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Marine Geology of the Huon Gulf Region New Guinea

BY

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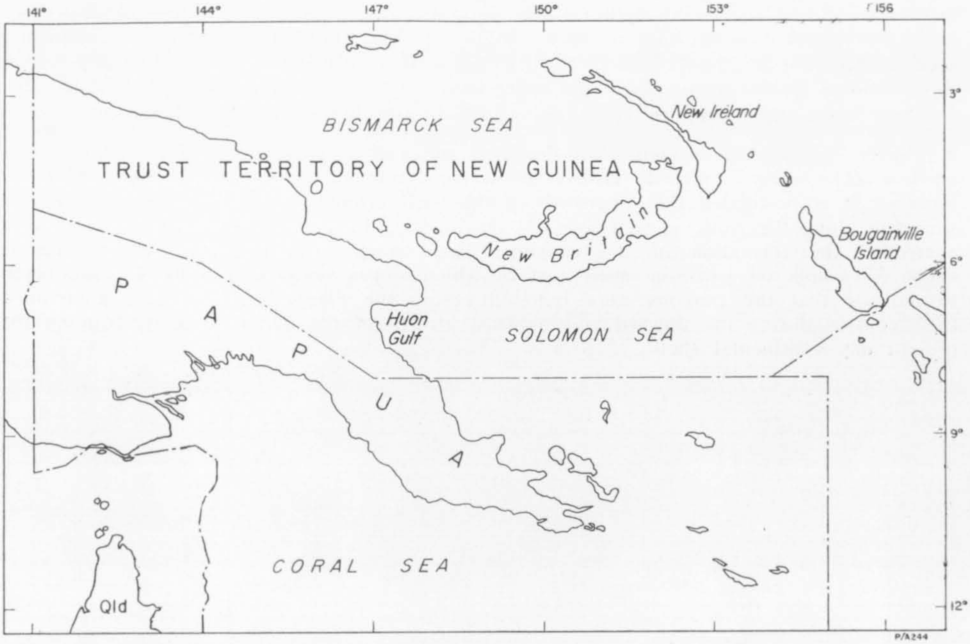
SUMMARY

The Solomon Sea is a semi-enclosed oceanic basin bordered by tectonically active land masses: its morphology is dominated by an arcuate trough, the New Britain Trench, which bounds the basin on its northern side and is over 8000 metres deep.

Density of soundings is sufficient to reveal a large scale left-lateral displacement near the western end of the New Britain Trench; this appears to be a continuation of the onshore Markham-Ramu Lineament. The same structure controls the position of the Markham submarine canyon, which is the major conduit feeding sediment to the ocean basin.

No continental shelf is developed along the northern margin of the Huon Gulf owing to the strong and continuing uplift of the Huon Peninsula, which lies within the Northern New Guinea Arc structural province. South of Lae, however, a narrow continental shelf is present. Seismic reflection profiles reveal that this shelf is a geologically young constructional feature, composed in its upper levels of a coalescing series of deltaic deposits. In some areas these can be seen resting directly on non-sedimentary basement.

Several submarine canyons cross the shelf and each is closely related to a large river onshore. The seismic records clearly show truncation of strata by the canyon walls; however, it is postulated that upgrowth of the shelf around the canyons, with occasional slumping along the rims, as well as axial downcutting by abrasive sediment flowage, have controlled the formation of the canyons. Their steep axial gradients, which average about 5° compared with the shelf surface which slopes seaward at only 1°, are taken to indicate that the canyons were initiated before the Pleistocene and have maintained their courses during the upward and outward growth of the deltaic deposits forming the present day continental shelf.



1. **Location map**

INTRODUCTION

The mainland of New Guinea and adjoining deep ocean basins currently constitute one of the earth's most tectonically active regions. Extreme contrasts in topographic elevation occur between the mountainous landmass of New Guinea and adjacent steep-sided ocean basins. Topography is youthful in many areas right down to the shoreline, and a continental terrace is either completely absent or in the early formative stage. High precipitation, coupled with the extreme relief, results in unusually rapid denudation and large-scale transport of sediment from land to sea.

