulted from opening of the Coral Sea are believed to have played a key role. Beginning with a stable situation in the Cretaceous, the Aure-Moresby Trough system was formed, and subsidence of the Eastern Fields Fan followed in the Tertiary. Later events include the cutting of canyons. Subsidence of the Eastern Fields Fan and deposition in the basins appears to be continuing.

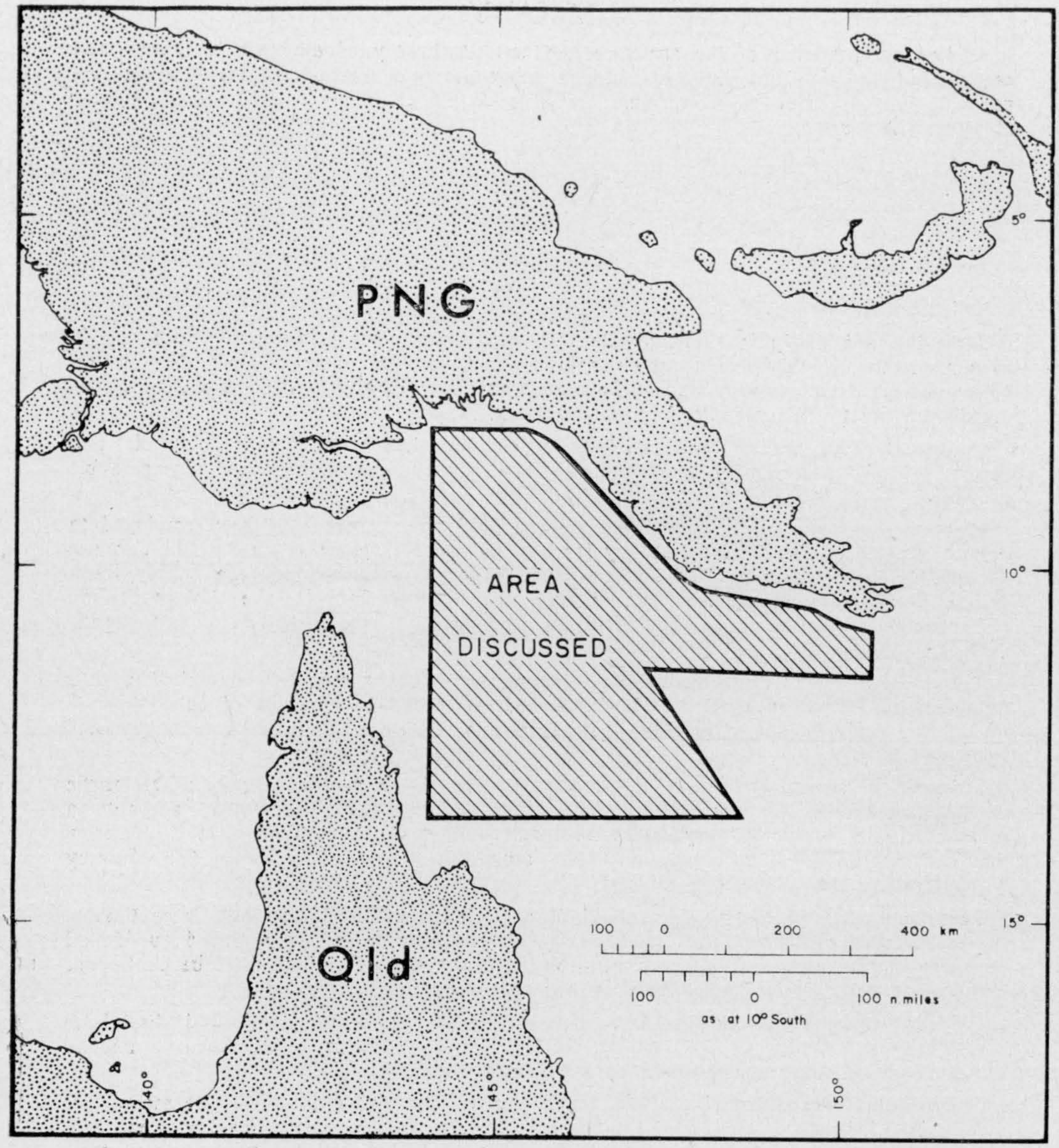

Figure 1. Locality map

1. INTRODUCTION

Since 1965, the Bureau of Mineral Resources (BMR) has engaged contractors to make four marine geophysical reconnaissance surveys. These have been in the petroleum prospective areas of the Joseph Bonaparte Gulf (Smith, 1966; Geophysical Associates, 1966), the Timor Sea (Jones, 1969), the Northwest Continental Shelf (Whitworth, 1969), and during 1970 in the Bismarck Sea, the Gulf of Papua, and offshore southeast Papua.

The 1970 work was contracted to Compagnie Générale de Géophysique (C.G.G.). About 20 000 km of traverse were surveyed during 70 operational days. In the Bismarck Sea, lines were oriented north-south, spaced at intervals of 20 nautical miles except along the New Guinea and New Britain coasts, where the spacing was reduced to 10 nautical miles by the use of tie-lines (Wilcox, in prep.). In the Gulf of Papua, lines were oriented east-west, spaced at intervals of 10 nautical miles. Several reconnaissance lines were surveyed in southeast Papua.

This report presents an interpretation of the results of work carried out in the Gulf of Papua and south to 13°30'S. Figure 1 shows the area concerned, and Plate 1 shows the traverse pattern. Traversing was conducted in four separate stages. In the first, lines 1 to 6 were run as the ship was travelling to the Bismarck Sea from Port Moresby. Lines 183 to 188 were run when the ship returned after completing the Bismarck Sea work. Then followed work in the Gulf of Papua itself, where lines 189 to 230 were surveyed. Late in 1971 the area was re-entered and the additional lines 18 to 32 were run. A total of 9650 km of traversing is considered here.

A full description of the equipment and its performance will be presented in the final field progress report (Tilbury, in prep.). Equipment included:

Seismic — 120-kilojoule sparker system with 4 electrodes
— six-channel streamer
— high-resolution single-channel streamer
— Hewlett-Packard 2116B computer with 8K core and disc storage for experiments in on-line CDP stacking
— Aquatronics and SSQ 41 expendable sonobuoys for seismic refraction
— An on-line analogue seismic recording system employing a set of HTL 7000B seismic amplifiers, five graphic recorders recording at 12 inches per hour, and a 14-channel Ampex tape recorder.

Gravity — LaCoste & Romberg stabilized-platform gravity meter, Serial No. S24.

Magnetic — Varian proton-precession magnetometer.

Bathymetry — Elac and Atlas fathometers

Navigation — Satellite Doppler receiver with PDP8 computer
— Marquardt sonar Doppler navigator
— Electromagnetic and pressure logs
— VLF-Omega radio navigation used in range-range mode

Digital data acquisition — A second Hewlett-Packard 2116B computer
— Hewlett-Packard 2020B tape recorder.

Satellite fixes were used for primary navigation control of the continuous dead-reckoned positions available from the sonar Doppler and backup systems as required. Preliminary positional accuracies of about 3 km or better apply to the data presented in this report. Final accuracies are expected to be within 0.5 km.

All gravity, magnetic, and navigational data were sampled at 10-second intervals. The data acquisition system provided periodic updating of the ship's position, checked the continuity of data, and recorded it on magnetic tape.

Printouts at 10-minute intervals provided data necessary for on-line assessment of systems performance and geophysical computations.

On most lines, data were of good quality. Failures were experienced in several pieces of equipment, but these were always short-lived and resurveying was never considered necessary. Some excellent seismic sections were recorded in good weather, but results generally deteriorated as the state of the sea worsened. Similarly, the quality of gravity results in bad weather is in doubt; for this reason, 650 km of gravity data was not used in the preparation of contour maps. Magnetic results on 740 km of traverse are suspect because of high instrument noise, but the results are suitable for contouring.

Several aims guided work in the Gulf of Papua. Although a great deal of work has been done by petroleum companies on the continental shelf, it has been almost exclusively seismic exploration. Thus gravity coverage was of primary importance. It was hoped that the known prospective areas would show a gravity effect and that the pattern of contours would give a lead to other prospective areas. Many structural trends had previously been mapped to the edge of the continental shelf. One specific aim of the survey was to find the deep-water extension of these structures.

Deep-water structures are of interest to the future prospector. Once the oilfields of the continental shelf have been exploited, the accent will shift to deeper water. The particular aims of the offshore work were to define areas of thick sediment accumulation and large structural relief. Reliable extrapolation of known onshore and shallow-water trends into deep water, and delineation of separate deep-water structures, were also aimed at.

A subordinate aim of the survey was to deduce the crustal structure of the area. Although a number of investigations have been made, it is fair to say that the crustal structure around New Guinea is known only in the most general terms. Different interpretations of structures are common. In particular, much uncertainty still surrounds the interpretation of the structure of southeast Papua; e.g. St John (1967) makes a case for two different models. With such uncertainty still current, any additional information from offshore areas is sure to be useful.

2. GEOLOGY

The existing geological knowledge relevant to a study of the Gulf of Papua falls into three categories: onshore data around the Gulf, information on continental shelf geology, and some data from deep-water investigations. Knowledge of the onshore geology has been gained over many years by numerous

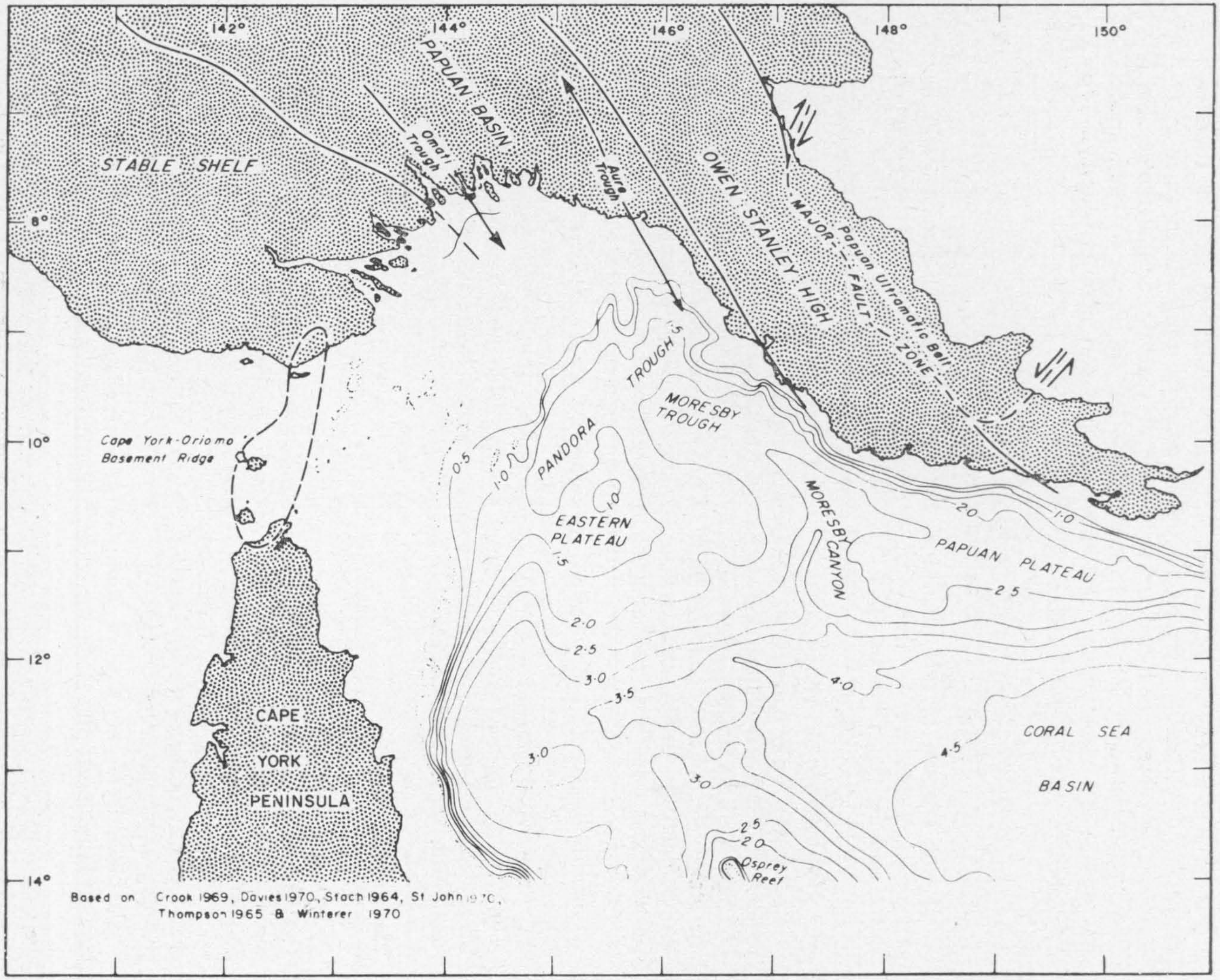

Figure 2. Basic structural elements of eastern Papua and pre-existing bathymetry of the northwest Coral Sea.

workers, e.g. Australasian Petroleum Company (1961); Glaessner (1950); Davies & Smith (1970); Thompson (1967). Of the three categories this is by far the most detailed. Information on shelf geology resulted from work by oil companies from the mid-sixties onward, and is sufficiently detailed to allow a confident extrapolation of onshore geological trends onto the shelf. Deep-water investigations have been conducted for a number of years by oceanographic ships from various institutes. No specific study of the Gulf of Papua has been made, but several ships have entered the subject area as part of larger surveys. The three categories will be discussed separately below.

Onshore Geology

For the purpose of this discussion, only gross structural elements will be considered. Three may be distinguished (Fig. 2): the stable shelf, the Papuan Basin, and the Owen Stanley High.

The Stable Shelf

The stable shelf consists of continental material. It covers the flat-lying regions of southwest Papua and extends across Torres Strait and covers part of Cape York Peninsula. It is essentially the north and northeast extension of the stable Australian continental block. Crustal thicknesses (Brooks & Ripper, 1966; Finlayson, 1968) greater than 30 km have been measured throughout the area, and there is no indication of thinning toward an oceanic section north of Australia. The shelf may be considered an extremely stable platform.

Granitic basement, poorly dated but probably Lower Mesozoic or Upper Palaeozoic, is exposed on some islands in Torres Strait which form part of the Cape York-Oriomo Basement Ridge (Stach, 1964). The basement dips gently north and east and is covered by Mesozoic and Tertiary sediments. These sediments thicken to the east into the Papuan Basin, of which the stable shelf forms the western flank.

The Papuan Basin

This is a large composite basin covering an area of nearly 275 000 km^2 and containing a huge volume of sediments (thicker than 10 km in the Aure Trough). The basin is asymmetric, having a gently sloping western flank (the stable shelf, above) and a deep trough, the Aure Trough, in the east. The trough is the site of the most intense folding and deformation in the basin. The crustal thickness here is not known in any detail, but St John (1967) has indicated that the regional onshore gravity anomalies can be explained only by crustal thinning under the Aure Trough.

The history of the Papuan Basin as it is seen today really began in the lower Miocene. At this time the eastern Papuan peninsula and the cordillera of New Guinea began to rise orogenically. Prior to this, no land existed between the palaeo-Pacific Ocean and the stable shelf, and for this reason the depositional environment was vastly changed from Mesozoic to Tertiary. This change is represented throughout most of the basin by a marked unconformity between Cretaceous and Miocene deposition (Phillips, 1965). The climate at the time and water depth on the western flank were well suited to the formation of reefs and limestone deposits, and these occur widely in the Lower Tertiary sequence in the basin. At the same time as the orogenic rise of New Guinea, the Aure Trough formed as a deep depression in front of the still stable western flank. With the development of the trough, easterly tilting of the shelf areas, which began early in the Tertiary, accelerated, and the trough and its surroundings received enormous volumes of sediment from lower Miocene to recent times. From upper Miocene, 'gravitational folding and diapirism' deformed sediments in the Aure Trough (Thompson, 1967). Folding is generally such that anticlines are sharp thrust-faulted features separated by broad synclines.

Thompson (1967) has questioned the use of the term 'basin' to describe this feature. However, there certainly exists a vast pile of sedimentary material accumulated in an upper crustal depression between a stable platform and an orogenic zone (the Highlands belt), and for the purpose of this report the feature will be referred to as a basin.

The Owen Stanley High

This name is taken from Crook (1969) who made a study of the 'New Guinea Geosyncline', which he considers to be a series of subparallel troughs and highs extending from the Coral Sea to the islands of New Ireland and Manus north of the Bismarck Sea. The Papuan Basin is just one trough in his system.

Crook's subdivision includes the whole of the mountainous backbone of New Guinea as the Owen Stanley High, but only the southeast Papuan peninsula is considered here. In fact, the whole of the mountain belt did not emerge at the same time. The Owen Stanley Ranges rose orogenically in lower Miocene time but the Central Highlands did not begin to develop until middle Miocene — a shallow seaway existed between the two until then (Thompson, 1967). The gap between the two mountain range systems can be identified in free-air and Bouguer gravity anomalies (St John, 1967). The detailed geology of the ranges is complex, but essentially they consist of 'a linear core of Mesozoic sialic metamorphics flanked by Mesozoic and younger mafic rocks and partly concealed by still younger sediments and volcanics' (Davies & Smith, 1970). The Owen Stanley High is bounded in the northeast by the Owen Stanley Fault, which forms the southern margin of the Papuan Ultramafic Belt (Davies, 1971). The creation of this major fault zone was a dramatic event of the early Eocene. Davies suggests that the fault may be part of a subduction zone down which the 'Australian Plate' was being consumed in the early Eocene, and was associated with both the emplacement of the Ultramafic Belt and metamorphism of Mesozoic sialic sediments.

The mountain belt therefore forms an orogenic zone northeast of the more stable areas of shelf and basinal depression.

Continental Shelf Geology

Information concerning shelf geology comes almost entirely from the Phillips Australian Oil Company, which has conducted a number of seismic surveys and drilled several wells on the shelf. The following division of the area into five structural units (Fig. 3) emerged from this work (Phillips, 1965).

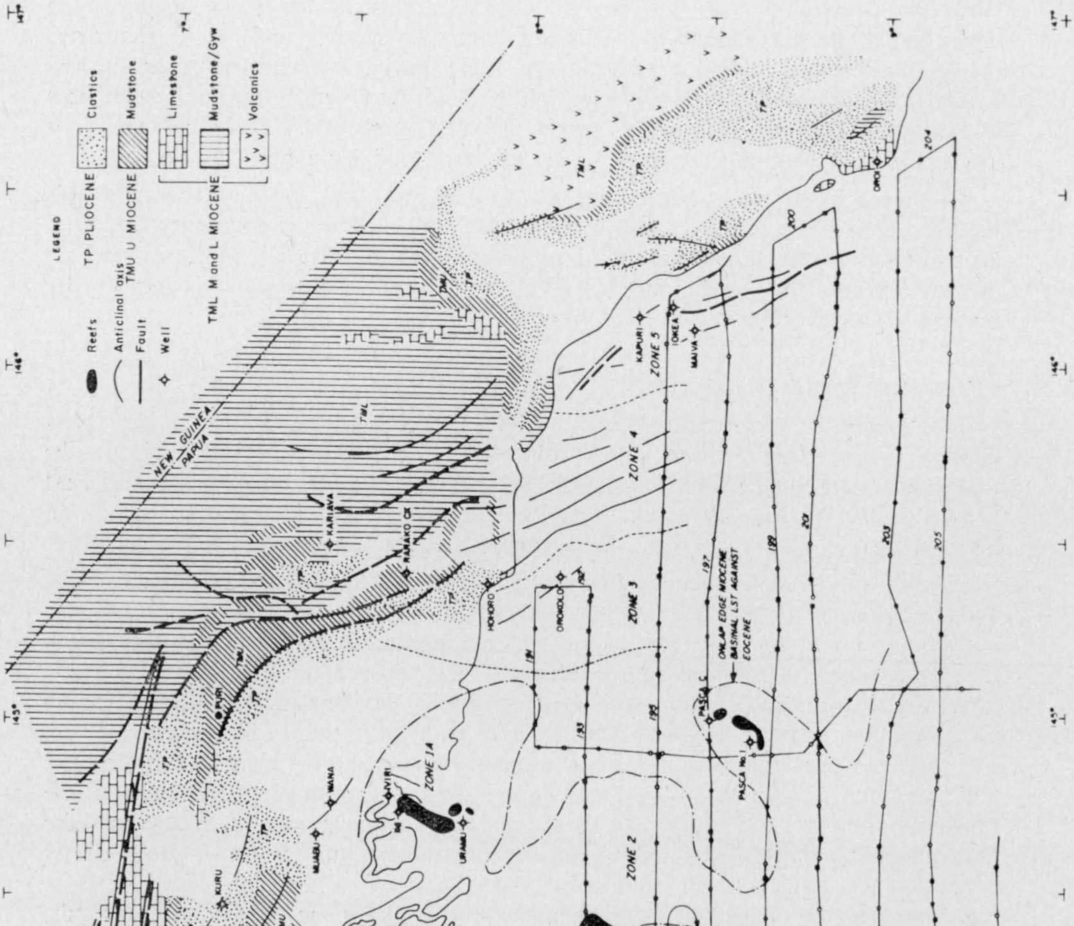

Figure 3. Geological map of western Papua, structural zones in the Gulf of Papua, and BMR tracks (after Phillips Australian Oil Co., 1965).

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

Zone 1A: A Miocene limestone shelf area in Deception Bay. Eocene block uplift and Miocene reef development was interpreted.

Zone 2: West slope of the basin in which the Tertiary dips more steeply, and rapidly thickens, towards the east. Tertiary (Miocene) 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 as a result of flow 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.

With this subdivision Phillips provided an essential link between onshore and offshore geology, so that known onshore features may be easily recognized on the shelf.

During the course of surveying, a Miocene barrier reef very similar in form to the modern Great Barrier Reef was detailed. Buried Miocene platform reefs, also very similar to their modern counterpart, were similarly recognized. These were considered highly prospective for oil and several of Phillips's wells (e.g. Borobi, Uramu, and Pasca) were aimed to intersect them. Other wells were aimed for structural traps in folded sediments in zones 3 and 5.

All of Phillips's zones are open-ended to the south, i.e. towards deep water, and it was one of the aims of the BMR survey to identify and extend these zones. In particular, if the further seaward extension of the Aure Trough was delineated, this would help in determining the southeast extent of the Papuan Basin — an outstanding question. Also, the Miocene barrier reef has been mapped no farther south than 9°S, and its association with the modern Great Barrier Reef has not been strictly established.

Deep Water Geology

All the surveys in deep water have been semi-detailed at best, and at worst they consisted of a few regional traverses. Several papers have appeared in the literature which report on aspects of these surveys. It is appropriate to simply provide a summary of the major contributions.

Winterer (1970) considered the submarine valley system around the Coral Sea Basin. This study was based on results from part of the 1967 NOVA Expedition of the Scripps Institution of Oceanography, on which the ships R. V. *Horizon* and R. V. *Argo* employed echo sounders and seismic reflection profiling. He treated the canyons and troughs as the submarine drainage system by which the Coral Sea Basin received its sediment fill, and deduced the history of some of the troughs from reflection profiles. He also defined several trough 'systems' and named some new features. His conclusions regarding the history of one of these 'systems' is of particular interest and is reproduced below.

'In the Moresby System, for example, the reflection profile across the canyon suggests a complex history of filling, cutting, and re-filling. The sequence is here interpreted as follows:

(1) Moresby Trough, which was originally cut off from the Coral Sea Basin by the shallower arch of the Papuan Plateau, was partly filled by sediments, up to the level of a low sill at about 2,300 m depth, at the present site of Moresby Canyon. Clastic sediments from New Guinea could then begin to spill southward across the Papua Plateau toward the basin. The uppermost layers outside the canyon may represent remnants of this earlier fill.

(2) The gradient was steep down the south flank of the Papua Plateau, and the Coral Sea Basin was not so full with sediments as today. A canyon was cut at the spill-over point on this slope, which was underlain by relatively soft older sediments, and a new grade was established.

(3) Sediment has continued to fill the basin and the troughs, raising the base level of deposition and forcing readjustments of gradients along the valley system. The canyon has been partly backfilled in response to the gradual filling of the basin'.

Winterer's paper is of particular interest in that it is a study of a specific phenomenon (the troughs) and does not attempt to draw sweeping conclusions regarding the evolution of the area from scanty data. The reflection sections from which he worked were not available to the author until after the BMR survey. They were collected on irregularly oriented lines using Arcer and Airgun techniques.

Gardner (1970) took a different view. Using seismic reflection and refraction data collected by the Lamont-Doherty Geological Observatory, together with Precision Depth Recordings and core and grab samples, he attempted to deduce the history of the western Coral Sea. His conclusion involved the concepts of continental drift and was ' . . . that during the middle Tertiary, probably no earlier that late Eocene, New Guinea rotated away from Australia, which resulted in the opening up of the Coral Sea Basin and the forming of continental margins along the seaward edges of the present Queensland Plateau and southern New Guinea'. This idea seems hard to reconcile with a Miocene emergence of eastern New Guinea (Thomson, 1967), but his view has been supported by others (Davies, 1971; Falvey & Talwani, in a personal communication to H. L. Davies) although the date of the event is not agreed upon.

Some of the findings from which Gardner (op. cit.) drew his conclusions were those of Ewing, Houtz & Ludwig (1970) and Ewing, Hawkins & Ludwig (1970). These two papers, which describe the sediment distribution and crustal structure of the Coral Sea, are applicable only in a broad sense as only three of the thirteen sonobuoy refractions listed and 220 km of traversing were shot in the subject area. The results of the sonobuoy refractions are shown in the following table.

Buoy 53 (Papuan Plateau)		*Buoy 54* (Papuan Plateau)		*Buoy 56* (Pandora Basin)	
*	**	*	**	*	**
	1.500		1.500		1.500
2.874	——	2.912	——	1.822	——
	1.834		1.559		1.807
3.331	——	3.345	——	2.327	——
	(3.010)		1.975		2.789
	(6.060)	3.530	——	2.691	——
			2.135		5.900
		3.836	——		
			2.320		
		4.067	——		
			6.600		

* Two-way time in seconds **Interval velocity in km/s

The unusually low velocity for sediments in the upper layers of the Papuan Plateau was taken by the authors to indicate ' . . . that the sediments of the Papuan Plateau are exclusively Fly River silts and turbidites'. This led to the suggestion that the plateau formed behind a basement ridge which was identified on reflection section. The 5.900 km/s basement velocity measured below the Pandora Basin is within the 5.9-6.3 km/s range given as being 'continental-type' by the authors. The same velocity was measured beneath the Queensland Plateau, and this may support the statement by Gardner (op. cit.) that 'three of the [Coral Sea's marginal] plateaus may have been connected in the past'.

Thus the geological objectives of the survey were twofold. Firstly to extend the detailed knowledge of onshore and shelf geology into deeper water and thus delineate areas which may be prospective in the future, and secondly to consider the area in a broad sense by its relation to the Coral Sea Basin and in its role as part of the system of marginal plateaus which surround the basin.

3. BATHYMETRY

Introduction

The bathymetric results are presented in the form of a contour map (Plate 2) with selected profiles across areas of special interest (Fig. 4). The contour map was produced by hand-contouring values sampled at hourly intervals (approx. 10 nautical miles). Thus a semi-regular grid was employed for contouring areas where the line spacing is ten nautical miles and a rectangular grid where spacing is twenty nautical miles. No other soundings were incorporated in the compilation. The profiles were extracted directly from the contour map as they do not, in general, coincide with traverse lines.

The Atlas fathometer was used in depths up to 200 metres, the Elac fathometer from 200 to 4000 metres, and the seismic return in greater depths. The average value of mistie at intersection point is 5 metres (range 0 to 22 m) with loop misclosures ranging from +32 to −25 m. Both misties and misclosures increase in absolute value with increase in water depth, this being related to both equipment performance and navigational inaccuracy (the sonar Doppler operates off seabed in depths only up to 200 m). Tilbury (in prep.) gives an account of equipment performances and an analysis of misties and misclosures.

General description

Before this survey, the only detailed bathymetric charts of the region have consisted of compilations by workers from the Scripps Institution of Oceanography (Winterer, 1970) and the Lamont-Doherty Geological Observatory (Gardner, 1970). These authors have named many of the features they observed. Their compilations relied, however, on old soundings in addition to their own somewhat irregular traversing. On the basis of systematic traversing it has been possible to review the nomenclature and suggest new names for some of the features.

A primary division of bathymetric features is made between deep and shallow waters. Shallow-water features are considered to be continental shelf and slope. In waters deeper than the base of the upper continental slope (roughly 2000 m in the subject area) the area consists of a complex of submarine troughs, canyons, plateaus, and basins. These are:

Moresby (or Fly River) Trough

Portlock (or Bligh) Trough (Portlock is a new name)

Moresby Canyon

Bligh Canyon

Eastern Fields Fan (renamed from Eastern Plateau)

Papuan Plateau

Pandora Basin (renamed from Pandora Trough)

Osprey Basin (renamed from part of Bligh Trough)

Continental shelf

The width of the shelf varies from virtually zero along the coast of southeast Papua to over 50 km in the Gulf of Papua, where it is effectively defined by the 200-m isobath. The large expanse of shelf in the Gulf of Papua south of 9°S and east of Torres Strait supports extensive reef growth, which varies greatly in size and type from large platform reefs such as Portlock and Boot Reefs to pinnacle reef chains. The Great Barrier Reef extends northward no farther than 9°S into the Gulf of Papua, and other forms of reef growth also are largely limited to this latitude. The termination of reef growth is attributed, by Winterer (1970) and other authors, to the muddy condition of the water off the mouth of the great river systems of New Guinea, particularly the Fly River. It should be noted, however, that there is no strict ecological reason why reefs should not grow in muddy waters. Reefs grow off the muddy Rewa River in Fiji and under similar conditions off the south coast of Molokai (Shepard, 1948). Other factors such as subsidence, reduced salinity, and food supply must also be considered.

In the gulf, the shelf has a distorted crescent shape, being widest off the Fly River and narrowing rapidly towards Port Moresby. The width of the shelf is considered to indicate differing tectonic evolutions within the region. The greatest width is to the north of the stable geological continent of Australia, which has remained cratonic throughout most of its long history. In comparison, the narrowest development is found off the coast of southeast Papua, an area known to have had a relatively rapid tectonic evolution. Reefs grow also on the narrowest parts of the shelf.

Continental Slope

The most interesting aspect of the continental slope in these waters is its gradient and profile. The worldwide average gradient for continental slopes off coasts with large rivers is 1°20′ down to 2000 m and off 'young mountain range coasts' it is 4°20′ down to 2000 m (Shepard, 1948). The slopes are generally straight or gently curved (concave).

In the Gulf of Papua the shelf edge trends northeast from Portlock Reefs towards the coast of Papua. Here the gradient ranges between 1° at the head of the Moresby Trough, where the profile is relatively smooth, to 1°40′ near the reefs where the profile is more concave. The effect of the Trough is to smooth and reduce the gradient of the continental slope at its head.

In the immediate vicinity of the reefs the gradient increases to a maximum of nearly 20°. This obviously cannot be considered as a conventional continental slope as it is greatly influenced by the reefs and the canyons cut between them.

In the eastern Gulf of Papua, the profile of the continental slope is very irregular, and appears to be tectonically controlled. Some acute valleys appear, on bathymetric evidence alone, to be faulted.

Off the coast of southeast Papua the continental slope is disturbed by the Papuan Plateau, which is intermediate in depth between the shelf and Coral Sea Basin. The gradient is near normal at about 2°10′, but the profile is so irregular that this area should perhaps not be considered as a true continental slope; it is also cut by numerous canyons not shown on the contours.

Finally, the continental slope in Torres Strait shows gradients from 0°45′ to 1°45′ and is obviously influenced by the Portlock (or Bligh) Trough, of which it forms the western flank. The expected gradients for stable continental slopes outside large rivers is around 3°. Erosion in the trough has apparently reduced the gradient of the continental slope.

Moresby Trough

The alternative name for this feature, used by Gardner (1970), is the Fly River Trough. This name, however, implies an association with the Fly River which should not be assumed.

The trough trends northwest, paralleling the coast of Papua for 250 km from the Moresby Canyon in the south to where its head is buried in the continental slope at approximately 8°30′S (Plate 2.) It is asymmetric, with the steepest gradient to the landward side, and is wide for its length — 75 km between 2000-m isobaths off Port Moresby. Its basinward gradient is very small (Fig. 4, profile P1), dropping only 1 km in the 250-km distance from the bottom of the continental slope to the Moresby Canyon, i.e. a slope of 4 metres per kilometre.

Although not shown on the contour map, many minor canyons and several major ones feed the Moresby Trough from the coast of Papua. The bulk of the sediment from Papua arriving in the Coral Sea Basin is believed to use this trough as an avenue for transport (Gardner, 1970; Winterer, 1970; and others).

A submarine fan is known to exist at the southern termination of the Moresby Trough (Winterer, 1970); it grades gently into the flat floor of the Coral Sea Basin, testifying to an intimate relation between abyssal plain sedimentation and this trough. The fan was not traversed on this survey.

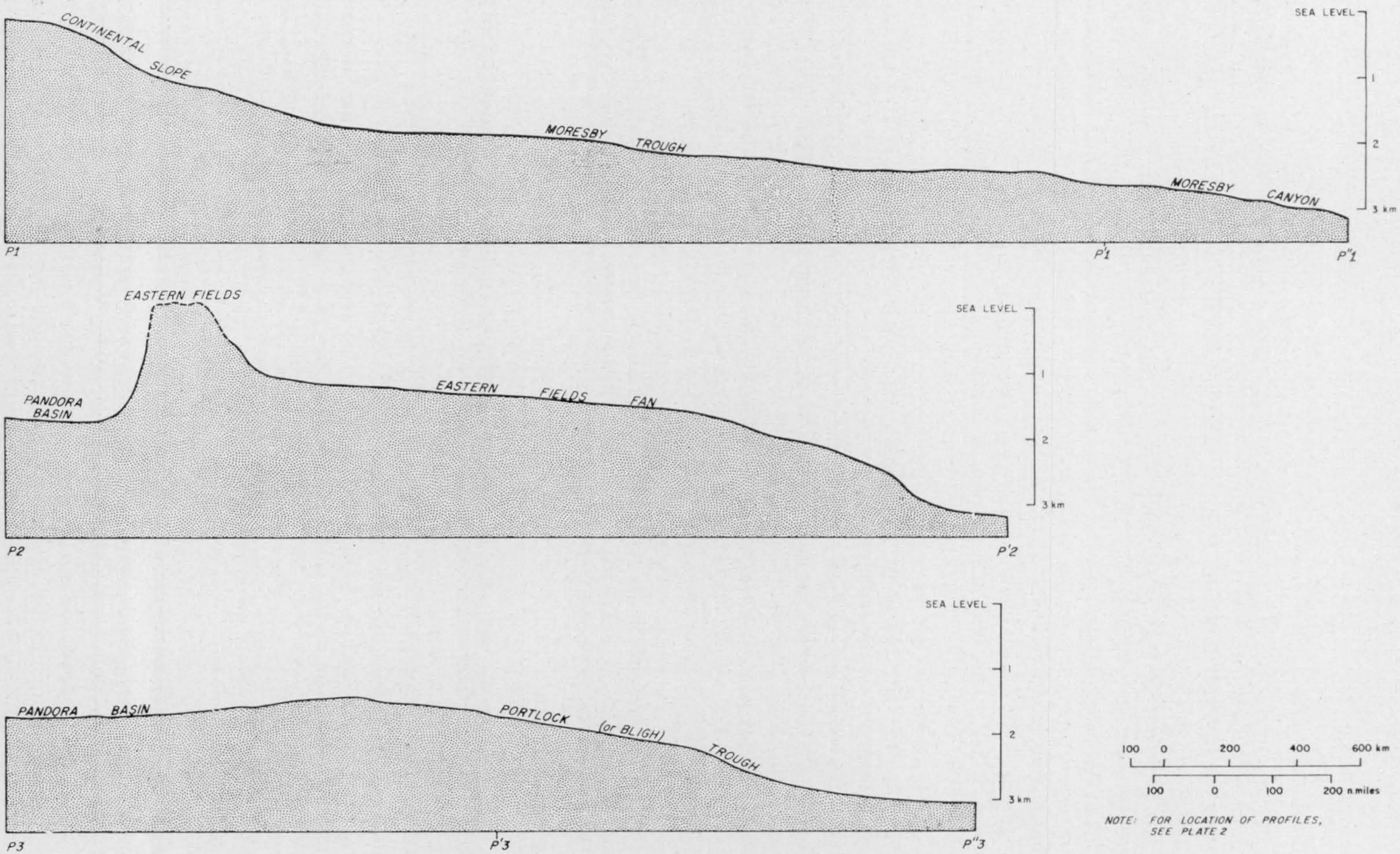

Figure 4. Bathymetric profiles.

Portlock (or Bligh) Trough

Formed between the continental slope of Torres Strait and the Eastern Fields Fan, the Portlock (or Bligh) Trough is a sharp submarine valley that trends NNE (Plate 2). It is roughly 140 km in length, beginning south of a saddle at 10°45'S at a depth of 1500 m and deepening southward to 3000 m, where it appears to bifurcate onto the Osprey Embayment. It has an average slope of 14 metres per kilometre, roughly equal to that of the continental slope at the head of the Moresby Trough (see also profile P3, Plate 2). It is asymmetric in cross-section, with its steepest slope to the east, i.e. towards the fan.

The Portlock Trough trends almost at right-angles to the direction which sediments might be expected to take after leaving the mouth of the Fly River. In detailed profiles, however, the trough floor shows relief features which strongly resemble those created by submarine erosional processes. One can thus deduce that the history of formation of the trough has involved the combined effects of tectonic movement and erosion.