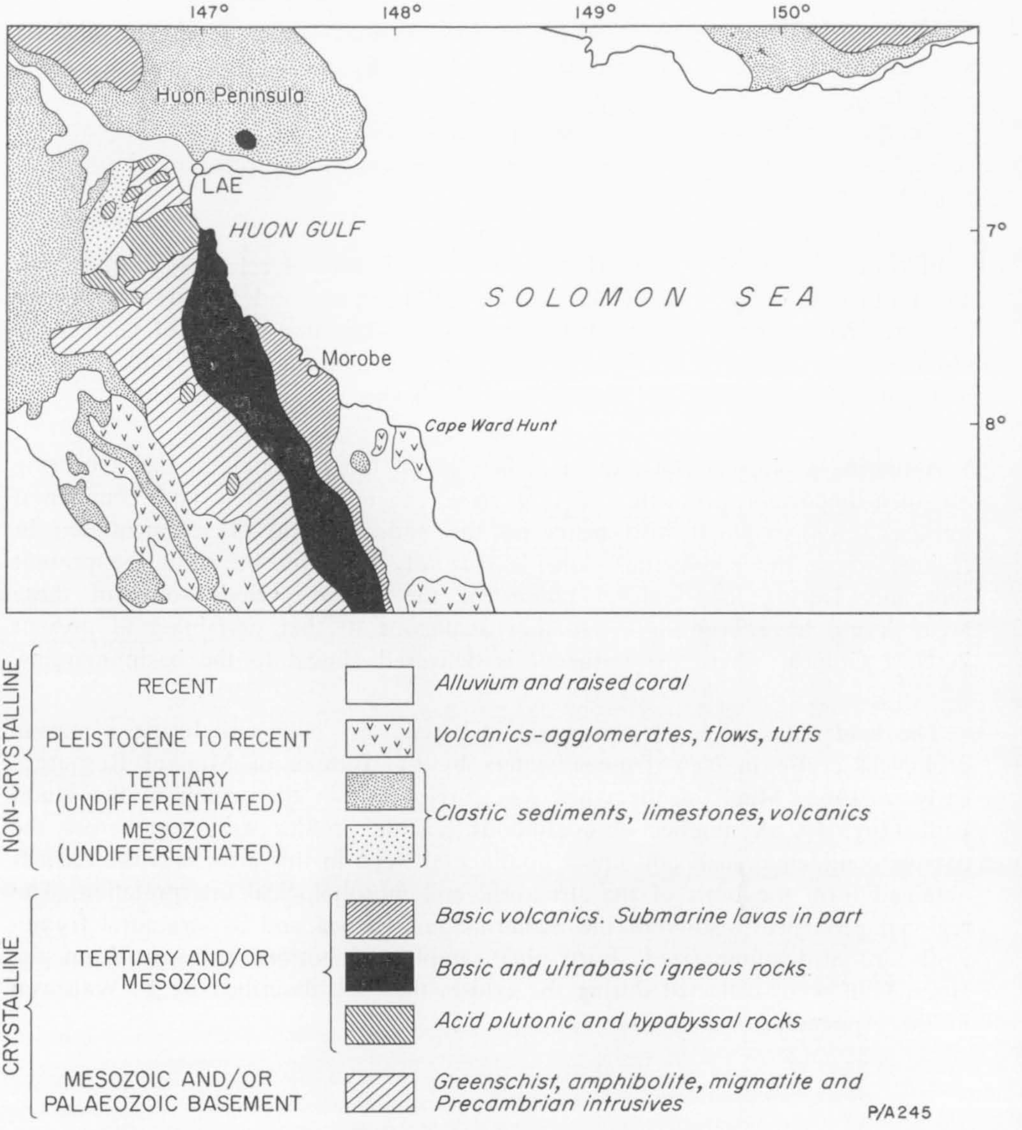
In contrast, the adjacent marine environment is one of relatively low energy. Tidal range in the region of the Huon Gulf is small, and the area is largely protected from long-period ocean swells. The result is that sorting of terrigenous sediment delivered to the basin is almost negligible, and the bulk of that material finds its way directly into the ocean basins via submarine canyons.

A marine geological study of area, in view of these anomalies, has a bearing on such important problems as submarine canyon formation and continental terrace development. It also bears on the understanding of sedimentation in regions where the continental slope is currently far removed from the present shoreline. During low sealevel phases of the glacial periods some of these areas would have been in a situation analogous to that pertaining at present in New Guinea, where the sediment is delivered almost to the basin margins.

The field data on which this study is based were collected during a marine geological cruise in New Guinea waters by the Bureau of Mineral Resources early in 1968. Much of the work was carried out in the region of the Huon Gulf (Fig. 1). A number of continuous seismic profiles were run across the narrow continental shelf and upper continental slope in this area, and the records obtained form the basis of the structural and morphological interpretation. The regional geological history of the western Solomon Sea and its structural framework are also summarized. Forty-nine samples of bottom sediment from the Huon Gulf were collected during the cruise; they are described by F. Walraven in the Appendix.

PREVIOUS WORK

A limited amount of data on the marine geology of the area exists as a result of previous studies in the region. Sprigg (1947) has described three submarine canyons in the area northwest of Cape Ward Hunt, and Krause (1965, 1967) has published reports on the marine geology and submarine



2. Geology of southeastern New Guinea, after Thompson & Fisher (1965).

structure of areas adjacent to the Huon Gulf. The geomorphology, climatology, geology, and pedology of land areas in the vicinity of Cape Nelson, southeast of the present study, have been documented by Haantjens et al. (1964) and Ruxton et al. (1967), and Holocene denudation rates on a young dissected volcanic cone have been determined by Ruxton & McDougall (1967).

HINTERLAND GEOLOGY

Thompson & Fisher (1965) have sumarized the geology of southeastern New Guinea (Fig. 2), and Thompson (1967) has described the geological history. The Papuan Ophiolite Belt was described by Davies (1968).

The area is generally one of late Tertiary to Recent tectonic activity, forming part of the circum-Pacific zone of island-arcs and ocean-trenches (Weeks, 1959; Glaessner, 1950). It is divisible structurally into several provinces (Fig. 3).

Northern New Guinea Arc

The Northern New Guinea Arc is bounded on the southern side by the Markham-Ramu lineament, which represents, at least in part, a major strike-slip fault. The arc extends into New Britain, where its southern boundary is taken as the New Britain Trench. Within the area of this study, on the mainland of New Guinea, the arc is composed of a series of young mountain ranges rising more than 4000 m above sea level. The ranges are composed of Tertiary clastics, volcanics, and limestones, broadly folded and recently uplifted. The importance of this region, from the point of view of this study, is the scale of Recent tectonic activity. Upper Miocene marine limestones have been elevated to more than 3000 m above sea level. Elevated coastal terraces are common, both on mainland New Guinea, particularly near Finschhafen at the top of the Huon Peninsula, and along the south and east coast of New Britain. Steep stream gradients, V-shaped valleys, active landslides and seismic activity, all mark this as being one of the most tectonically unstable regions in Papua-New Guinea at the present time.