Winterer's (1970) nomenclature grouped the features extending from 10°45'S to 13°45'S into one feature — the Bligh Trough. For the present report, the trough north of 12°10'S is considered as a separate feature and the alternative name Portlock Trough is suggested here.

Moresby Canyon

Only two crossings of this feature were made, but these were sufficient to show that the canyon is a very steep-sided, narrow valley trending near south from the southern termination of the Moresby Trough (Plate 2). It is asymmetric in profile, with its steepest side to the east. The canyon separates the Papuan Plateau from the eastern flank of the Eastern Fields Fan, and forms the last part of a direct avenue for sediment transport from the Fly River mouth to the Coral Sea Basin (see also profile P1). The southern part of the canyon was not surveyed, but on other published maps of the area by Gardner (1970) and Winterer (1970) it can be seen to grade, via a deep sea fan, onto the floor of the Coral Sea Basin.

The slope of trough and canyon are virtually continuous from the base of the continental slope to the Coral Sea Basin.

Bligh Canyon

This feature lies immediately north of the Eastern Fields Fan but is not apparent on the bathymetric contour map. However, on the 1967 NOVA Expedition of the Scripps Institution (Winterer, 1970) several zigzag traverses were run to detail the canyon. On the present survey the canyon was not encountered as it lies between two east-west lines. Thus no new information has been brought to light, and the reader is referred to Winterer (1970) for an account of the Canyon's morphology.

Eastern Fields Fan

Located in the central Gulf of Papua is the Eastern Fields Fan, the largest physiographic feature in the region (Plate 2). It is roughly triangular, being confined in the west by the Portlock (or Bligh) Trough and in the northeast by the Moresby Trough. The apex of this triangle lies at the Eastern Fields, a very large platform reef and the only one in the area which rises from greater than shelf depths. North of the fan is a shallow depression in which the Pandora Basin and the northern end of the Moresby Trough join.

The surface of the fan slopes south and southeast away from Eastern Fields from 1000 down to 3000 m. From 1000 down to 1500 m the gradient is very gentle (about 5 metres per kilometre) after which a break occurs and the gradient steepens down to the 3000-m isobath, which can be considered as the limit of the fan in the south (see also profile P2). To the northeast the fan grades into the southwestern flank of the Moresby Trough.

Eastern Fields rise from depths of between 1000 and 1500 m to break water in a distance of less than 5 km — a very rapid rise. In the immediate vicinity of the reefs, the waters are deeper to the north than south (see profile P2).

In its gross morphology, the fan appears as a large wedge of material distributed south of Eastern Fields in a triangular form between two troughs. It cannot be considered a plateau and must be treated as atypical of the Coral Sea's marginal plateaus. The feature, in fact, reminds one of the submarine fans in deep water off the mouths of many great rivers, e.g. the Rhine (Menard, Smith & Pratt, 1965).

Papuan Plateau

Located off the coast of southeast Papua at an average depth of 2500 m, intermediate between the continental shelf (200 m) and the Coral Sea Basin (4500 m), is the Papuan Plateau, a true plateau with a very flat surface.

The plateau is said to have formed between 'the upper and lower continental slopes off Papua' (Krause, 1967); these two slopes merge at 153°E. Its western limit is marked by the Moresby Canyon. It has been postulated (Ewing, Houtz & Ludwig, 1970) that the Papuan Plateau formed behind an east-west basement ridge by the accumulation of exclusively Fly River silt and turbidite (this based on seismic reflection velocities), which were then breached and formed the Moresby Canyon by erosion. That interpretation is based on very little information, and must be considered tentative.

No reefs have developed on this plateau.

Pandora Basin

This occupies the region between Portlock and Boot Reefs and Eastern Fields; it extends south to the saddle at the head of the Portlock Trough and north to approximately 9°40'S (northern limit defined below on seismic evidence). In gross morphology it is a trough, but northwest of Eastern Fields on two successive lines (209 and 211) its surface is almost flat. For a distance greater than 100 km in an east-northeasterly direction from the bottom of the slope associated with Boot Reefs, the surface of the basin drops only 100 m — a slope one-quarter that of the Moresby Trough.

Despite the gentleness of this gradient there will be some transport of sedimentary material from valleys in the continental slope, but deposition rather than transport will be dominant; hence the name 'basin' is considered appropriate.

Osprey Basin

On the western side of the Osprey Embayment and south of the Portlock Trough is a basin feature named here the Osprey Basin. The justification for naming this feature a basin rests largely on seismic evidence (see below) supported by bathymetric evidence.

The basin lies between a NNW-trending bathymetric high and the steep rugged slope immediately east of the Great Barrier Reef, between latitudes 12°30′S and 13°30′S. Its surface slopes gently northwest (3 metres per kilometre) to meet the Portlock Trough at its deepest point (about 3000 m). This gradient is certainly enough to allow transport of sediment and thus for the basin to be part of the submarine drainage system of Cape York Peninsula. However, the gradient is gentle and the basin contains sediment (see below), so deposition is likely to be active.

The Osprey Basin is the largest of a number of basins and smaller sediment-filled depressions in the Osprey Embayment.

Osprey Embayment

This is a complex region between the Eastern Fields Fan and the Queensland Plateau, which lies south of the subject area. It is confined to the west by the Great Barrier Reef and to the east by a steep scarp which forms the northwest limit of the Coral Sea abyssal plain in this region. Gradients on this scarp reach 50 metres per kilometre.

The embayment consists of a complex of bathymetric highs and lows; the low areas have gentle gradients, but the highs are generally steeper. The relation of the embayment to the Queensland Plateau is not yet known, nor can its detailed morphology be ascertained because the traverses are 20 miles apart. The region appears to lack any marked trends in the bathymetry apart from a roughly east-trending high, which includes two local peaks at latitude 12°50′S.

Cross trend

Apart from the main physiographic units recognized from the contour map, there exists also a distinct trend in the bathymetry which cuts across the strike of most other features. This is a 'cross trend' striking east at 11°S. It begins at around 145°E near the head of the Portlock (or Bligh) Trough and is discernible in the contours east to 147°20′E, where it meets the Moresby Canyon. It is subparallel to the trend in the Osprey Embayment, and if its strike were continued farther east it would be subparallel to the southern margin of the Papuan Plateau. The significance of this trend will be seen in the following chapters.

The profiles (Fig. 4)

The profiles illustrate some of the points made about gradients in the text.

Profile P1 shows the continental slope and Moresby Trough and canyon system. Note that the basinward gradient is virtually continuous from the base of the continental slope.

Profile P2 shows the Eastern Fields reefs and longitudinal section through the Eastern Fields Fan. It demonstrates that the Pandora Basin lies at a greater depth than the fan and that the gradient of the fan changes at around the 1500-m point.

Profile P3 shows that the Pandora Basin has a relatively flat surface and that the Portlock Trough deepens with a gradient roughly equal to that of a continental slope.

4. SEISMIC RESULTS AND INTERPRETATION

Introduction

Three types of record were available from the seismic system: any single channel from the six-channel streamer; the display from the single-channel streamer; and a stacked record produced with the use of the computer. In fact, only the display from channel 2 of the long streamer was used for the following analysis, as records from the other systems contained little additional information that was relevant.

The quality of the seismic data varies. It is generally good with high signal-to-noise ratio (S/N) for areas north of 11°30′. Penetration here was deep (up to 2.5 seconds' reflection time) and the information content is high. In the southern part of the area, on lines 4 to 16, the quality is lower. Sections show a reduced S/N owing to high random noise from the hydrophone streamer. Interpretation of the results in this area has been more difficult and consequently less detailed.

Refraction shots were fired about once a day using the sparker as an energy source and Aquatronics sonobuoys as a receiving system. To date the velocities obtained from these shots contain such large errors that they have not been used in the analysis of sediment distribution. No basement refractor was recorded.

The interpretation of seismic reflection sections was made with the following aims in mind: to determine the distribution of sediment types based on acoustic properties; to determine whether the origin of the troughs was tectonic or erosional; to investigate any structures upon which reef development has taken place; to determine the thickness and type of sediment which covers the plateau region; and to extend the knowledge gained from work by oil companies on the continental shelf into deep water.

The above aims have been met with varying success. Accurate sediment thicknesses were not generally determined, as a definite basement reflector can seldom be identified. The extension of shelf geology into deeper water has been hampered by lack of deep penetration by the sparker — less than two seconds of reflection time, on average. The results are portrayed in two forms. Plate 3 shows the distribution of sediment types and the basement structures seen on the sections. The region has been divided into six provinces on the basis of characteristic sediment type, and an attempt was made also to keep the provinces consistent with the basic morphologic units shown in Plate 2. Plates 4 and 5 show profiles across areas of special interest. The three plates will be described separately, beginning with the province map (Plate 3).

Province I — Western Shelf

The area of the western shelf, in fact almost the entire continental shelf of the Gulf of Papua, has been thoroughly surveyed by Phillips Australian Oil Company in search of oil and gas in the Miocene limestone reef formations that exist at depth below the shelf. These reefs are covered by great thicknesses of Pliocene to Recent sediments (2200 m in the case of the Pasca No. 1 well) and were at one time considered highly prospective. Using techniques that enabled them to obtain penetration up to five seconds of reflection time, this company accurately mapped the location of the Miocene reefs, and delineated facies and epoch boundaries.

With the methods employed during the survey it was not possible to distinguish epoch boundaries, and it is unlikely that the sparker 'sees' very far below the bottom of the Pliocene to Recent sequence. On our records the shelf sediments appear as a highly stratified, well bedded sequence dipping gently to the east, i.e. toward the Aure Trough. Sediments are completely undeformed in the west and folded into broad gentle anticlines in the east (see also AA′ and BB′, Plate 4). This province lies within Phillips (1965) zones 1, 2, and 3 (Fig. 3), and constitutes the shelf and western continental slope of the Papuan Basin, of which the Aure Trough can be considered the depositional axis. The Tertiary section thickens to the east into the trough, the thinnest section being landward on the western side.

A lower Miocene barrier reef, similar in type to the modern Great Barrier Reef, was mapped by Phillips southward to approximately 9°S. Evidence of the reefs can be seen on the 1970 BMR records as strongly dipping reflectors which presumably mark the top of the reef formation. Lack of deep penetration by the sparker has precluded the detailing of these formations although the positions of the reef itself, at points of intersection with BMR traverses, agreed precisely with Phillips's maps.

It is possible to map this reef farther south than Phillips was able to do. In doing this a somewhat surprising result was obtained. It might have been anticipated, on the basis of their similar character, that the ancient and modern barrier reefs would form a continuous feature. However, south of 9°S evidence suggests that the Miocene reef turns eastward directly toward Portlock Reefs — a modern platform reef. Lines 220 and 222 (Plate 1) both show a patch of disturbed reflectors apparently continuous with the Miocene reefs. The chain of modern reefs from Portlock Reefs to Claudine and Mary Reefs (Plate 3) is parallel to the Great Barrier Reef, but displaced from it to the east by about 75 km. The evidence is not irrefutable as the disturbed reflectors are high in the section and may therefore represent a submerged extension of the modern reefs, but there is no good reason to suggest that ancient and modern reefs should form an unbroken line.

On many of the sections minor diffractions and disturbances are seen from the top of the sequence to depths of about 500 milliseconds of reflection time. The general appearance, however, is still of evenly bedded undisturbed sediments. The reason for the minor disturbances is not clear, but several possibilities may be considered. The features may represent attemps by organisms to form reefs in ecologically unfavourable conditions (e.g. muddy water or rapid subsidence).

They may also represent minor filled channels, or velocity variations caused by localized mud flows. Any of these explanations seems equally likely for this wide shelf close to the Fly River.

Province II — Aure and Moresby Troughs and Pandora Basin

To simplify the division into provinces, a large region has been defined which includes several physiographic features and crosses a number of seismic boundaries. The boundaries in the east and west are the continental slopes, but to the north the province includes shelf and slope and extends to the north border of the map. To the south the limit of the province is taken (from west to east) as the southern boundary of the Pandora Basin, the Eastern Fields reef complex, and a change in reflection character occurring at about 10°S. The last does not coincide with a distinct morphologic boundary, although it lies just north of the Eastern Fields Fan.

In the north, the offshore extension of the Aure Trough was mapped by Phillips Australian Oil Company (op. cit.). It is a belt of strongly and complexly folded sediments lying between the stable western shelf and a mobile zone to the east. Sediments of thickness greater than 10 km were encountered. Folding has resulted in the formation of tight asymmetric anticlines, often thrust-faulted with diapiric cores, separated by broad synclines. The mapping was based on identification of this characteristic folding, and many of the anticline axes were followed to the edge of the continental shelf, i.e. the southern limit of Phillips's permit area. One such anticline, on which the Orokolo No. 1 well was drilled by Phillips, could be seen clearly on sections from the present survey. It lies on the western margin of the trough and is strictly outside the intensely folded zone. On BMR sections it appears as a symmetric fold extending from near surface to the limit of penetration of the sparker (approximately 1.5 s). It is about 9.3 km wide and has a relief of about 200 m at a depth of 500 m. All beds can be traced from one side of the fold to the other with no thinning or compaction over the crest, indication that folding most likely occurred during deposition, in thick incompetent beds as stated by Phillips (1965).

In the trough itself, and the mobile zone, folds identified by Phillips were also seen. The folds in the trough are asymmetric; the western sides are steeper than the eastern and display diffractions and reflection crossovers suggestive of thrust-faulting. However, the diapiric nature of the cores could not be seen on the section owing to lack of penetration (see also AA′ and BB′, Plate 4). The Maiva structure (Phillips, 1965) in the mobile zones was also located.

These structures were delineated first by Phillips using powerful seismic techniques and post-processing; that they could be identified on unprocessed sparker records from the present survey has given confidence in extrapolating into areas outside the permit area in which Phillips worked. Thus, in the deeper-water regions of the continental slope and the floor of the Moresby Trough, folds in stratified sediments of the type characteristic of the Aure Trough were observed to extend south to nearly 9°S. Once the shelf break is passed the folds show expression in the bottom topography as bumps in the floor of the trough. Again, the folding is generally asymmetric; the steeper side is on the west and shows some evidence of thrust-faulting. Generally synclines are much broader than anticlines. In fact all aspects of these folds conform very closely to the folding in the Aure Trough.

No basement reflector can be identified in the Moresby Trough. The Aure Trough contains a large volume of sediments and trends directly towards the Moresby Trough; sediments in the Moresby Trough show folding characteristic of the Aure Trough. There is no evidence for thinning in the Aure Trough sediments before the Moresby Trough is reached. It is suggested therefore that these two troughs form a continuous belt of sedimentation to at least 9°S.

Flanking these troughs are the stable western shelf and the eastern mobile zone (Fig. 3) in the case of the Aure Trough; and the continental slopes of the western shelf and Papuan coast in the case of the Moresby Trough (Plate 2). The two continental slopes differ markedly in character.

The Papuan continental slope can hardly be called a true continental slope (see Bathymetry). It is extremely rugged in profile and very steep; the drop from shelf to trough floor (at 1500 m) occurs in less than 20 km. The slope consists of sedimentary material, which appears to be strongly folded; smaller channels and hummocky relief superimposed on the larger features testify to the forces of submarine erosion. The continental slope at 9°10'S is disturbed by faulting; slope sediments have formed into a large slump block below the fault. This area, marked as 'rugged topography' in Plate 3, forms a virtually continuous feature with the mobile zone farther north.

Between some of these rugged features, horizontal sediments have ponded in small pockets, indicating that the most recent event in the history of the region may have been deposition under relatively quiet conditions, but certainly the folding and deformation was the major event and occurred in the not-too-distant past.

The western flank of the Moresby Trough, i.e. the continental slope of the western shelf, is quite different from the eastern flank. It is much more gentle in gradient, and sediments appear very little disturbed by tectonic movements. However, the slope is cut by a number of channels running parallel to the shelf break. Very probably there are also channels perpendicular to the shelf break but which have not been identified owing to the bias introduced by systematic east-west traversing. Some slumping near the shelf break also occurs. Apart from these relatively small features, the slope is virtually undisturbed and grades gently into the floor of the Moresby Trough.

The floor of the trough and the other areas in Province II are characterized by three types of sediment: both opaque and stratified sediments are present, plus a type which will be referred to as 'disturbed'. The last occurs only in the northern part of Province II. The material shows many discontinuous reflectors and often diffracts the seismic waves, and reflectors generally appear jumbled and show great variation in dip over short distances.

When considering the above description of sediment types, it should be remembered that 'type' refers to the acoustic appearance of sediments to a 120-kilojoule sparker, towed at 10 knots, with the returning energy filtered 18-92 Hz and displayed with further 20-80 Hz filtering on an E.G.&G. recorder running at a paper speed of 12 inches per hour.

Stratified reflectors occur largely throughout the entire province. At the base of the Papuan continental slope, they form the upper sequence of sediments in a narrow belt parallel to the slope. Thicknesses up to 500 metres (assuming an average velocity of 2 km/s) have been deposited in flat-lying sequences.

They abut, with differential compaction, structures in the older rock sequences, which generally are much poorer reflectors. Some drape structures are present, and infilling of minor depressions has occurred. Westward from the Papuan slope the stratified sediments grade into the disturbed type in the centre of the province (Plate 3).

Stratified reflectors also occur in the west of the province, where they form the continental slope sediments, but again they grade into the disturbed type of reflector in deep water. The largest deposit of stratified sediments is found in the Pandora Basin (see also CC′, Plate 4).

The Pandora Basin lies between Eastern Fields reefs and the Portlock to Claudine and Mary chain of reefs, and occupies an area greater than 5000 km^2. In the south it is terminated by a saddle which separates it from the Portlock (or Bligh) Trough, but in the north its limit is defined by seismic evidence and does not correspond to a morphologic boundary. Deep structure of the saddle is controlled by a basement ridge. Sediments confined in the basin form a two-layer sequence. The upper sequence is formed of stratified reflectors to a depth of up to 800 m. They are very flat-lying and evenly bedded. Sediments abut the Eastern Fields structure in the east but gently grade into the continental slope in the west. This sequence unconformably overlies an older sequence, which can be identified by its poorer reflecting characteristics (opaque). It is roughly the same thickness, and its upper surface is roughly basin shaped; the stratified upper sequence forms the basin fill. The lower sequence, in turn, lies above basement. The basement topography is also basin-like, rising to the Eastern Fields structure in the east and below the continental slope to the west. It is at this level that the structural framework for the basin is formed. The area occupied by the basin (Plate 3) is taken as being the area over which this basement structure can be identified. Canyons lead from the reef areas in the west onto the basin floor.

The following history of the Pandora Basin has been interpreted from the seismic sections. Apparently a depression formed between positive structures on which the modern reefs are located. This depression filled with sediment to perhaps a depth of more than one kilometre, and there followed a period of erosion, which produced a concave upper surface to the older sequence. This was followed by a further period of deposition during which the basin received its fill of stratified sediments. It would appear that deposition is still continuing as no erosion is evident in the modern surface. In the northern part of the basin, stratified reflectors grade into and interbed with the disturbed type (see also BB′ and CC′, Plate 4).

Disturbed reflectors occur within the centre of the province north of the Pandora Basin and extend to the southern edge east of Eastern Fields. They may be interbedded with stratified sediments or form the complete sequence. The boundary of the region characterized by these reflectors is not clearly delineated as the change is never sudden. In a small pocket north of Eastern Fields they occur in a two-layer sequence with a stratified layer overlain by a thin cover of disturbed-type reflectors. The upper sequence is replaced by a stratified layer to the base of the continental slope.

Down the middle of this zone runs an area of hummocky topography (see also BB′) forming a sinuous narrow strip down the centre of the zone of disturbed reflectors, beginning on the continental slope in the north and ending on flat sea-bed just east of Eastern Fields. On some lines it consists of a flat central section with material piled up on either side. In the immediate vicinity of this zone of hummocky topography, the reflectors are generally more strongly disturbed.

Though many processes can produce hummocky relief to the sea bottom and more than one type of material can produce disturbed reflectors on a seismic section, the following interpretation is offered as a suggestion.

The waters of the Gulf are very warm and receive a great deal of sunlight; they support a large amount of organic life and in bathymetrically suitable places reef growth has developed vigorously. The environment therefore is suitable for the deposition of a highly calcareous rock. It is suggested that the material that shows a highly disturbed and diffracting aspect to the sparker in the centre of the province is limestone deposited on a relatively flat surface in quiet conditions away from strong currents. This type of deposition would not be possible on the continental slope or in the troughs; there stratified material replaces the limestone. The ?limestone is interbedded with stratified rocks; quiet periods probably alternated with conditions of stronger currents during which turbidite deposition was possible.

The sinuous band of hummocky relief on the sea-floor may represent the path of a submarine current which has brought water from the warmer upper layers into deep water. It begins in the north at about 9°S, which is also the northern limit of reef growth on the shelf. This may account for the general increase in intensity of disturbance around the relief feature. Alternatively the feature may represent a large-scale slump or turbidite flow. Beginning on the continental slope, a turbidite avalanche may have run down to the smooth floor near Eastern Fields where it would eventually come to rest. Such an event may be expected in view of the large quantity of potential turbidite material emanating from the Fly River.

Province III — Eastern Fields Fan and Portlock Trough

This province coincides with the morphologic units of fan and trough, but also includes the continental slope east of Torres Strait. The importance of the fan in the overall tectonic scheme, and certain clues to the origin of the trough, are most evident from their seismic characteristics.

The Eastern Fields Fan occupies an area of nearly 50 000 km^2, and over most of this area its subsurface is characterized by a strong unconformity at an average depth of about 500 m (see also EE′, Plate 5). This horizon, hereafter referred to as the 'G' horizon, marks the limit of recognizable sedimentary character on the sections. It is virtually continuous over the whole fan, being traceable as a narrow band of reflectors for distances greater than 50 km. It cannot be recognized with certainty in any area other than below the fan.

Sediments above the unconformity fall into two categories: stratified and opaque. Over most of the area, the appearance of these sediments to the sparker, when the graphic display ran at 12 inches per hour, was opaque to weakly stratified. This is particularly so in the northeast of the province, where reflectors above the 'G' horizon are very difficult to recognize. In the second stage of the survey, when lines 17 to 32 were run, the recorder speed used was 3 inches per hour and sediments above the 'G' horizon were shown to be highly stratified, and the horizon itself appears simply to mark basement. The sediments of the fan are characteristically neither good nor poor reflectors. They are variable, but neither the disturbed type described in Province II nor the completely transparent sediments are observed.

On the 12-inch per hour record, opaque reflectors are most common, but toward the centre of the province sequences of stratified reflectors begin to appear. These generally form the lower layer immediately above the 'G' horizon, and a less stratified sequence forms the top layer. The stratified material does not form a fill as its surface is convex upward, approximately draped over the surface of the fan.

The surface of the fan itself often shows strong ripples. These have an average wavelength of 500 m and have relief up to 30 m. They are generally stronger on sloping surfaces but on the relatively flat central part of the fan the surface appears to have been deeply incised by channels. If all the ripples and minor indentations arise from the effects of bottom currents then these must certainly be strong and persistent; however, it is considered more likely that some of the effects are due to minor slumping.

No features in the 'G' surface can be seen to form a trap for sediments to accumulate, and the fan would seem to be open-ended and open-sided as an environment for deposition. Sediments drape over the 'G' surface rather than form a basin or accumulated fill. In fact, in its present-day morphology, any sediment accumulation on the fan apart from pelagic deposits is extremely unlikely. All material derived from the Papuan mainland would be deposited in the Pandora Basin or follow the submarine valley systems to the Coral Sea abyssal plain. Some material forming the fan's cover may have been derived from reefs; however, if the river systems of Papua are considered as the major source of sediment supply, then it would seem that the fan formed at a time when its fringing troughs did not exist. As stated above, the appearance of the fan is not unlike the deep-sea fans which form off the mouths of large rivers. These fans usually spill onto a flat surface approaching abyssal depths, e.g. the Rhone deep-sea fan in the Gulf of Lyon (Menard et al., 1965). The environment does not exist today for the creation of a deep-sea fan in the Gulf of Papua, but it may have done so in the past before the Coral Sea Basin was formed.

The 'G' horizon surface dips strongly to the south and southeast and is disturbed by faulting from its centre to the west toward the Portlock Trough. Faulting has formed a horst in the 'G' surface and perhaps at a deeper level; the intensity of the disturbance increases toward the west (Plate 3). Everywhere except close to the reefs, only very weak reflectors can be seen below the horizon surface. But as the reefs are approached, deeper reflectors can be seen and it is clear the 'G' surface is not at the top of igneous basement. All reflectors rise toward the reefs, and the deepest of these form the structure on which the reefs have grown. The deepest continuous reflector recognized near the reef has been interpreted as representing basement. It dips under the 'G' horizon away from the reef but appears to be close to it in other areas. The distinction between basement and the 'G' horizon is not always obvious, and they appear to coincide in many places. The form of the 'G' horizon at the boundary of the fan varies around the margin and is of some importance.

In the north of the fan the 'G' horizon simply disappears from the sections. It is present on one line, but 20 km farther north it is either very weak or completely absent. No north-south lines were run in the region, so the nature of the termination is not clear; hence the questioned line in Plate 3. In the east it dips under the stratified section and under the Moresby Canyon. In the canyon region it is at great depth and amid spurious reflectors caused by steep gradients in the canyon, so it cannot be recognized on the sections. In the south it follows the topography of the fan, i.e. it does not dip with respect to the fan's surface. However, when the Bligh Canyon is reached, the horizon is again lost from the sections.

The horizon cannot be seen in the Portlock Trough (see also DD′, Plate 5). Sediments bordering the trough are the continental slope sediments of the Torres Strait continental slope in the west and the two-layer sequence (upper opaque, lower stratified above 'G' surface) in the east. Within the trough, sediments are crumpled near the surface and become stratified and more evenly bedded lower in the section. On the continental slope a shallow fault can be seen, below which is a section of near-surface crumpled material apparently formed as slump deposits resulting from the fault. It is likely that the sediments in the trough are also partly slump deposits. This possibility is reinforced by the fact that crumpled sediments were not found on all crossings of the trough. The upper opaque layer on the eastern side terminates at the edge of the trough, and is not found on its western side. There is some evidence that a much deeper trough may have existed in the past; deeper reflectors form a trough-like depression which has apparently been filled with stratified material. Faults in the deep, older material can be seen on the eastern flank of the trough.

Some clues to the formation of the present-day morphology of the region are available from a study of the seismic sections, and a sequence of events can be distinguished in part. Apparently a superficial wedge of material derived from the Papuan mainland was deposited over a subsiding surface which is now marked by the 'G' horizon. In all likelihood this occurred at a time when neither the Portlock Trough nor the Moresby Trough existed, as it would seem virtually impossible to produce a fan under present conditions. The Portlock Trough postdates the fan. It formed by tectonic movement and was further incised by erosion, but is today filling and receiving slump deposits. Formation of the trough terminated deposition on the fan apart from the influence of reef-derived deposits and pelagic sediments.

Province IV — Papuan Plateau

The Papuan Plateau has not been extensively covered, either by this survey or by previous work. Several authors have speculated as to its origin (Krause, 1967; Ewing, Houtz & Ludwig, 1970) but no conclusive results are available. The results of this survey, although more detailed than any previous work, have not yielded much additional information regarding the history of the area, so the appearance of plateau sediments will be described briefly and the analyis left at that.

The surface of the plateau east of 148°30′ is generally smoother than that of the Eastern Fields Fan and is underlain by more than 1 km of well stratified sediment (see also GG′ and HH′, Plate 5). The limit of sedimentary material is clearly marked by an abrupt change from stratified to weak reflectors. The base of sediments may represent the top of basement material, but no proof of this exists. Neither the base of the sedimentary column nor sediments within the column form flat-lying reflectors. The 'basement' is rugged and uneven.

Two lines (21 and 23) cross the southern edge of the plateau, and one (22) runs parallel to it, part way down to the abyssal plain. On these three lines the plateau surface begins to take on the rippled character of the Eastern Fields Fan. The ripples die out as the plateau proper is reached. Apparently these ripples arise in a similar way to those of the fan: from the combined effects of slumping and bottom currents.

Ewing, Houtz & Ludwig (1970) have suggested that the plateau formed by a damming of sediments behind a basement ridge, which filled to overflowing. Although our traversing is not detailed or extensive, no such structure could be identified and it is suggested that the ridge described by these authors is not a striking or characteristic feature of the plateau's subsurface.

Province V — Moresby Canyon

This province lies between the Eastern Fields Fan and the Papuan Plateau and south of Province II, but in the south it is open-ended. It is dominated by the Moresby Canyon and the slopes each side of the Canyon.

Only two crossings of the canyon were made in the course of the survey, but on both occasions the following was observed: the 'G' horizon of the Eastern Fields Fan begins to dip steeply downward at the same place as the Fan's surface began to slope toward the canyon and show ripple marks (see also EE′, Plate 5). It dips steeply near the canyon and is lost from the record. From the Papuan Plateau side a similar situation occurs; the reflector marking the base of sedimentation dips strongly in the vicinity of the canyon and cannot be recognized below it, i.e. the deepest reflectors do not appear to be continuous below the canyon. On the other hand, reflectors at a depth of about 500 milli-seconds below the canyon floor are continuous and very nearly flat. Disregarding the canyon itself, sediments form into a large synclinal shape between structural rises which form the edges of the Eastern Fields Fan and Papuan Plateau.

The Moresby Canyon is clearly an erosional feature. There is nothing to suggest that tectonic movements played any part in the shaping of the present-day feature, although the strongly dipping deep reflectors suggest that the structural framework of the site of the canyon may have been fault-controlled. On the more northerly of the two crossings, the canyon floor is very flat and roughly 3 km wide. The sides of the canyon extend below the canyon floor, and the first 400 m of subsurface is apparently material filling an older canyon.

The evidence available therefore suggests that the Moresby Canyon was once much deeper, incised into quite a thick sequence of sediments, but has since been partly filled. The thickness of sediment through which the canyon cuts approaches 2 km, and again it is difficult to understand how such a thickness could have accumulated under the present physiographic conditions. There is apparently no barrier structure to prevent sediment travelling directly to the Coral Sea Basin.

Province VI — Osprey Embayment

This is the last subdivision to be considered. It takes in all areas south of 12°S and thus includes several physiographic units. It covers the Osprey Embayment itself, the Osprey Basin which lies to the west, part of the continental slope of the Great Barrier Reef, and the extreme northwest corner of the Coral Sea Basin.

The embayment region is separated from the Eastern Fields Fan by the Bligh Canyon (Winterer, 1970). The canyon, or possibly tributaries of it, was crossed on four occasions and in each case it had a roughly similar appearance not unlike the northern part of the Moresby Canyon. It appears to be an erosional feature cut into older sediments and partly filled so that the canyon floor is now flat. The filling material appears stratified to the sparker, but the older section through which the trough cuts is poorly reflecting. A complete change in the style of the physiography occurs south of Bligh Canyon (see also HH′ Plate 5).

Here, and west of the Coral Sea Abyssal Plain, the region consists of both old, weakly reflecting material and newer, well stratified sequences. Stratified material generally forms a fill in depressions in the surface of older material. One such fill, in the extreme west—i.e. at the base of the slope off the Great Barrier Reef—has sediments up to 2 km thick and may legitimately be called a basin. It has been named the Osprey Basin. It is roughly in line with the Laura Basin onshore but owing to insufficient traversing a connexion cannot be established. Its source of sediment is similarly not clear. Certainly a great deal of sediment would be shed from the area of the reefs and farther south, but since the main source in the area is the Papuan mainland then a great deal of sediment within the basin was most likely derived from the north. A direct avenue for transport is available in the Portlock Trough.

The surface of the embayment is often marked by ripples. Its subsurface is nearly featureless. Some deep reflectors in the old sequence are always present but they are always weak and difficult to associate with any rock type. A probable basement reflector can be seen at depth but there are no striking reflectors such as the 'G' horizon. Magnetic anomalies show little relation to relief features in the surface, and it is apparent that basement is never close to the surface. Some weak expression of very large topographic features is present.

At the far east of the embayment an intrusion penetrates through the older sediments and is exposed above the surface of the sea-floor. Sediments on either side of the intrusion are crumpled. On the eastern side this is due to slumping as it lies at the top of a steep slope, but on the western side crumpling occurs on a shallow slope and may have resulted from tectonism associated with intrusion of the dyke. The intrusion produces a 300-gamma magnetic anomaly from a water depth of 3000 m.

The intrusion lies just west of a steep scarp which leads to the floor of the Coral Sea abyssal plain. This scarp has formed in the older sediments, and the sediments of the abyssal plain abut them. On bathymetric grounds alone the scarp may be interpreted as a fault; this interpretation is confirmed by the seismic evidence, which shows that the plane of the scarp extends well below the sea-floor. Sediments of the abyssal plain form a generally flat-lying evenly-bedded sequence up to 2 km thick in the area surveyed.

The profiles

The profiles shown in Plates 4 and 5 are line drawings taken directly from the seismic records and projected onto a true longitude grid. It has been assumed that the lines were run at constant latitude. The plates illustrate some of the features described in the previous section and point to further aspects of the seismic results which were considered too difficult to describe from Plate 3.

Reflectors presented in the profiles are those most representative of the style of sediment deformation. The dip of the strata is shown to indicate general trends, and all major reflectors have been marked. Any spurious reflections (multiples, refractions, diffractions, etc.) recognized on the original sections were excluded from the profile drawing.

Profile AA′ is a typical traverse across the northern parts of the Moresby Trough and Western Shelf. From west to east the following features should be noted:

(a) The group of dipping reflectors, which is the only indication available of Miocene reef formation.

(b) East of the reefs a thick sequence of evenly bedded sediments dipping eastwards and a broad anticline just west of the shelf break.

(c) The upper part of the continental slope shows nicks in its surface, which are apparently channels cut by current action.

(d) The Moresby Trough. Folding in the trough is expressed in the bathymetry; anticlines are asymmetric and faulted on the west. The intensity of deformation increases to the east.

(e) The Mobile Zone shows folding and thrust-faulting. The structure at 146°20′ is of the type drilled by the Maiva No. 1 well (Phillips, 1965).

The sequence is entirely sedimentary material. Basement cannot be identified anywhere on this line; and magnetic anomalies testify to deep basement by showing little relation to any major features and being dominantly of long wavelength. There is little variation in strength of reflectors in the sequence encountered. The strongest reflection occurs over the Miocene reefs and as such expresses the only change in gross lithology (sandstone to limestone) in the region.

Profile BB′. Profile BB′ crosses the Western Shelf and Moresby Trough about 200 km south of AA′. The most important features that indicate a change from conditions farther north are as follows:

(a) Disturbed reflectors are characteristic.

(b) Stratified sediments appear only in the centre of the Moresby Trough and on the continental slope.

(c) Folding in the trough cannot be identified.

(d) In the east the mobile zone has been replaced by an area of rugged topography.

The cross-hatching has been used to indicate areas in which the dominant reflector is of the disturbed type. It has been shown as overlapping into areas of stratified reflectors to indicate that the change from one type to the other is not sudden. The effect seen on a typical seismic section is that of disturbed reflectors at first being found within a stratified sequence, then becoming more common until they dominate the record sections.

Reflectors which comprise the subsurface of the area of rugged topography are deformed. They cross each other and do not obviously relate to the present topography, but on other lines the larger structures show anticlinal forms.

Profile CC′. Profile CC′ shows the basic structure of the Pandora Basin and its relation to the Eastern Fields structure. The following points are of note:

(a) The level of sediment fill in the Pandora Basin is some 400 m above the general level of the Moresby Trough.

(b) The two-layer sequence in the basin.

(c) The turn-up of the upper sequence of sediments against the Eastern Fields structure.

(d) The interbedding of disturbed and stratified reflectors in the trough as in BB′.

(e) The basement structure underlying the basin and adjoining reef.

The accompanying magnetic anomaly profile shows that the value of anomaly rises to a maximum of 100 gammas near the reefs and drops off on either side. This is taken as confirmatory evidence that the reflector marked as basement does, in fact, lie at or near the top of igneous material.

Profile DD′. Profile DD′ crosses the Portlock (or Bligh) Trough at its northern end. In quality of seismic recording this traverse was inferior to the rest of the survey. It was taken under particularly rough sea conditions. However, this line is of specific interest as it shows the following:

(a) The upper 400 milliseconds of the Eastern Fields Fan is poorly reflecting (no reflectors marked), but this character does not extend into the trough or on its western side.

(b) Dipping reflectors on the east side of the trough indicate that a fault may control this margin.

(c) The trough is filled with piled-up material showing crumpled reflectors. The fill is apparently slump material.

Profile EE′. Profile EE′ is a long line which crosses the margins of both the Eastern Fields Fan and Papuan Plateau and shows their relation to the Moresby Canyon. The most important features seen on this crossing are the following:

(a) The 'G' horizon can be clearly identified as a strong reflector at the base of the sedimentary column on the eastern Fields Fan.

(b) Sediments on the Papuan Plateau are roughly twice as thick as those on Eastern Fields Fan.

(c) The base of sediments on the Papuan Plateau is marked by a clear horizon (possibly basement).

(d) Both horizons dip strongly below the Moresby Canyon and are lost from the sections. The deep structure below the canyon may therefore be fault-controlled.

(e) The Moresby Canyon is an erosional feature cut into a thick sequence of sediments.

(f) On either side of the canyon, at the margins of the fan and plateau, the horizon at the base of the sediments rises to form structural highs which may have controlled the location of the fan and plateau.

Profiles FF′ and GG′. Profiles FF′ and GG′ are oriented north-south; the first crosses the Bligh Canyon and Eastern Fields Fan and the second the Papuan Plateau.

Profile FF′ is the only usable north-south crossing of the Eastern Fields Fan. The original record is of poor quality, but nevertheless the section demonstrates that the Bligh Canyon is asymmetric in profile and is an erosional feature similar to the Moresby Canyon. The canyon floor has a sediment fill and its sides extend below bottom. The surface of the Eastern Fields Fan shows the characteristic ripples observed on east-west lines. The subsurface here appears to be poorly reflecting, but this may be due to poor record quality. The 'G' horizon can only just be recognized and apparently dips strongly under the canyon and may be fault affected.