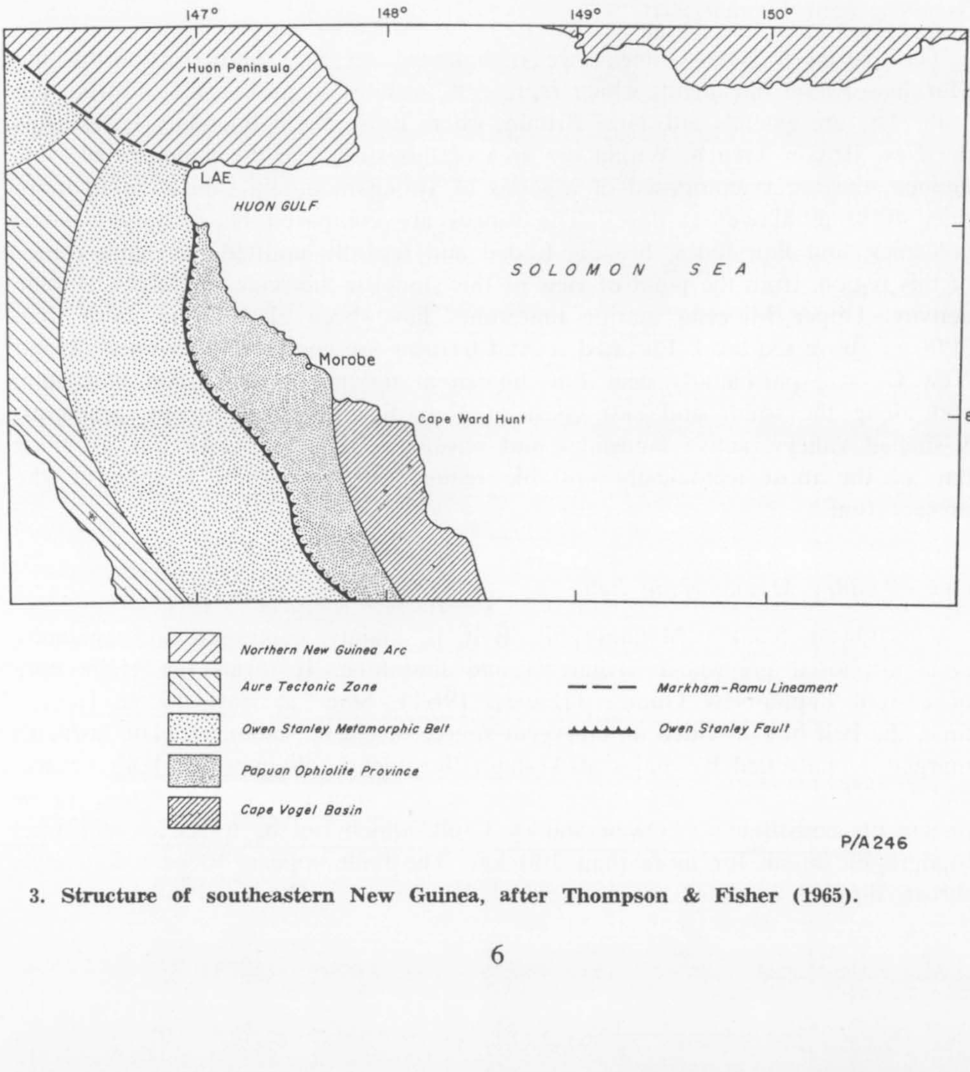
Owen Stanley Metamorphic Belt

The Owen Stanley Metamorphic Belt is mainly composed of regionally metamorphosed greywacke sediments and limestone. It forms the sialic core of eastern Papua-New Guinea (Davies, 1968). Since at least middle Eocene time, the belt has provided an emergent source of clastic sediments. The northern margin is controlled by major strike-fault lineaments, along which both vertical and lateral movements have taken place in Pleistocene to Recent times. These lineaments constitute the Owen Stanley Fault, which can be traced as a distinct topographic break for more than 300 km. The fault appears to be a low-angle thrust, dipping eastward at an angle of 20° to 30° (Davies, 1968).

Papuan Ophiolite Province

The Papuan Ophiolite Province is separated from the Owen Stanley Metamorphic Belt by the Owen Stanley Fault. It is composed of an oceanic association of ultrabasic and basic plutonic rocks, basic submarine lavas, grey, red-brown, and green siliceous claystones, inorganic calcilutites, and bedded cherts. Evidence is presented by Thompson (1967) and Davies (1968) to show that this is probably a slab of oceanic mantle and crust which has moved westward in late Cretaceous or Eocene time and over-ridden the sialic core of New Guinea along the Owen Stanley thrust fault. The Papuan Ophiolite Province probably extends beneath volcanics and sediments of the Cape Vogel Basin to the east and south.

An interesting point, relevant to the present study, is the statement in Thompson & Fisher (1965) that large sections of the eastern New Guinea coastline show evidence of Recent submergence, and that these sections fall within the Papuan Ophiolite Province. In addition, vertical displacements of the Owen Stanley Fault, and erosional remnants of a mature landscape on the crest of the Owen



3. Structure of southeastern New Guinea, after Thompson & Fisher (1965).

Stanley Range, indicate Pleistocene to Recent uplift of the Owen Stanley Metamorphic Province relative to the Ophiolite Province. The Owen Stanley Metamorphic Belt has been a positive structural element throughout Cainozoic time, whereas the Ophiolite Province is currently being submerged.

Cape Vogel Basin

The Cape Vogel Basin is a structurally depressed and topographically lowlying coastal zone, extending from Morobe in a southeasterly direction, and continuing an unknown distance out to sea to the east of Morobe. A thick section of Miocene and Pliocene sediments is exposed on Cape Vogel (southeast of the map boundary, Fig. 2). Between here and Morobe, unconsolidated coastal plain deposits and Pleistocene to Recent volcanics mask any possible northward extension of the Miocene-Pliocene succession. Many centres of Pleistocene to Recent volcanic activity exist within the Cape Vogel Basin in the area of this study; the most recently active was Mount Lamington in 1951 (Taylor, 1958), which ejected an andesitic magma during a catastrophic eruption.

COASTAL MORPHOLOGY

Comprehensive descriptions of coastal morphology, mainland morphology, and geology and climatic conditions of areas immediately to the southeast of this study area are included in CSIRO Land Research Series publications by Haantjens et al. (1964) and Ruxton et al. (1967). Data for the area of the present study, presented below, are based largely on personal observations, supplemented by extrapolations from the areas studied by CSIRO workers.

Emergent Coastal Areas

Within the area of Figure 3, all coastal portions of the Northern New Guinea Arc, including the Huon Peninsula and New Britain, are topographically emergent with respect to present sealevel. At least two well defined marine terraces occur along the south and southeastern portion of New Britain. A series of striking elevated marine terraces occurs on the Huon Peninsula near Finschhafen. Coastal topography in these regions is typically steep both above and below sealevel. Lowlying swampy coastal regions are absent and the coastline is not deeply embayed. Highlands of more than 2000 m typically lie only about 11 km inland. Fringing coral reefs are absent or poorly developed. Elevated reef coral of possible Pleistocene age forms low shoreline cliffs along New Britain's southern coast, and along the seaward side of Dreger Harbour on Huon Peninsula.