Profile GG′ is similar in subsurface aspect to the eastern part of EE′, but also demonstrates how ripple marks begin to appear on the sloping margin of the plateau. No major basement ridge which could act as a sediment dam can be seen at the edge.

Profile HH′. Profile HH′ is a typical crossing of the southern part of the area. It crosses the Osprey Basin in the west, the embayment region, and onto the Coral Sea Abyssal Plain in the east. The following features are presented and are characteristic of areas south of 12°S.

(a) Two types of sediment which are different in acoustic character: a newer sequence of stratified sediments and an older sequence of poorly reflecting sediments.

(b) The older sequence always forms the bathymetric highs; the younger sediments form the fill in bathymetric lows.

(c) The descent to the Coral Sea abyssal plain is very steep and apparently fault-controlled.

(d) Abyssal plain sediments show only slight dip to the east.

Magnetic profiles are very smooth and of low amplitude in the west, but in the area of the intrusion at the edge of the abyssal plain anomaly values rise to 300 gammas. The source of the anomalies is certainly intrusions and sharp basement drop-off associated with faulting along the margin of the abyssal plain.

5. GRAVITY RESULTS AND INTERPRETATION

Interpretation of the variation in the gravity field is based on a study of both free-air and Bouguer anomalies. Results are illustrated in Plates 6-8. The aim of the interpretation was firstly to extract information about the depth and topography of the crust/mantle density interface, and secondly to determine thickness of sediment and basement topography where these were not directly available from the seismic evidence.

In the marine environment, the Bouguer anomaly is computed by adding to the free-air anomaly the attraction which would be produced in a plane slab model if the water were replaced with material of density equal to that of the material lying immediately below the water layer (taken to be 2.2 g/cm^3). This procedure aims to eliminate the gravity effect of the water/sediment interface. The Bouguer anomaly should therefore be related to the topography of the crust/mantle interface and the sediment/crust interface (i.e. basement topography). However, because a water depth correction is inherent in the reduction to a Bouguer anomaly, the contoured anomaly maps generally show a strong correlation with bathymetry. As the reduction is made on the assumption that an infinite slab of material replacing the water layer is a good approximation to the real situation, some spurious effects may also result on continental slopes or sharp-gradient features such as seamounts and guyots.

The free-air anomaly produced by simply removing the latitude variation from the observed gravity and adjusting for the Eotvos effect, although generally showing some correlation with water depth, is not subject to spurious effects introduced by the infinite-slab assumption. This anomaly contains no assumptions about the gravity effect of an included slab of material replacing the water, and was used for a preliminary study of the sediment distribution and upper crustal structures.

To study crust/mantle interface topography and sediment thickness, a simple modelling program was written. This computed, for a given depth to base of crust, the value of free-air anomaly for different distributions of water depth and sediment thickness (ranges of 0-4.9 km and 0-9.5 km respectively). The reference model is the standard continental crust consisting of 33 km of material of density 2.85 g/cm^3. In the variable crustal model all four layers — water (1.03), sediment (2.2), crust (2.85), mantle (3.3) — were considered as infinite slabs. Thus the model is correct only, as in the case of the Bouguer anomaly, when the infinite slab is a good approximation.

The choice of the standard crust is based on the work of St John (1967) and deep seismic refraction measurements from the Carpentaria Region Upper Mantle Project (CRUMP) (Finlayson, 1968), and Brooks & Ripper (1966). The standard continental crust is that which produces a zero Bouguer anomaly at sea level. At 9°05.3′S, 143°12.3′E, the CRUMP data indicated a depth to Moho of 35 km with a sediment cover of 4 km. In this region our results give a free-air anomaly of +30 milligals. This would correspond to a standard crust of 35.5 km. Brooks & Ripper (1966) have indicated that the crust is of continental thickness in a line from Port Moresby northwest to the coast of Western Australia, and that there is no great thinning of the crust north of Australia.

Brooks (1969), in studying Rayleigh waves in southern New Guinea, arrived at a model appropriate to the Gulf of Papua in which the Moho lay at a depth of 33 km and the deduced densities across the crust/mantle interface were 2.9/3.32 g/cm^3.

From a consideration of the above work and that of Bolt & Niazi (1964), and Santo (1963), St John (1967) decided on a standard crust 35 km thick — but conceded that a thickness of 30 km was in closer agreement with CRUMP data from Torres Strait.

Considering all the information now available it would seem that a 33-km crust is the most reasonable estimate and agrees with the measurements of Brooks (1969) in southern New Guinea, an area which is in approximate isostatic equilibrium.

The choice of densities used in the model is probably open to question. The value 2.85 g/cm^3 for the crust is a little less than the normally accepted value of 2.87 g/cm^3 used for continental areas, and should also be varied between continental and oceanic crustal regions. However, the interpretation aims at determining the regional topography of mantle and basement and not absolute depths. A density change of 0.02 g/cm³ produces a change in the determined depth to mantle that is insignificantly small and well within the errors of the method used.

The gravity data have been studied in two ways. First, qualitative interpretations of features and structural controls were made from an analysis of the contour maps, Plates 6 and 7. Secondly, these discussions are followed by the results of model studies of three profiles, shown in Plate 8.

Free-air Anomaly Contours

A pleasingly uncomplicated pattern is presented by the free-air anomalies (Plate 6). The most striking feature of the contours is a deep low associated with the Moresby Trough. Here the anomaly exceeds -100 milligals and is the most intense anomaly on the map; the greatest positive value is $+70$ milligals near the shelf edge. However, the total area producing positive anomalies is somewhat greater than that producing negative features, the average anomaly being approximately zero.

The anomalies have formed a pattern such that negative anomalies coincide with areas of thick sediment (identified on seismic sections) or trough features, and the positives with areas of relatively shallow bathymetry and thin sediment cover. Thus the Pandora Basin exhibits a negative anomaly branching off the Moresby Trough, and the entire area of the Eastern Fields Fan shows long-wavelength positive gravity features culminating in a 50-milligal high associated with Eastern Fields reefs.

For convenience of description the region has been informally divided into the following eight provinces. These provinces are not analogous to the gravity provinces described by various BMR authors from gravity surveys in Australia. Those latter provinces are based on Bouguer anomaly patterns, not free-air patterns.

Moresby Regional Low	named	after	Moresby Trough
Pandora Low	,,	,,	Pandora Basin
Eastern Fields High	,,	,,	Eastern Fields reef
Western Shelf Regional High	,,	,,	Western Shelf
Eastern Fields Fan Regional High	,,	,,	Eastern Fields Fan
Osprey Low	,,	,,	Osprey Basin
Osprey Province	,,	,,	Osprey Embayment
Papuan Plateau Province	,,	,,	Papuan Plateau

One can subdivide these provinces into smaller areas, but the larger divisions coincide with broad physiographic provinces and are therefore simpler to consider. Each of the provinces will be discussed in turn.

Moresby Regional Low

This deep depression associated with the Moresby Trough is the most pronounced feature of the contour map. The depression follows the line of the trough, parallel to the Papuan coast, is maintained as a negative feature on the continental slope where it is crossed at right angles by a positive nose originating from the western shelf, and joins a negative feature associated with the Aure

Trough on land (St John, 1967). The southern end of the depression is essentially open, but has weakened considerably at the point where the trend of the Papuan coast changes from southeast to approximately east. The main depression can be considered to end here.

The depression is asymmetric, having its deepest part on the landward side, in the same manner as the Moresby Trough itself; however, the deepest gravity low does not coincide with the deepest water along the length of the trough. Although a bathymetric low may be expected to produce a corresponding gravity low, the fact that there is incomplete correlation between bathymetric and gravity lows indicates a deeper control of the feature. A deep control is further indicated by the fact that the normal gravitational edge effect of the western continental shelf is present only as a weak nose crossing the general trend. Conversely, the edge effect of the Papuan coast has been accentuated. In this region the edge may be expected to produce an effect less than 40 milligals (see discussion of profile I, page 00) whereas the observed anomaly is more than 100 milligals. The southern termination of the depression in deep water (2500 m) is significant as it occurs in the same general area as a marked change of character in the sediments (Chapter 2) and is in line with a cross-trend in bathymetry, which appears to be associated with the basement rise that terminates the Pandora Basin in the south.

The existence of this marked elongated gravity low is interpreted as indicating that the Moresby Trough has a very thick sediment fill and that it is a further seaward extension of the Aure Trough. This, in fact, lends weight to the seismic interpretation, which pointed to the same conclusion. The southern limit of this sediment-filled trough is marked by the termination of the gravity depression associated with the cross-trend mentioned above, which appears to extend an influence across the entire breadth of the gulf and perhaps onto the Papuan Plateau.

Pandora Low

This feature is a southwest-trending tongue of the Moresby Regional Low. It can be directly associated with the Pandora Basin, the zero contour effectively defining the limit of the basin in the west and southwest. The −30 and −40 milligal contours are closed around the region where the thicker sediments were found on the seismic section.

This province is an example of how the gravity anomaly may be used to give information about sediment distribution. Fortunately the results of a sonobuoy refraction shot by a group from the Lamont-Doherty Geological Observatory (Ewing, Houtz & Ludwig, 1970) could be used as a control point from which the quantitative interpretation presented in profile form in Plate 8 was begun.

Eastern Fields High

This province consists of two separate closed gravity highs of 30 and 50 milligals; the lesser is situated directly over Eastern Fields reefs, the greater being southwest of them. It should be pointed out that no gravity readings have been made on the reefs, so the 30 milligal value is an extrapolation.

A positive anomaly associated with the reefs is a good indicator that positive structural control has influenced the location of reef building. The area of 'reef influence', i.e. shallow basement and reflection characteristics, is known from the seismic work to extend south of the exposed reefs and is expressed in the gravity by the larger closed anomaly. The fact that the two anomalies are not continuous would seem to indicate that the area of the reefs is associated with two structural highs — a broad feature with deep structural significance, and a sharper structure on which the modern reef complex is located.

Western Shelf Regional High

Northwest of Eastern Fields, the anomalies first dip into the Pandora Low, then rise across the continental slope to form an area of large positive anomalies (up to 70 milligals) on the shelf margin, before dropping to lower values (20 milligals) as the Papuan coast is neared.

One can anticipate this behaviour from the known gravitational edge effect produced by the continental slope in association with a thinning of the crust. In this case, however, the edge effect has been perturbed so as to increase the amplitude of the anomaly by the existence of the Pandora Basin, which flanks the lower continental slope, and by structural influences below the shelf.

The existence of structural influences on the Western Shelf is known from previous work. The Miocene reefs so characteristic of the Shelf region are known to have structural control (Phillips, 1965). The edge of the shelf west of the Pandora Basin is marked by the Ashmore and Portlock Reefs, and the western basin edge has been seen from seismic evidence to be structurally controlled. The modern reefs themselves have had an undoubted influence on the shaping of the shelf, as is demonstrated by the change in gradient of the continental slope in their vicinity.

The Western Shelf Regional High has thus been formed by two influences — the normal gravitational edge effect and positive structures underlying the shelf. Its existence is taken to indicate that the structure on which Ashmore and Portlock Reefs are located, and which has strongly influenced the morphology of the shelf margin, extends farther northeast under the shelf and perhaps influences the shaping of the shelf in the past. Unfortunately, owing to severe ringing and other problems that arise in shallow water, no direct confirmatory evidence is available for this interpretation from the unprocessed seismic results.

Eastern Fields Fan Regional High

This large area of positive anomalies is very similar in shape to the Eastern Fields Fan itself. The free-air anomaly value ranges from zero (this contour forming the eastern boundary of the province) to 60 milligals in the centre of the province. The anomalies are long-wavelength features of relatively low amplitude which testify to the relatively uniform geology of the fan.

In terms of sediment distribution and thickness, and assuming that no extraordinary behaviour of the crust/mantle interface occurs under the fan, the free-air anomalies indicate that the sedimentary cover on the fan is thin. In approximately the same depth of water (1500 m), the Pandora Basin has produced a deep negative feature. The sediment fill of the basin is roughly twice that of the fan and hence the fan produces a weakly positive feature; owing to its large areal extent these anomalies show long wavelengths.

An alternative explanation for positive free-air anomalies can also be advanced. Since the fan is a large physiographic feature it may be expected to be isostatically compensated. Lack of compensation may be reflected in the free-air anomalies. In the case of the fan, the anomaly is positive and this would indicate that it is 'riding too high' on the mantle. To reach equilibrium and reduce the anomaly to zero it is necessary that the fan subside by about 500 m.

Osprey Low

The province covers the Portlock Trough and Osprey Basin. It is roughly triangular and extends in a general north-south direction. Although named a low because the free-air anomaly values are generally negative, the province includes areas of positive anomaly as these lie within the geological-physiographic region in which the gravity values are dominantly low.

Although the Portlock (or Bligh) Trough is an abrupt bathymetric depression it does not produce a similarly abrupt gravity depression. The maximum anomaly is —20 milligals at the southern extremity of the trough in 3000 m of water, but the deepest minimum value in the province (—40 milligals) is found in a similar depth of water in the Osprey Basin. That no simple relation can be detected between bathymetric and gravity depressions implies that sediment distribution and deep crustal features contribute substantially to the gravity anomaly. Their influence is best illustrated in the profiles shown in Plate 8, but the association of negative anomaly with thick sediments is clear from the contours.

The 30-milligal closed positive anomaly included in this province noses southward from the embayment region. It is the expression of a similar bathymetric feature which rises from the embayment. From seismic evidence it appears to have only a thin cover of newer sediments. The bathymetric feature is very localized and cannot be expected to be compensated at depth. The anomaly arises entirely from topographic effects. It has been included in this province as it corresponds to a feature that forms part of the Osprey Basin margin.

Osprey Province

The boundaries of this province are less well defined than the others, and it is open on its eastern and southern sides. It contains both positive and negative anomalies, with conflicting trends. Anomaly values range from +40 to —10 milligals. Several contours form large closed anomalies, but no features in the anomaly pattern suggest any localized geological anomalies.

The gross bathymetric trends show expression in the gravity anomalies; thus the east-west trend that crosses the embayment is seen in a somewhat filtered version in the gravity pattern, and the northwest-trending scarp in the east appears as a gravity low of identical trend. This low is displaced slightly to the east of the scarp; i.e. it flanks the scarp and lies largely on the Coral Sea abyssal plain. This would indicate that the gravity low may originate from the gravitational edge effect, but it is possibly influenced by intrusions associated with the scarp.

The area between the scarp and the Osprey Basin is characterized by positive anomalies, which decrease in wavelength to the south and change trend from roughly east to north with decrease in wavelength. This area is complex in bathymetry and seismic character and is difficult to understand from a study of its gravity picture alone. It is certainly quite unlike any other area of the gulf region.

An interesting fact is that the Coral Sea abyssal plain produces positive anomalies of up to +20 milligals. The plain is known to have a thick sediment cover (often referred to as the Coral Sea Basin), and in order to explain the positive anomaly a considerable amount of crustal thinning east of the embayment is required. This then marks the transition zone from continental to oceanic crust, and is important to a regional study. The variation of crustal thickness is better illustrated in the profiles of Plate 8.

Papuan Plateau Province

The plateau itself was not detailed by the survey, and any comment on its gravity picture must of necessity be very superficial. One observes that the anomaly value decreases from almost zero near the coast to around —30 milligals when the plateau surface is reached. This may indicate that thick sediments lie on the plateau, but little more can be said as crustal thickness is very uncertain in this region.

Remaining areas

One region of the map has been left unnamed. It lies on the continental slope of Torres Strait and is characterized by positive anomalies of shallow gradient. The gradient of the continental slope is very shallow here and has not produced the normal edge effect. The base of the slope is occupied by the saddle between the Pandora Basin and the Portlock (or Bligh) Trough, which coincides with a positive feature. The continental slope in fact forms the western flank of the Portlock Trough. In the region of the saddle, small closed anomalies are seen. These are by no means strong, but may indicate that the saddle is situated over a positive structure; i.e. they may be an expression of the basement rise seen on the seismic sections at the southern end of the Pandora Basin.

Bouguer Anomaly Contours

The Bouguer anomalies (Plate 7) do not form as simple a pattern as do the free-air anomalies. Although they show a general correlation with water depth (increased depth produces larger anomaly values) the relation is by no means a simple, first-order one. The pattern of contours is obviously disturbed by local geological features.

The region has not been divided into Bouguer anomaly provinces but will be discussed in a general sense, and any correlation between free-air and Bouguer features will be noted.

If the effect of the density contrast at the water/sediment boundary has been successfully eliminated, the primary factor influencing the Bouguer anomaly pattern in an area of uniform surface geology should be variation in the depth of the crust/mantle interface. In this region we can detect three major changes in the depth to the base of the crust. The first, shown in Plate 7 by a sharp gradient, occurs off the coast of Papua in a continuous zone from around 10°00′S, parallel to the Papuan coast, to 8°30′, where it swings west, then southwest at 144°30′ to the edge of the map. It is in approximately the same position as the continental slope off Port Moresby, but is somewhat north of it elsewhere and by no means mirrors the slope. Between this line of steep gradients and 12°00′S, although relief features exist, the change in absolute anomaly value in that distance is roughly the same as that of the initial change over the continental slope. Changes in depth to the crust/mantle interface are thus rather gradual. The second major change occurs at approximately 12°S where the anomaly value rises from +110 to +160 milligals in the south and west before smoothing out on the embayment. The third change is over the scarp in the east of the embayment region, where an anomaly value of +230 milligals is reached on the abyssal plain.

In crossing the continental slope in an oceanward direction, one usually expects to find a transition in crustal type from continental to oceanic. The transition may be interrupted by a region of subcontinental material such as the Queensland Plateau (Ewing, Hawkins & Ludwig, 1970), i.e. there may be two transition zones. In this region, however, three zones can be detected. From the profiles of Plate 8 we see that an oceanic section is not encountered until the Coral Sea abyssal plain is reached. The material between the first and third transitions, then, is intermediate between continental and oceanic in thickness.

It is suggested that the first zone represents the transition from true continental to a subcontinental block similar to the Queensland Plateau, that the second is the transition from a subcontinental to suboceanic block, and that the third represents the transition from suboceanic to oceanic; the sections may be defined in terms of crustal thickness as:

continental	35 to 25 kilometres
subcontinental	25 to 20 kilometres
suboceanic	20 to 15 kilometres
oceanic	less than 15 kilometres

Superimposed on the broad trends are those features which may be attributed to local geological, i.e. upper crustal, features. The Pandora Trough is expressed as a south-trending relative low nose. That this feature has persisted as a low through both free-air and Bouguer reduction testifies to its basinal nature. Eastern Fields show as a north-trending positive with an anomaly of 100 milligals in the region where the reefs break water. Part of this anomaly can be attributed to topographic effects, but it also indicates that basement is very near the surface. The free-air anomaly named the Western Shelf Regional High is seen again as a group of closed anomalies landward of the continental slope, and is interpreted as reflecting structural influences at depth below the shelf as was deduced from the free-air anomalies. The Portlock Trough is not seen, indicating that the Bouguer reduction has been successful in removing the horizontal density contrast produced by this feature and that it is too small to be compensated by a lower crustal inverse feature. North of the trough, however, a north-trending relative high flanks the continental slope in the region of Claudine and Mary and Boot Reefs (Plate 2). This high is at about the same longitude and trends in the same direction as the trough, and may indicate that the structural rises associated with modern reef development on the shelf edge and with the Portlock Trough are two features in sympathy. Again, the southern termination of the Moresby Trough is expressed as a group of closed contours and is believed to be associated with the basement rise cross-trend noted in the discussion of free-air anomalies. Neither the Portlock Basin nor any feature of the Osprey Embayment has any marked expression in the Bouguer anomaly. Similarly, little can be said about the Papuan Plateau.