Submergent Coastal Areas

Both the Papuan Ophiolite Province and the Cape Vogel Basin possess drowned coastlines which provide evidence of regional submergence. From the Markham River mouth near Lae, southeast to Morobe, the coast is backed by steep ranges, with elevations of about 2700 m, some 27 km inland. In this region, inundation of a dissected topography has produced a number of deep steep-sided embayments typified by Baden Bay and Morobe Harbour. Large coastal swamps are absent in this zone. In contrast, the area of the Cape Vogel Basin, southeast of Morobe, is one of generally flat-lying swampy coastal plain. The presence of beachridges suggests a locally prograding shoreline. Lagoonal and deltaic developments are relatively common, and deltaic bulges occur off major rivers such as the Waria, Mambare, Kumusi, and Musa. Fringing coral reefs are important features of the morphology along most of the submergent coastline. They are not well developed in the turbid-water areas off large rivers such as the Markham, but from Parsee Point to the southeastern margin of the study area, the exceptionally clear ocean water has encouraged reef building. Most of the steep-sided embayments are fringed by reef developments, and particularly luxuriant growths occur around islands and peninsulas.

CLIMATE AND OCEANOGRAPHY

Climate

The portion of New Guinea covered by the study lies within the province of northwest monsoons and southeast trades, and away from the belt of tropical cyclones.

Generally the northwest monsoons blow from October to April; weather during this period is variable, with intermittent thundersqualls and frequent rainstorms interspersed with periods of calm. During squalls, northwest to southwest winds may attain velocities of 40 knots for short periods. Seas of the Huon Gulf region and east of New Britain are generally smooth, except in the vicinity of Vitiaz Strait.

The southeast trades blow between May and October. During this period, weather is generally fine in areas remote from high landmasses. Morning calms are common, followed by southeasterlies which consistently blow at velocities of 20 to 30 knots.

Rainfall in the area of this study is variable. The climate is humid tropical, with an average annual rainfall in coastal areas of 100 to 200 inches. In the region of the Huon Gulf, situated generally to the east and north of mountainous areas, most rain falls during the season of the southeast trades (Table 1).

January	2.80	July	18.74
February	2.91	August	18.62
March	5.28	September	12.72
April	8.90	October	14.60
May	12.83	November	9.57
June	17.32	December	3.86

Table 1.—Average rainfall figures for Finschhafen, quoted in US Hydrographic Office Sailing Directions for New Guinea, 1936.

Drainage

The high rainfall and extreme topographic relief of the areas are responsible for high stream-discharge rates. The main rivers flowing into the Huon Gulf area, from northwest to southeast, are the Markham, Francisco, Morobe, Waria, Gira, Mambare, Kumusi, and Musa. Collectively, these rivers drain a hinterland with an area of about 40,000 km^2, and a relief in excess of 4000 m. There are few data on stream discharge for the region (Table 2) and none on sediment loads. The Waria River figures were collected at Garaina, a mountain station situated at least 80 river kilometres from its mouth. At best, the figures only give a sketchy idea of the orders of magnitude of stream-discharge rates.

River	Mean Flow (Cu.ft/sec.)	Max. recorded flow (Cu.ft/sec.)	Drainage area (km^2)
Markham	15,000	>150,000	13,000
Waria	3,000	58,200	4,200

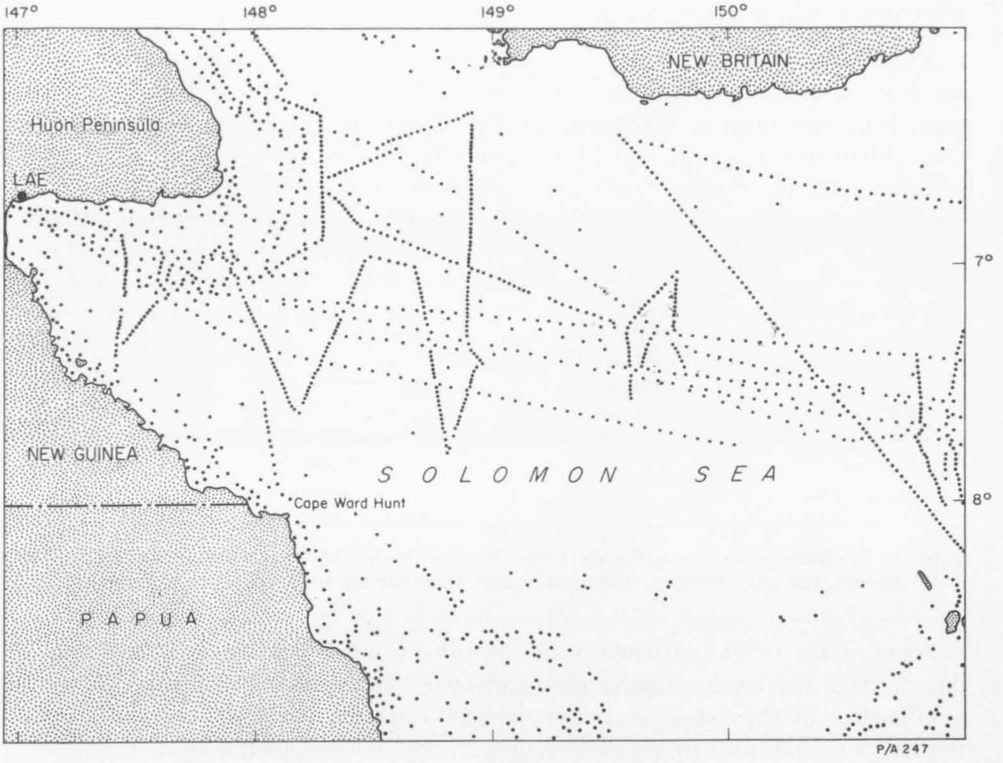
Table 2. Available river discharge data for the Markham and Waria Rivers. Data from the Stream Gauging Section, Commonwealth Department of Works, Port Moresby.