PROFILES (PLATE 8)

Profile I. Profile I shows the crustral structure under the stable Western Shelf and the Aure-Moresby Trough. The interpretation of crustal structure made here is considered to be the extreme case. It is shown as such to indicate that thickening of sediments and thinning of crust occur under the trough, but it may not be as extreme as shown—sediment thickness not being accurately known. Under the Western Shelf the crustal section approaches continental thickness, and a control point for the profile is available here from the Carpentaria Region Upper Mantle Project's shot number 10 (Finlayson, 1968). This indicated 4 km of sediments with 35 km to the crust/mantle interface at a point approximately 20 km west of the western end of the profile. Results from the gravity study are therefore in reasonable agreement. The eastern side of the profile is much less precise; the rapid thickening of the crust shown in Plate 8 is assumed to take place under New Guinea, but depths here are not accurate.

The uncertain nature of the eastern end of this profile creates a fundamental problem. The normal continental edge effect of crustal thinning under the continental slope can produce anomalies on the seaward side of the slope of as much as -100 milligals. This 'edge effect' requires no thickening of sediments in the trough. The profile shown does not include the shelf area or any part of southeast Papua. However, it is not unreasonable to assume that the crust thickens rapidly under the peninsula to become of continental thickness. The 2 km drop to the floor of the Moresby Trough occurs in about 25 km, and thus an edge effect of approximately 40 milligals may be anticipated.

If the crustal thinning shown on the profile is assumed correct then approximately 2 km of sediment must be removed from the trough to accommodate the edge effect. The trough fill remains very thick, nevertheless.

Profile II. Profile II shows the structural setting of the Pandora Basin. On its eastern side, a structural high associated with the Eastern Fields reefs forms a barrier for sediment deposited in the basin. The western flank is formed by a steep rise in the basement toward the Boot Reef complex. It is notable that no variation at the base of the crust is required for this interpretation, indicating that the Basin is a relatively minor upper crustal feature. Sediment thickening and crustal thinning can be interpreted east of the Eastern Fields structure.

Again the continental edge effect is evident. Its effect is to increase the amount of sediment over the thickness computed without taking the edge into consideration. That is, the thicknesses of sediments shown in Plate 8 are too great in areas where the edge effect is significant.

Profile III. Profile III crosses the Osprey Basin and Embayment and extends onto the Coral Sea Basin. Sediment thickness used for this profile were almost entirely available from the seismic sections (assuming velocity 2.0 km/s) so that the 2.85/3.30 interface is the only interpretation shown.

Again, the area of thickest sediments in the Osprey Basin is accompanied by crustal thinning. Average crustal thickness on the embayment is 17.5 km (i.e. suboceanic). Crustal thinning is rapid in the Coral Sea Basin, and the crust diminishes to oceanic thickness at the eastern end of the profile.

6. MAGNETIC RESULTS AND INTERPRETATION

Introduction

The magnetic results are presented in two forms: contours of residual total magnetic intensity (Plate 9) plus hourly values of the intensity to accompany the seismic profiles (Plate 4 and 5). The values plotted have been corrected by removing the regional pattern and the diurnal variation monitored at Port Moresby. The International Geomagnetic Reference Field was used for the regional corrections.

The primary aim of the interpretation has been to use the magnetic profiles to complement the seismic interpretation, especially to aid in the identification of basement. The contours have also been examined as a source of information on depth to magnetic basement. In all cases it has been assumed that the source of the anomalies is an induced-magnetized crystalline basement, and that the susceptibility contrast between basement and sediment is constant throughout the area. Positive and negative features are attributed only to magnetic basement topography; remanent magnetization has not been considered.

The age of the magnetic basement rock is not known precisely. A sonobuoy shot in the Pandora Basin (Ewing, Houtz & Ludwig, 1970) found an acoustic basement of velocity 5.9 km/s. The same group found 'continental type velocities' (5.9 to 6.3 km/s) for the acoustic basement below the Queensland Plateau, and attributed them to rock of 'Palaeozoic and/or Precambrian' age. Sedimentation in the Papuan region has continued from at least late Mesozoic although the record is incomplete owing to a deep Tertiary cover (Thompson, 1967). It will therefore be assumed that the source of the magnetic anomalies is a crystalline pre-Mesozoic basement. It may, in fact, be much older, but there is no evidence to support this.

The northern part of the area surveyed (north of 9°S) was covered by an airborne magnetometer survey conducted by C.G.G. for BMR in 1967 (BMR, 1969). Flight altitude was 4000 feet and the flight-lines formed a regular grid with 9.2 by 19.2 kilometre sides. The authors of the C.G.G. report concluded that the survey 'clearly outlined' the Papuan Basin 'with the exception of its eastern boundary'. The area is typified by long-wavelength, low-intensity anomalies which lead to basement depth estimates of 20 to 30 thousand feet (6000-9000 m) generally throughout the northern half of the area surveyed. One major closed structure just south of the location of Pasca No. 1 (Fig. 3) forms a local high of nearly 3000 m relief. This structure (structure A4) was said by the authors to be 'especially interesting for oil research'.

The contours

The magnetic values vary from +275 gammas to −100 gammas. This is a very small range compared with 3000 gammas in the Bismarck Sea (Wilcox, in prep.) and 800 gammas in the southeast Papua area (Tilbury, in prep.). The quietness of the magnetics is taken to indicate a lack of shallow magnetic basement areas — i.e. the presence of generally thick sediments — and a lack of volcanism. The contour map shows isolated anomalies superimposed on a slowly varying background. For this reason the region has not been divided into provinces, but individual anomalies have been numbered (Plate 9). Each of these will be discussed in turn, and then the pattern of background variation will be treated.

Anomaly No. 1

Anomaly No. 1 consists of three local highs marked (a), (b), and (c). These are associated with Eastern Fields (see also seismic profile) although none of the three anomalies lies over the reefs — (a) is to the south, (b) to the east, (c) to the west. The maximum anomaly is +140 gammas at (b), where the water depth is between 2000 and 2500 metres; (a) and (c) are in 1500 to 1000 metres of water and have maximum values of +100 and +75 respectively.

Very little is known about Eastern Fields. Its morphology is uncertain because its southwest extent is unmapped. Its profile is characteristic of a platform reef of the type common on the Queensland Plateau. That it is built on a basement high appears certain from the results of this survey; that it has been subjected to subsidence is indicated by the fact that reef material is present at depths well below the ecological limit of reef growth, but its detailed structure and history remains unknown.

These anomalies are interpreted as indicating that magnetic basement is very shallow in the vicinity of Eastern Fields. This reinforces both the seismic and gravity interpretations, which pointed to the same conclusion. The large area occupied by the positive anomalies would indicate that the area of shallow basement is not confined to that of the exposed reefs, but extends for a considerable distance around it.

Anomaly No. 2

Anomaly No. 2 is a very clear dipolar anomaly with its positive and more intense half to the north. It is asymmetric (+275 and −100 gammas) and lies just south of Claudine and Mary Reefs, the positive half actually covering the southern end of these reefs. The negative half lies on the continental slope of Torres Strait. Although intense, it does not coincide closely with features in either of the gravity anomaly contours. It may be associated with the Bouguer anomaly feature that was attributed to structural influences controlling the position of the shelf edge, but a relation is by no means clear.

South of the Claudine and Mary Reefs, the seismic sections have revealed a sharp basement rise trending toward the reefs (Plate 3). The source of the magnetic anomaly is attributed to this feature. Such an anomaly may be produced when a body of high susceptibility is inductively magnetized by the local magnetic field. If the material from which the anomaly arises can be considered as a block forming a relief feature above the general basement level, the anomaly will be dipolar and have its positive half toward the equator.

The source of the anomaly, therefore, is interpreted as being the southern end of the structure on which the Claudine and Mary Reefs have grown. It is assumed to be a magnetic basement ridge which has exerted an influence on the position of the shelf edge.

Anomaly No. 3

Anomaly No. 3 is an east-trending negative anomaly which separates the dipolar anomaly (No. 2) from those of the Papuan continental shelf. It reaches a low value of —100 gammas — the lowest found on the map. The anomaly lies over the Pandora Passage, a deep-water passage between Ashmore and Boot Reefs. The deepest part of the anomaly is in 1500 metres of water at the base of the continental slope of Ashmore Reef.

This anomaly is interpreted as reflecting the magnetic basement topography between the reefs. An east-trending trough, possibly a valley in the pre-Mesozoic landscape, formed the structural setting that has resulted in the present-day reefs being separated by a deep-water passage. If Pandora Passage (Plate 3) were simply a canyon excavated out of shelf sediments no magnetic anomaly would result.

It is of interest to note that Pandora Passage shows a free-air anomaly nose pushing northwest from the Pandora Basin, but no similar Bouguer anomaly feature. The free-air anomaly is a direct result of the topographic relief of the Passage, and the absence of a Bouguer feature would indicate that there is no local compensation effect. This would be expected for such a small feature.

Anomalies No. 4 and 5

Anomalies No. 4 and 5 are two closed positive anomalies, each of 75-gamma amplitude. Anomaly 4 lies on the continental shelf but No. 5 is entirely within the continental slope due east of No. 4. Both lie immediately north of Pandora Passage. This corresponds roughly to the region defined as the Western Shelf Regional High in the discussion of free-air anomalies.

The seismic section provides no direct evidence of the origin of these features, owing to the problems of shooting in shallow water, so one is left with indirect methods. It seems a reasonable hypothesis that the free-air, Bouguer, and magnetic highs associated with the Western Shelf are related. That both potential fields produce positive anomalies in the same region is interpreted as indicating that positive structural influences have controlled the formation of the shelf edge. As none of the anomalies are abrupt features they must originate from a broad, deep-seated structure which today only weakly influences shelf building, but which may have been the primary controlling factor that determined the position of the continental slope.

In addition, if anomalies 4 and 5 are taken together with anomaly 3, they define a dipole pattern which suggests that the Pandora Passage may be faulted on its northern margin.

Anomaly No. 6

Anomaly No. 6 is another closed positive anomaly of 75-gamma amplitudes, this time located in 2400 metres of water toward the southern end of the Moresby Trough. Again it is in the same general area as relatively positive free-air and Bouguer anomalies.

It has not been possible to definitely identify basement anywhere in the Moresby Trough. The gravity evidence was interpreted as indicating a great thickness of sediment which thinned out considerably by 10°30′S. The positive magnetic anomaly is at approximately 10°15′S and is interpreted as expressing the thinning of sediments caused by a basement rise.

Anomalies No. 7, 8, and 9

Anomalies No. 7, 8, and 9 have been grouped together because of their similarity of shape. Anomalies 7 and 8 lie on the southern margin of the Eastern Fields Fan and anomaly 9 is on the southern end of the Portlock Trough. None of the anomalies are the expression of physiographic features. No gravity feature can be associated with anomalies 7 and 8, but 9 is located on a gradient in the free-air anomaly contours on the eastern side of the Osprey Low.

There is apparently no seismic expression of any of the three anomalies. If semi-infinite dyke models are assumed, depth estimates arrived at for each anomaly are greater than 3.5 km, which is below the limit of seismic penetration in this area.

Alternatively it is suggested that anomaly 9 arises from a sharp dip in the basement at the margin of the Osprey Basin/Portlock Trough system, and that 7 and 8 arise from deep intrusive bodies. These intrusions are assumed to have been injected along faults in the Eastern Fields Fan basement layer. The fan is essentially a complete, relatively stable unit, devoid of large faults in its interior. It is suggested that the intrusions occurred along minor faulting of insufficient severity for injection to reach the surface.

Anomaly No. 10

Anomaly No. 10 is a large positive anomaly trending north-northwest at the eastern edge of the Osprey Embayment. It coincides exactly with the scarp shown on the bathymetric map, and has a maximum amplitude of 275 gammas. The southern extent of the anomaly is not defined on the map.

On line 14, in the immediate vicinity of the maximum of this anomaly, an intrusion can be clearly identified on the seismic section. It is therefore not unreasonable to assume that the greater part of the amplitude of this feature can be attributed to intrusive material. The intrusion is just west of the steep scarp shown in Plate 2. The relation between scarp formation and intrusion is clear.

The scarp is considered to be important; its formation was certainly violent and is the only example of major tectonism observed in the area. Gravity evidence indicated that the scarp marks the transition zone from suboceanic to oceanic crustal material and is subparallel to the Aure-Moresby Trough. It is the only feature resulting from tectonism which has both physiographic and magnetic expressions.

Anomalies No. 11 and 12

These two anomalies lie near the southeastern margin of the Eastern Fields Fan; anomaly 12 lies on the region where the Fan surface changes gradient (see bathymetric profile P2, Fig. 4). Both anomalies are similar in trend to the local physiographic features, which also are associated with a similar elongated free-air anomaly. The free-air anomaly actually lies between the two magnetic anomalies.

In the discussion of seismic results it was noted that sediments on the Fan constitute a drape structure rather than an accumulated fill. No evidence was found for any structure that could act to dam the sediments.

However, the easiest interpretation that can be placed on anomaly 12 (under the assumptions of this discussion) is that it results from a basement ridge underlying the margin of the Fan. Depth estimates using a combination of the methods of Peters (1949) and Vacquier et al. (1951) give very large depths (greater than 10 km), so a simple ridge model is certainly not applicable. Thus all lines of evidence available suggest that no basement ridge exists under the Eastern Fields Fan.

Alternatively anomaly 12 together with the negative feature south of it may be the expression of downwarping of the basement toward the Coral Sea Basin. This behaviour can be observed on the seismic sections and is considered to be the most plausible explanation.

Anomalies No. 13

These are the Papuan Plateau anomalies. Values range from +100 to —100 gammas, and some steep gradients are present. The anomalies do not appear to reflect 'basement' topography observable from the seismic results.

Two conflicting magnetic trends are present: one subparallel to the Papuan coast near Port Moresby, and the other at right angles to the first, trending off the coast of southeast Papua. The former trend arises from within the plateau; i.e. it does not reflect behaviour at the margin. The latter crosses the slope and ends just on the plateau surface. In addition it conflicts with the dominant structural grains of southeast Papua.

No direct evidence for these anomalies is available. Free-air and Bouguer anomalies do not show a similar pattern, and no assistance is available from the known onshore geology of southeast Papua.

It is suggested that these anomalies are related to those on the opposite side of the Coral Sea Basin, i.e. anomaly 10. It will be proposed in the final discussion that these two areas were once close together and that the tectonic events responsible for the anomaly pattern occurred just prior to the separation.

The background variations

The background variations are considered to arise from the broad basement structure on which the numbered anomalies express the local geological features. These variations are of long wavelength, and have an amplitude ranging only from +75 to —75 gammas. The background is divided into two regions: one north of Eastern Fields and the other south of it.

North of Eastern Fields the background forms a southeast-trending feature containing both positive and negative values. The trend begins offshore in the vicinity of Port Moresby and extends across the Moresby Trough and onto the continental shelf just north of Portlock Reef. It does not trend in the same direction as the Aure-Moresby Trough, but takes in the area of the Pasca wells (Phillips, 1965), where the anomaly is positive (+25 gammas). In trend it is closer to that of the Omati Trough (Thompson, 1965, and Fig. 2) than to the Aure-Moresby Trough.

Such a large low-amplitude anomaly is difficult to interpret. In gross shape and trend it approximates to the dominant structural grain of the region. It extends only to 9°45'S, and this may indicate a change in the tectonic style south of this latitude.

The background field, or regional, in this area agrees quite closely with the contour maps given in the 1967 C.G.G. survey report (BMR, 1969). Hourly-value contours, however, suppress the shorter wavelengths mapped by C.G.G. and the interesting anomalies from which the 'structure A4' was delineated cannot be recognized in results of the subject survey. The amplitude and trend of long-wavelength anomalies agrees very well with the airborne work.

South of Eastern Fields the background appears to lack any simple trend. In the region of the Eastern Fields Fan the anomalies are generally negative, but farther south, on the Osprey Embayment, they become positive again. The background on the Coral Sea abyssal plain appears also to be generally positive. It is interesting to note that the change from dominantly negative to positive background occurs at round the same place as the second Bouguer anomaly transition zone discussed in Chapter 6.

7. DISCUSSION

The major points that have come out of the study may be listed as follows:

1. The Aure and Moresby Troughs appear to form a continuous belt of sedimentation parallel to the coast of southeast Papua to 9°S. Crustal thinning beneath this trough system has been interpreted.
2. The Moresby Canyon at the southern end of the Moresby Trough is an erosional feature cut into a thick section of sediments.
3. The Papuan Plateau is covered by an average of one kilometre of sediments, and no structure that could have acted to dam these sediments has been discovered.
4. The Eastern Fields Fan is a superficial wedge of sediment, averaging 500 metres in thickness, deposited over an unconformity surface.
5. The Portlock Trough developed by tectonic movement and postdates the fan.
6. A steeply sloping bathymetric feature with associated ?intrusions in the northwest corner of the Coral Sea Basin has been interpreted as a fault scarp.
7. All areas of reef growth occur on structural highs within the basement. No reefs exist in the embayment region.
8. On gravity evidence we may define areas of continental, subcontinental, suboceanic, and oceanic crust corresponding to the larger physiographic provinces.

Another major event occurred outside the survey area and is of particular importance to a study of the Gulf region. This is the opening of the Coral Sea Basin.

Until Leg XXI of the JOIDES project was completed the age of this event was in doubt. Drill-hole 210 in the Coral Sea Basin did not reach basement but penetrated a sequence of middle Eocene (50 m.y.) chalks which apparently form the base layer, and showed that turbidite inflow began in middle Miocene (15 m.y.). In addition, there is a clear Eocene/Oligocene unconformity.

These results set a limit on the age of the basin and help to date some of the features farther north. The Coral Sea Basin was in existence, or at least coming into existence, in the middle Eocene. Turbidite inflow to the basin would have occurred only after unbroken avenues of transport were created between the Fly River area and the basin. This did not occur until after the Moresby Canyon was cut; prior to this, deposition was restricted to areas immediately south of New Guinea.

However, a considerable amount of sediment was deposited before the canyon was formed. The entire area of the Eastern Fields Fan and Papuan Plateau is blanketed with pre-canyon sediments. A thickness greater than one kilometre has been deposited on the Papuan Plateau. The time of onset of this deposition is believed to have coincided with the emergence of a source area — New Guinea. This began (Davies & Smith, 1970) in the upper Oligocene and is continuing today. If it is assumed that sedimentation began in the middle Miocene, the sedimentation rate required is 13.5 cm per 1000 years for the Papuan Plateau and roughly half that amount for the Eastern Fields Fan. This corresponds to slow turbidite deposition such as may be expected from a slowly emergent land mass.