Some of the rivers, particularly the Markham and Waria, drain into the ocean directly into the heads of submarine canyons. These canyons approach to within a kilometre of the estuaries, and apparently intercept most of the bed load of the rivers as well as a proportion of their flocculated suspended load.

Oceanography

Few data have been published on oceanographic conditions in the Huon Gulf area. Most information is based on visual observations and estimates of currents, published in Admiralty Sailing Directions. The *Pacific Islands Pilot* (1956) states that a strong current, setting southeast, is initiated in the Huon Gulf, apparently by discharge of water from the Markham River. The US Hydrographic Office (1936) states that close under the coast a tidal current with a velocity of 2 knots is evident, influenced greatly in velocity and direction by the prevailing wind. During the Bureau of Mineral Resources cruise in the area, a current of about 2 knots was noted during sparker traverses on the shelf near the Waria River, adjacent to the Waria Canyon. This current was directed, at the time of observation, in a northwesterly direction, despite the fact that it was the northwest monsoon season. However, conditions had been calm for some days.

During the northwest monsoon, seas are generally calm in the Huon Gulf. A short-period choppy swell develops during the southeast trade season, owing to the limited fetch in the Solomon Sea. Long-period swells associated with the high wave energy occur only along the southeast-facing coast of New Britain. They originate from areas to the south and southeast, and may be generated by



4. Density of soundings, western Solomon Sea. Taken from R.A.N. Hydrographic Office Oceanic Soundings Sheet area 290.

cyclonic disturbances in the Coral Sea or by remote storm centres in the Tasman Sea or south Pacific Ocean.

BATHYMETRY AND STRUCTURE

SURVEYS AND DATA

The description of the regional bathymetry and structure of the western Solomon Sea is based on the bathymetric contours shown in Figure 5. These contours have been plotted from soundings shown on the Australian Hydrographic Office Oceanic Soundings Sheet, Area 290 (Fig. 4). Cross sections of the New Britain Trench have been plotted from the soundings.

The somewhat more detailed bathymetry of the Lae/Cape Ward Hunt shelf (Pl. 1) has been constructed from Australian Charts numbers 573 and 574. The average sounding density is between one and two soundings per square mile. Detailed contours of the Eia and Gira Canyons (Pl. 2) have been constructed from a local beacon-triangulated survey by HMAS *Moresby* in 1944. An average of seven sounding lines per mile is published on this plotting sheet. Contours of the Waria Canyon (Fig. 9) have been constructed from a triangulated survey by HMAS *Shepparton* in 1943. Sounding line density on the *Shepparton* survey was about three sounding lines per mile. The last two areas have previously been contoured by Sprigg (1947).

Bathymetric profiles were obtained during the Bureau of Mineral Resources cruise through a Furuno 850 echo sounder. In steep topography usable bathymetric profiles could only be obtained by reducing ship's speed to about 3 knots, because of slow chart speeds. The echo-sounder had a depth limitation of 480 m.

Seismic profiles were obtained through an Edgerton Germehausen and Grier 3-electrode Sparkarray, powered and activated by an E.G. & G. power supply and trigger capacitor bank. This combination produced a 1000 watt-second spark. Data were recorded on an Ocean Sonics GDR-T recorder. Sediments were penetrated for 0.25 to 0.5 seconds (two-way travel time) in water depths of up to 600 metres. Profiles were run at a speed of about 5 knots.

REGIONAL BATHYMETRY AND STRUCTURE

The regional bathymetry of the western Solomon Sea is shown in Figure 5, and the structural interpretation in Figure 6.

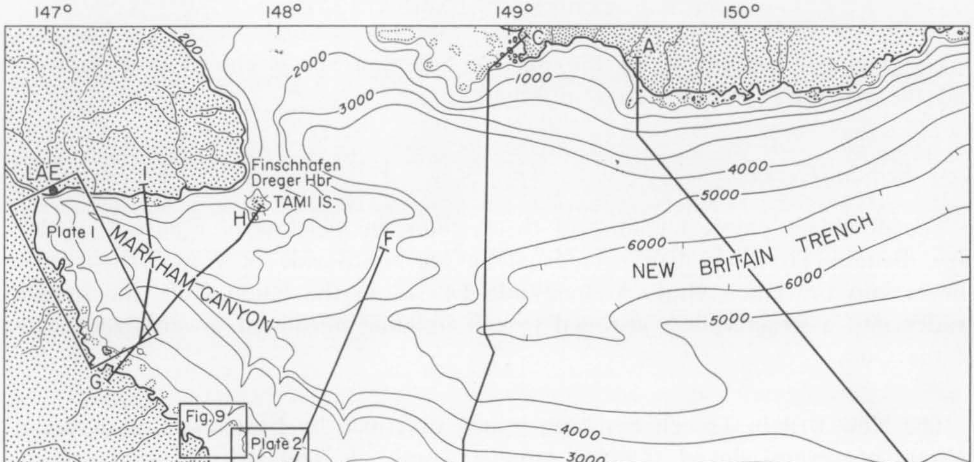
New Britain Trench

The dominant physical feature of the seafloor, in the area of Figure 5, is the New Britain Trench, which extends along the south side of New Britain and curves into the Huon Gulf. At longitude 149°E, in the Huon Gulf, the trench grades into a structurally controlled trough trending northwest towards the head of the Gulf.

The New Britain Trench has been briefly described by Fisher & Hess (1963) as one of several linked trenches situated south of New Britain, southeast of the Solomon Islands, and west of the New Hebrides. The whole of the region is seismically active, and evidence for Recent and sub-Recent volcanism is widespread along the islands adjacent to the trenches. These trenches, including the one off New Britain, are on a somewhat smaller scale than normal circum-Pacific examples, and exhibit a unique tendency to shoal off in the middle of arcs. Krause (1967) discusses evidence which suggests a Pliocene or possible Miocene age for them.