These events must also be reconciled with deposition in the Aure-Moresby Trough. This trough was initiated in early Miocene and deposition was rapid thereafter (Phillips, 1965). The trough was sinking, and folding occurred in incompetent beds during deposition. Sedimentation rates as high as 80 cm per 1000 years occurred during upper Miocene (lower Muruan). The greater portion of material shed from southern New Guinea was trapped in the trough, but evidently some spill-over occurred which resulted in the blanketing of the plateau regions.

If opening of the Coral Sea began in middle Eocene and was achieved by a process of seafloor spreading at a rate of 5 cm per year, the sea would have been open to its present width in the upper Eocene — the time of the Eocene/Oligocene unconformity. In this case the opening was followed by a period of 15 m.y. of non-deposition in the basin. No sediments of lower or middle Oligocene age have been positively identified in eastern Papua, and the Eocene/Oligocene unconformity is found to be widespread in the Queensland Plateau, Lord Howe Rise, and New Caledonia Basin. Apparently the period from late Eocene to middle or late Oligocene was a time of very widespread non-deposition.

JOIDES results from drill-hole 209 on the Queensland Plateau have shown that the eastern edge of the plateau has continued to submerge since mid-Eocene time. It is suggested here that this event was common to all areas north to Eastern Fields reef, but that whereas the Queensland Plateau received only pelagic sediments the Eastern Fields Fan was close to a source area and received turbidite deposits.

On the basis of the above evidence, conclusions, and assumptions it is possible to postulate the following geological history for the subject area beginning in the late Mesozoic.

Cretaceous

The area now occupied by the Gulf of Papua, Eastern Fields Fan, and Osprey Embayment existed as a continental margin facing the palaeo-Pacific Ocean. The island of New Guinea did not exist; sediments were being shed from the Australian continent into the area now occupied by the island. The region was tectonically very stable and continued thus until the early Eocene.

Eocene

Davies (1970) gives the age of overthrusting of the Papuan Ultramafic Belt as upper Eocene and correlates this event with the beginning of the movement of Australia away from Antarctica. Other Eocene events include the opening of the Coral Sea, the beginning of a widespread period of non-deposition, and the submergence of the Queensland Plateau. Davies (op. cit.) has also suggested that overthrusting and metamorphism occurred close to the coast of Australia and that the metamorphosed sediments moved away from their initial position as the Coral Sea opened in the mid-Eocene. This view is supported here, and it is suggested that the steep scarp in the northwest corner of the Coral Sea is part of a rift which formed as the sea opened. The initial impact of metamorphism would have been taken just east of this feature.

It is further suggested that subsidence along the Queensland coast extended as far north as the Gulf of Papua so that the Eastern Fields Fan was subsiding after the initial rift in late Eocene. Some structural features remained more stable during subsidence and these are now the sites of modern reef growth.

Oligocene

The record does not begin until upper Oligocene. Between late Eocene and late Oligocene the Coral Sea was open to its full width but no deposition occurred. Similarly, the marginal plateaus were sinking but no deposition occurred. From the start of its emergence, New Guinea constituted a source area for sediments, which began to cover the sinking Eastern Fields Fan and Papuan Plateau.

It is suggested that the opening of the Coral Sea was also responsible for crustal thinning in the Aure-Moresby Trough, and created a potentially unstable situation.

Miocene

Emergence of New Guinea continued and the island became a major source area. The Aure-Moresby Trough received a large volume of sediment from early Miocene, and the weight of sediment resulted in deepening of the trough in the region of thin crust. By the middle Miocene the influx of sediment from New Guinea was so great that deposition of continental margin type was not possible on the Eastern Fields Fan and Papuan Plateau; canyons began to form down the slopes — particularly the Moresby Canyon. With the formation of the canyon, turbidites began to flow into the Coral Sea Basin, and turbidite deposition on the Plateau and Fan greatly decreased.

Pliocene to Recent

Later events cannot be dated accurately. Deposition continued in the Aure Trough with folding and some thrust-faulting. The Portlock Trough formed by faulting, probably at around the same time as the Moresby Canyon. After this event, turbidite deposition was no longer possible on the Eastern Fields Fan, and pelagic deposition took its place. Turbidites could still be deposited on the Papuan Plateau from southeast Papua via canyons leading to the plateau surface. Reef growth developed vigorously on every bathymetrically opportune location.

Many of the troughs and canyons which downgraded strongly under turbidite influence began to back-fill as the Coral Sea Basin became fuller (see also Winterer, 1970). The canyons now contain up to 500 metres of newly deposited sediments.

It would seem that some slow movement is still taking place. The continental shelf is quite stable, with crust of continental thickness, but the Eastern Fields Fan has not yet reached equilibrium and is probably still sinking. Crustal thickness here is of subcontinental or continental margin type. The Osprey Embayment apparently subsided much more than the surrounding areas and is likely to be still subsiding. Partial melting at the base of the crust may account for suboceanic crustal thickness here. Between the scarp feature and the Papuan Plateau only oceanic crust exists, as would be expected if we assume a seafloor spreading hypothesis.

The general aspect of the area is again one of tectonic quietness.

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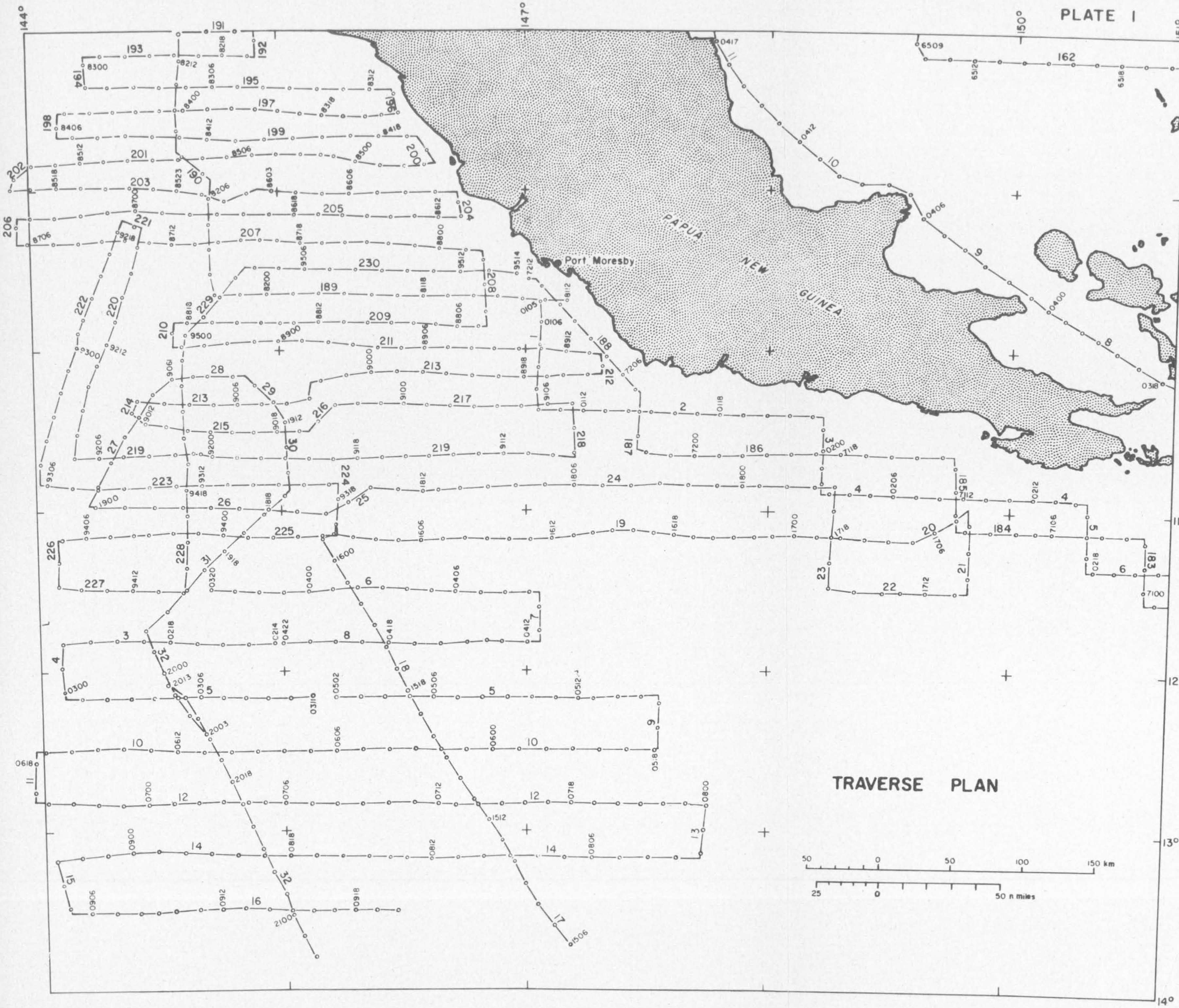
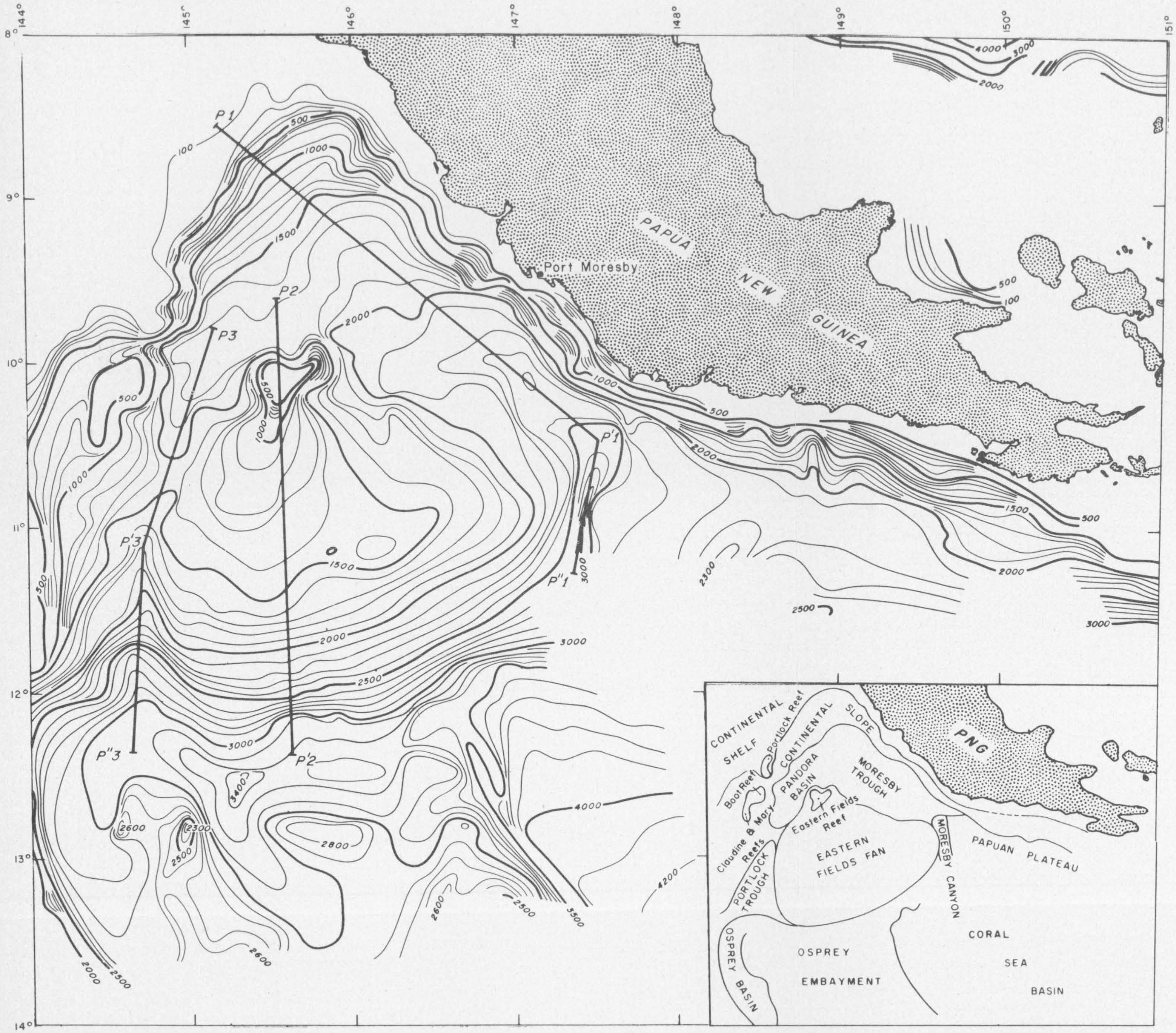


TRAVERSE PLAN

PLATE 2



LEGEND

3000 Isobath (metres)

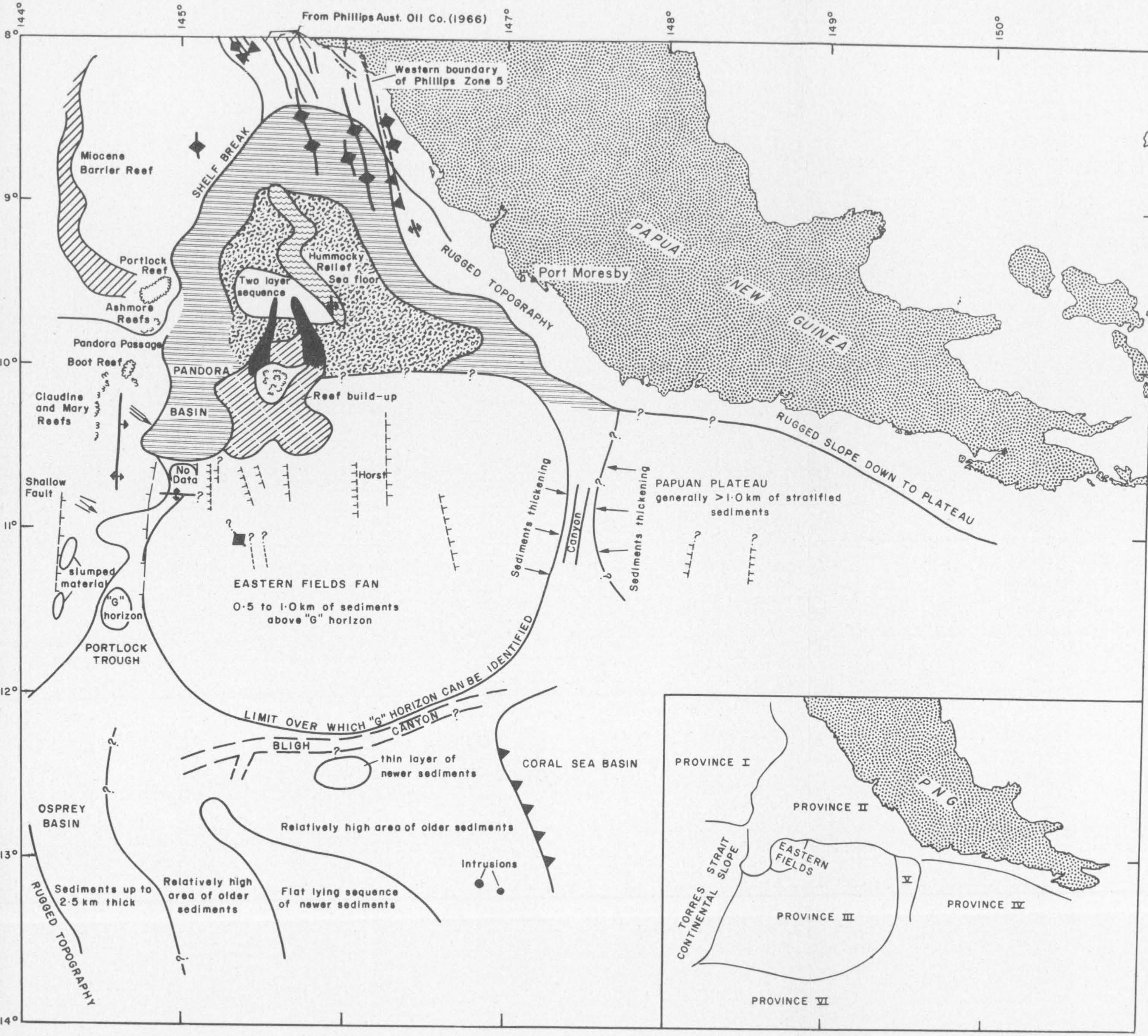
P2 — P'3 Bathymetric Profile (see fig.4)