Between longitudes 149° and 150°E sounding density is sufficient to reveal a pronounced inflexion in the axis of the New Britain Trench. This is undoubtedly the morphological expression of a large-scale transcurrent displacement of left lateral sense which, on bathymetric evidence, extends into the head of the Huon Gulf. This structure appears to be an extension of the Markham-Ramu lineament (Fig. 3), which is a major structural feature on the New Guinea mainland, separating distinctly different geological provinces. The apparent left lateral nature of the shear on the seafloor is in agreement with the widespread shearing of the same sense described by Davies & Ives (1965) and Krause (1967) in the D'Entrecasteaux Islands and Louisiade Archipelago.

Bathymetric sections across the region are shown in Figure 7. These sections have been re-plotted from published soundings, and therefore do not exhibit the fine structure shown on the original echo-sounding traces. However, gross morphology is adequately demonstrated. Section A-B, from New Britain to Kiriwina Island, crosses the trench at a point where the floor is at a depth of 6500 m. Very little evidence for a flat floor is present. The northern wall of the trench is a continuous relatively smooth slope down from New Britain. The southern wall is composed of a step-like rise to a planar tilted block, which may be a large fault block. A slope showing large-scale irregularities leads from this point up to the Trobriand Platform at B. Section C-D, from New Britain to the north coast of New Guinea, crosses the western end of the trench in the

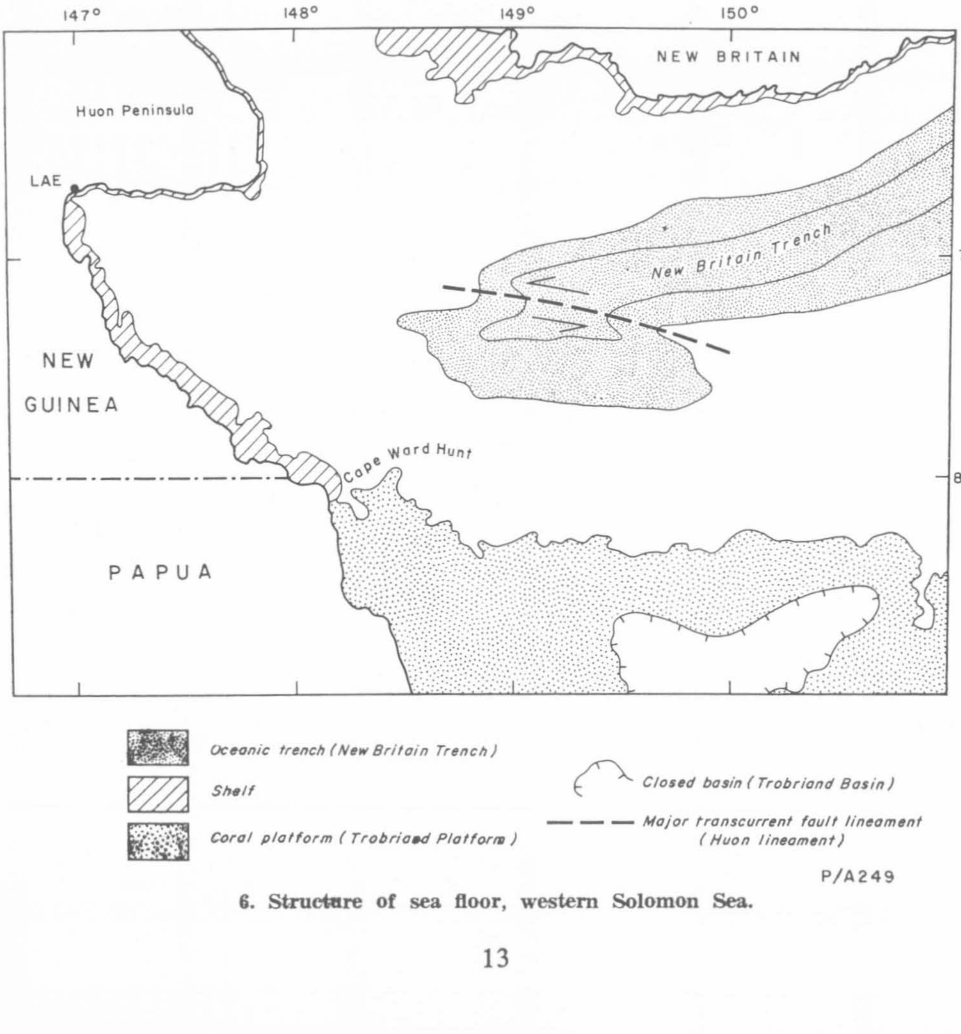


5. Regional bathymetry, western Solomon Sea. Contours (metres) constructed from Oceanic Soundings Sheet, area 290. Location of cross sections (Fig. 7) indicated by letters.

area of the seafloor shear zone. In the axis of the trench a broad, flat, sedimentary floor, possibly an abyssal fan deposit, is bounded on the south by a steep 1000 m scarp. A channel with an axial depth below the flat floor of 200-300 m occurs on the north side of the trench axis; it is evidently an erosional channel related to the Markham Canyon. The south wall of the trench is formed by the steep seaward edge of the flat Trobriand Platform. Sections E-F, G-H, and G-I, along the structurally controlled trough of the Markham Canyon, indicate a V-shaped profile, with no evidence of a flat floor. Section G-H shows a steep, narrow canyon development, presumably the result of submarine erosion by Markham River sediments.

Trobriand Platform

An extensive and poorly surveyed area of shoal water, here called the Trobriand Platform, occurs south of the latitudes of Cape Ward Hunt and the Trobriand Islands (Fig. 6). Hydrographic charts of the area show occurrences of shoal coral reefs over most of the platform, and water depths are generally



6. Structure of sea floor, western Solomon Sea.

less than 100 m. Formerly, this area was included within the province of the Cape Vogel Basin (Paterson & Kicinski, 1956). This may be structurally correct, but the term platform is more appropriate, following accepted marine geological terminology.

The eastern portion of the Trobriand Platform may be somewhat complicated structurally, as Kiriwina Island is formed by an elevated coral reef. This emergence may be local, however, as the major portion of the platform shows signs of slow subsidence, as evidenced by the coral reef distribution. It is likely that the whole area is one of calcareous sedimentation, dominated by reef-building coral and algae and derived talus. The northern margin of the platform, as mentioned earlier, slopes down either directly into the New Britain Trench (Fig. 7, C-D) or down to the possible fault block (Fig. 7, A-B).

Trobriand Basin

Enclosed by the shoal area of the Trobriand Platform lies a deep, poorly charted basin zone, here called the Trobriand Basin (Figs 5 and 6). Sparse soundings on Admiralty Charts indicate water depths of at least 970 m within the basin. On existing data, the basin is silled at a depth of 200 m at its connexion with Goodenough Bay, off the southeastern corner of Figure 5. Elsewhere around the basin the sill appears to be no deeper than about 100 m. Terrigenous sediment could be carried to this basin in the vicinity of Cape Vogel, where the basin adjoins the mainland of New Guinea.

Lae/Cape Ward Hunt Shelf

A narrow continental shelf, 5 to 8 km wide, fringes the northeast coast of New Guinea, between Lae and Cape Ward Hunt. Several submarine canyons cut across the shelf to head close inshore off mouths of large rivers. The break in slope at the edge of the shelf is at 102 m in the southeastern section and 117 m near Lae. The shelf is terminated near Lae by the Markham Canyon. In the southeast, near Cape Ward Hunt, the shelf merges with the Trobriand Platform.

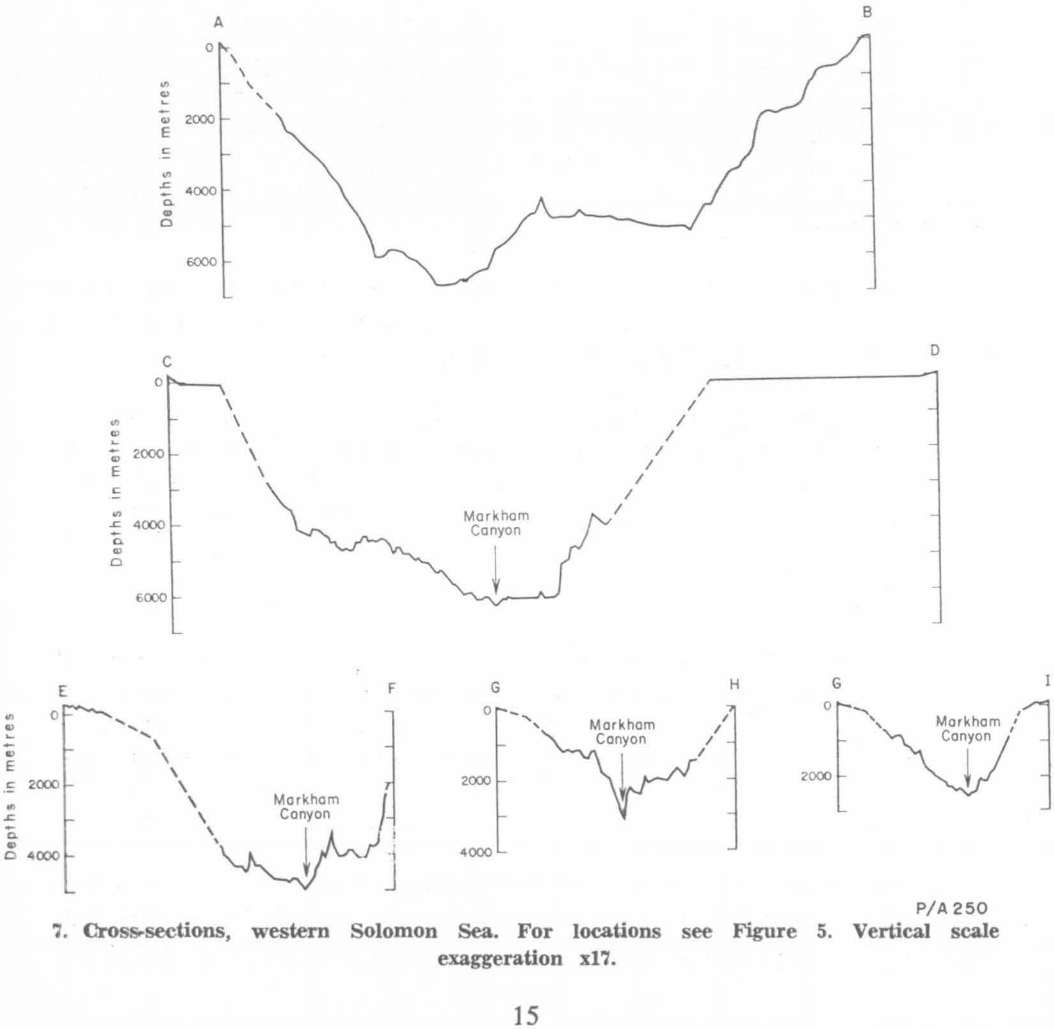
DETAILED BATHYMETRY AND STRUCTURE OF THE LAE/CAPE WARD HUNT SHELF

Plate 1 shows a contoured chart of the area of detailed study. Clearly, i.e. no shelf has developed on the Huon Peninsula east of Lae. This area is rising under the influence of tectonism, and the continental slope is essentially a continuation of the steep subaerial coastal declivity. Sediment delivered by such rivers as the Bupu would slump and flow downslope directly to the floor of the New Britain Trench.

Immediately southeast of the Markham Canyon, however, conditions have been favourable for progradation of the shelf. This area, coinciding with the Papuan Ophiolite Belt, has been tectonically more stable than the Northern New Guinea Arc, and in fact appears to have been slowly subsiding; so that sedimentary deposits have been preserved and terraces developed as a result.