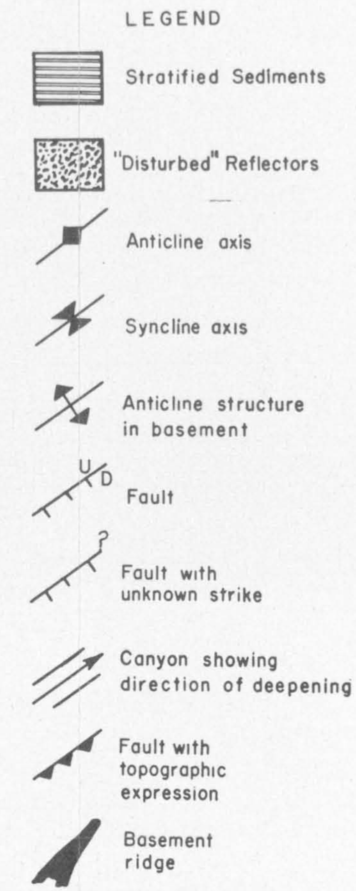
BATHYMETRY AND LOCATION OF PROFILES

20 0 40 80 120 km

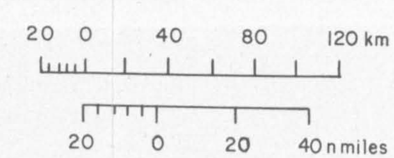
20 0 20 40 n.miles

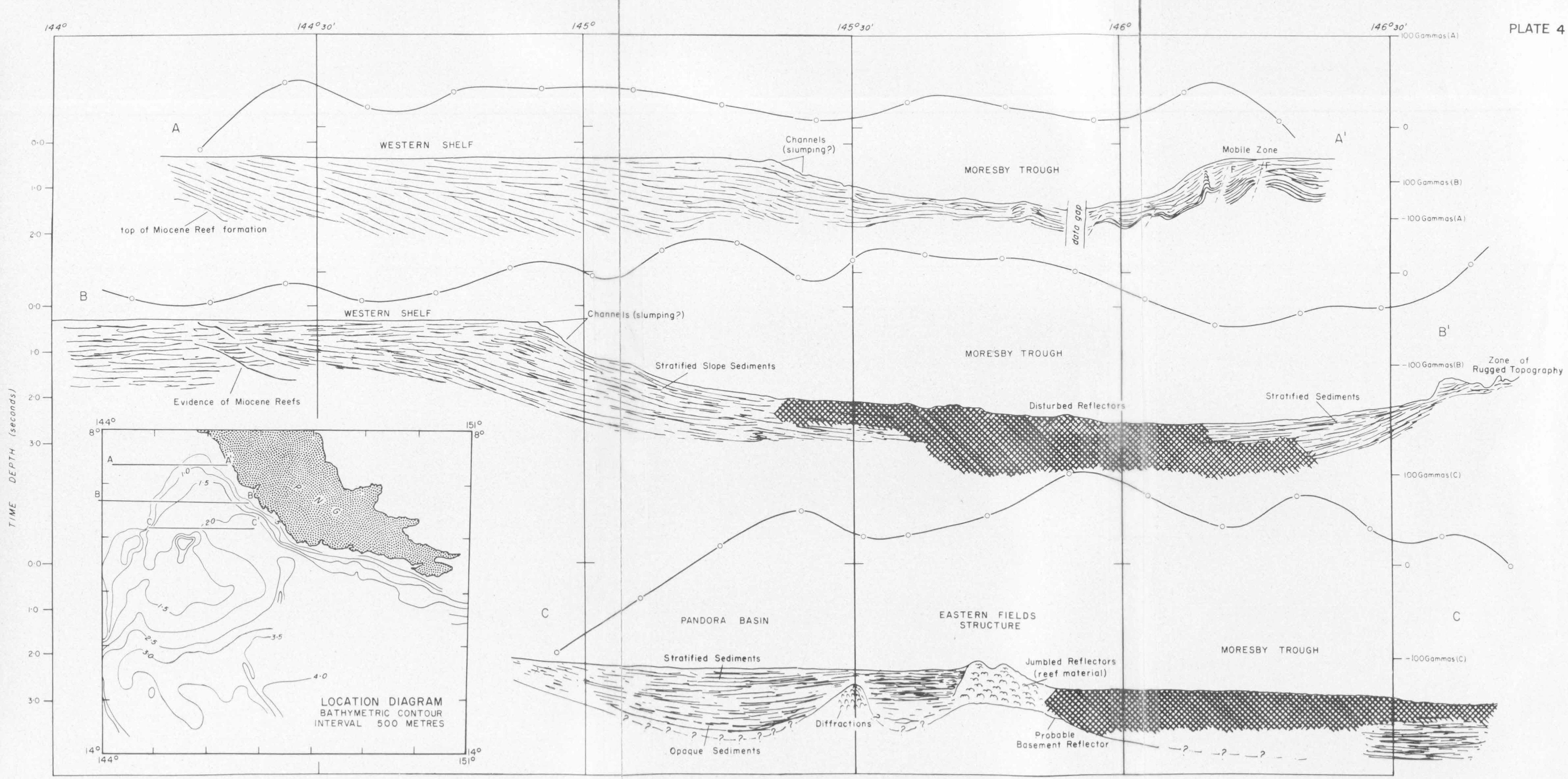
PLATE 3





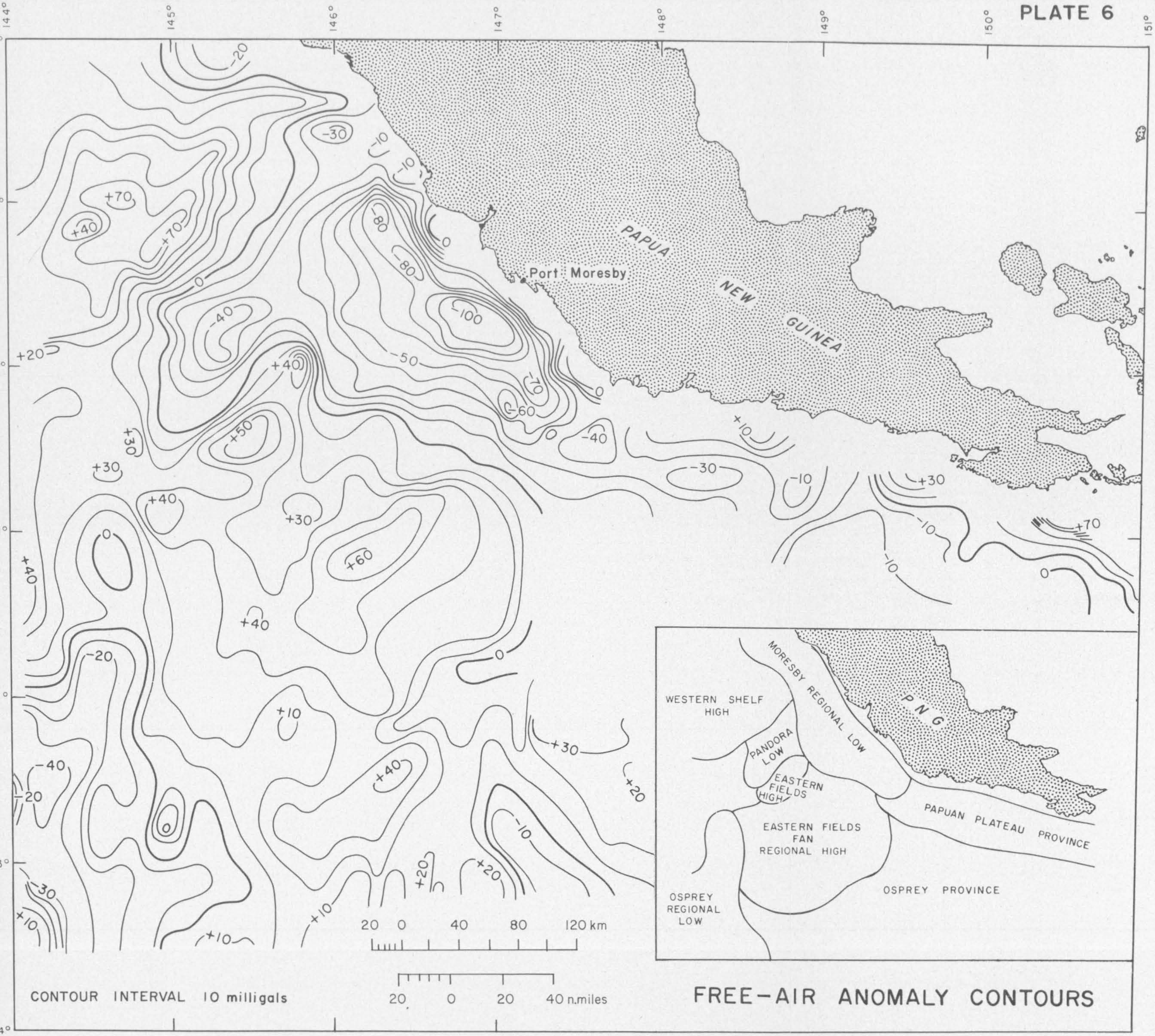
SEISMIC RESULTS AND PROVINCE BOUNDARIES





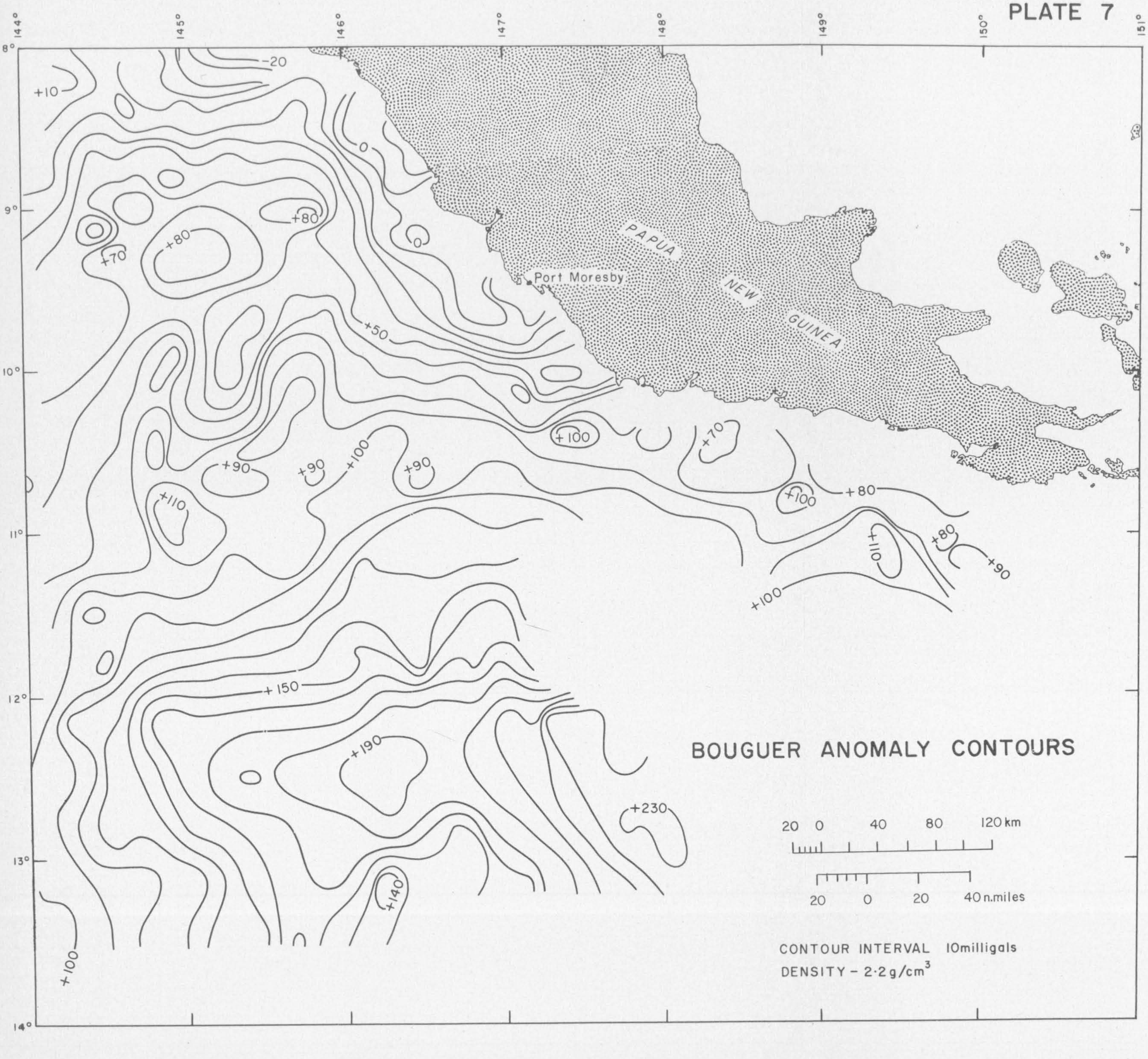
SEISMIC SECTIONS AND MAGNETIC PROFILES A, B, AND C

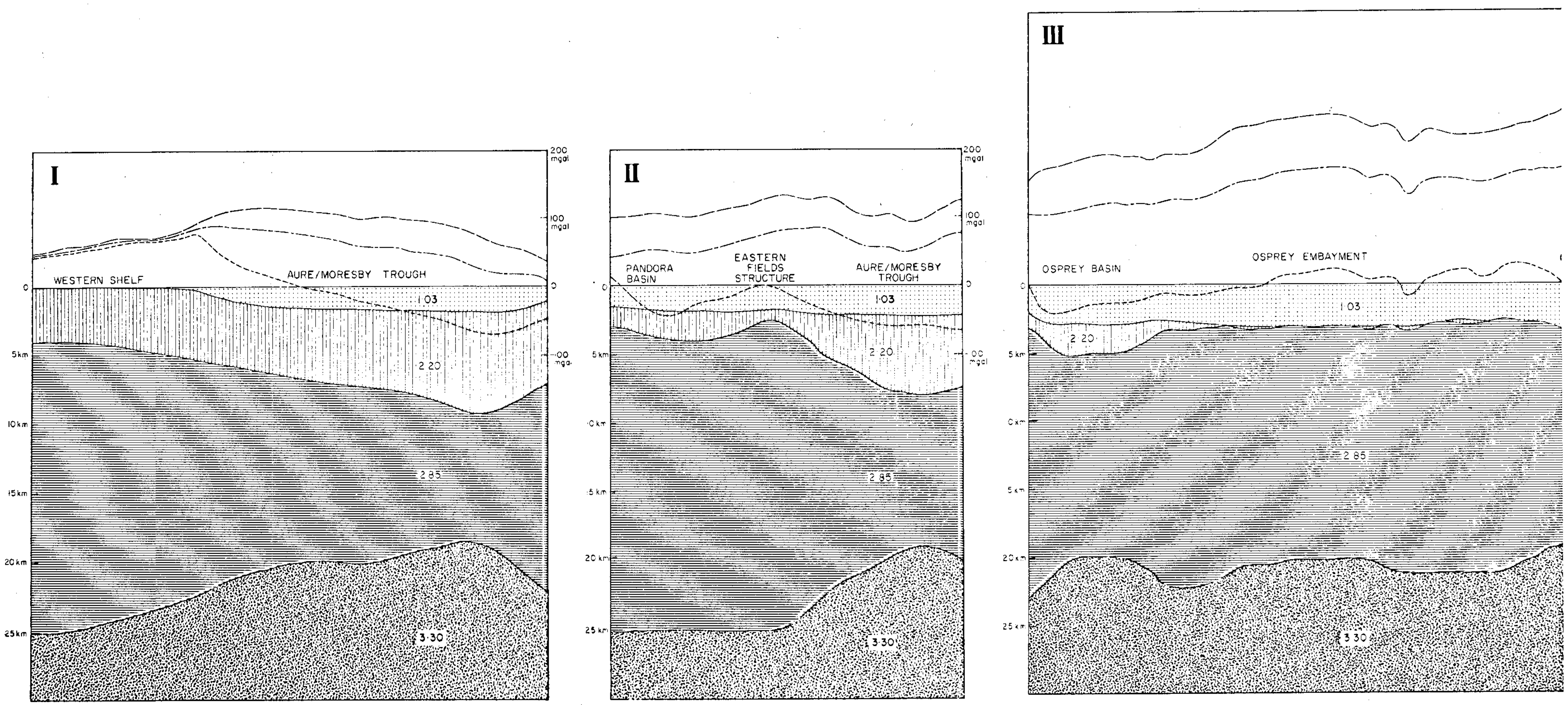
PLATE 6

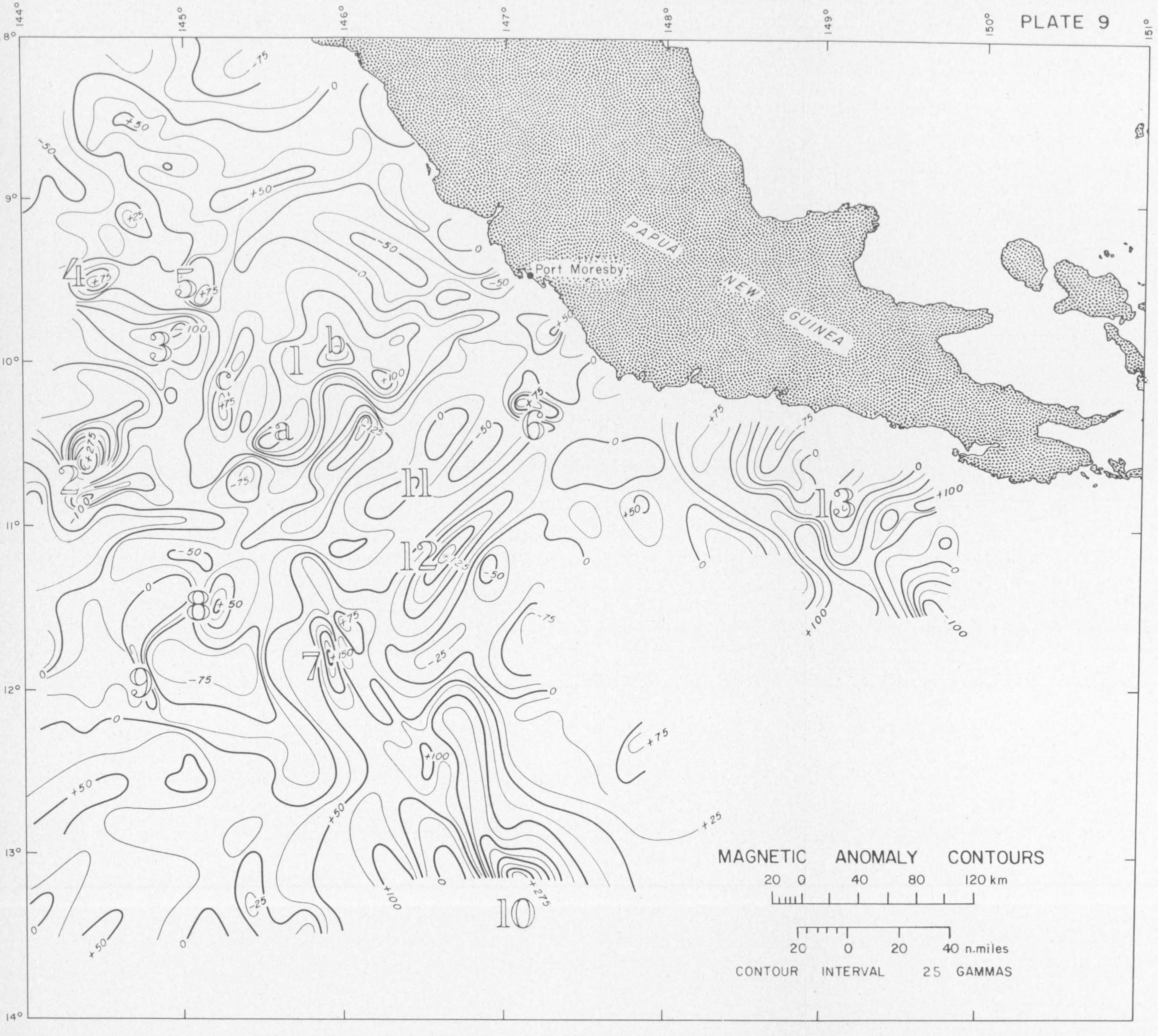


FREE-AIR ANOMALY CONTOURS

PLATE 7


144°
145°
146°
147°
148°
149°
150°
151°
8°
9°
10°
11°
12°
13°
14°
PAPUA NEW GUINEA
Port Moresby
-20
+10
0
+80
+70
+50
+100
+90
+110
+80
+100
+90
+150
+190
+230
+140
+100
BOUGUER ANOMALY CONTOURS
20 0 40 80 120 km
20 0 20 40 n.miles
CONTOUR INTERVAL 10milligals
DENSITY - 2·2 g/cm³


I
WESTERN SHELF
AURE/MORESBY TROUGH
1·03
2·20
2·85
3·30
200 mgal
100 mgal
0
-100 mgal
5km
10km
15km
20km
25km
II
PANDORA BASIN
EASTERN FIELDS STRUCTURE
AURE/MORESBY TROUGH
1·03
2·20
2·85
3·30
III
OSPREY BASIN
OSPREY EMBAYMENT
1·03
2·20
2·85
3·30


PAPUA NEW GUINEA
Port Moresby
MAGNETIC ANOMALY CONTOURS
20 0 40 80 120 km
20 0 20 40 n.miles
CONTOUR INTERVAL 25 GAMMAS