Morphology

A zone of rather straight parallel depth contours occurs between the Markham Canyon and Parsee Point, partly related to deposition of sediment by the Markham, Ingari, Buang, and Bwussi Rivers. Deltaic bulges in the 50 and 100 m contours are evident off these rivers, opposite convexities of the present shoreline, and suggest active deltaic progradation. This portion of the shelf lies in a turbid water zone, under the influence of suspended sediment from the Markham River.



7. Cross-sections, western Solomon Sea. For locations see Figure 5. Vertical scale exaggeration x17.

Elongated ridges occurring immediately landward of the 150 m contour south of the Markham Canyon are coral reef formations, rising to within about 40 m of present sealevel. These are typically situated above the drop-off into deep water at the edge of the shelf. Depths of shelf-break for this section, as determined from the sparker records, range from 109 to 117 m, and the angle of the continental slope averages 1.6°. According to Shepard (1963) the world average for shelf-break depth is 132 m and the continental slope angle is 4°. In this area the angle of the slope increases suddenly to about 4° at a depth of about 150 m.

Parsee Point is a prominent feature projecting across the narrow shelf immediately southeast of the largely depositional zone described above. It is composed of greenstones of the Papuan Ophiolite Province and may be controlled structurally by the Owen Stanley Fault, which meets the shoreline in this vicinity. Farther seaward a steep-sided knoll known as Benalla Banks forms an en-echelon pattern with Parsee Point. Benalla Banks are capped by living and dead reef coral.

Immediately southeast of Parsee Point a submarine canyon (Francisco Canyon) crosses the shelf towards a shoreline embayment. From this point almost to Lasanga Island, the morphology of the shelf is dominated by a pronounced convex bulge of the shoreline and bathymetric contours to a depth of at least 300 m. This is apparently a large submarine and subaerial deltaic body related to the Bitoi River.

Southeast of the Bitoi River a series of basement-rock islands occurs across the shelf. Shelf-break in this area, on limited traverse data, is somewhat shallower than that farther north, of the order of 102 m.

Several well defined submarine canyons extend across the shelf zone between Lae and Cape Ward Hunt and drain into the New Britain Trench. These include, from north to south, the Markham, Francisco, Waria, Eia, and Gira Canyons. Of these, the last three have been previously discussed by Sprigg (1947).

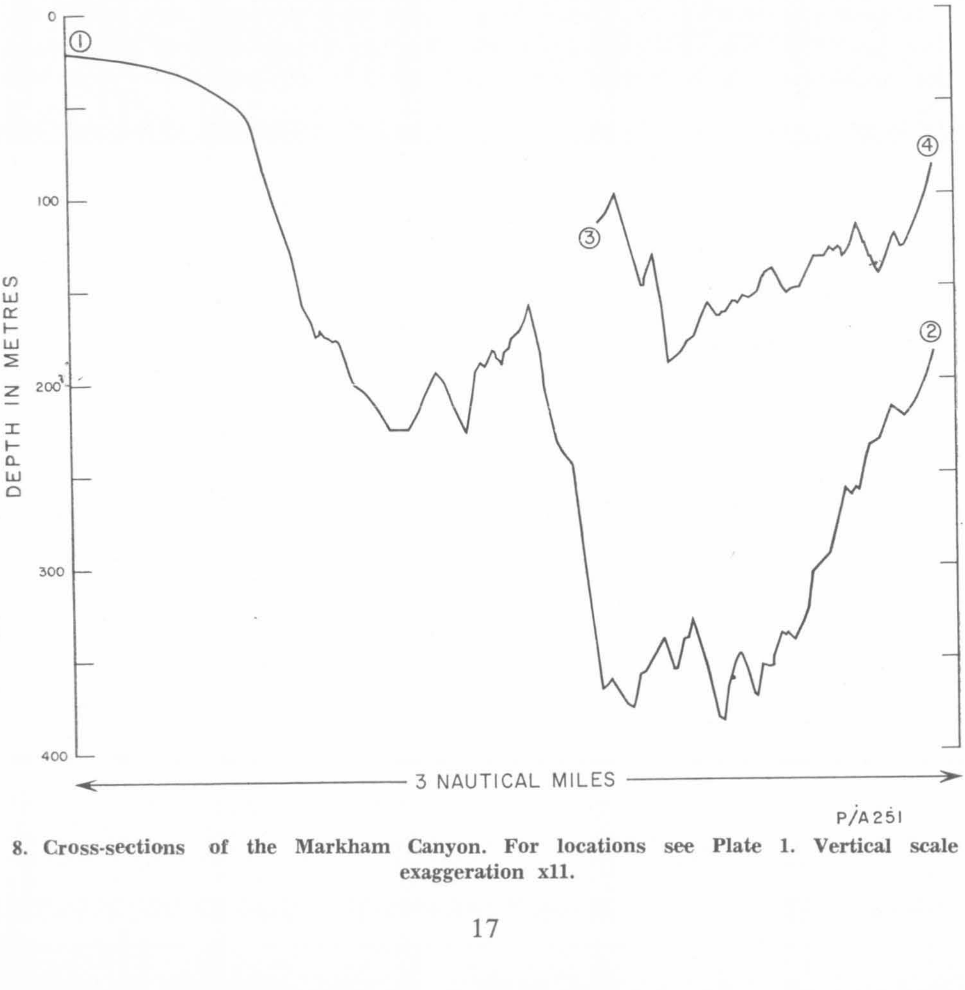
Markham Canyon

The Markham Canyon extends to within a few tens of metres of the mouth of the rapidly flowing Markham River. Between the head of the canyon and the estuary is a series of rapidly shifting sand and mud bars. The canyon has two main tributaries, one opposite the present mouth of the Markham River and the other off an extensive lagoon and swamp area about 2 km to the south. This lagoonal zone may have been a previous outlet of the main river.

The configuration of the head of the Markham Canyon in section is seen in Figure 8. Section 1-2 at its southern end crosses a smooth depositional slope related to the deltaic lobe shown in the contour plan. The southeastern tributary of the canyon is then crossed; it is separated by a spur from the main canyon. Both tributaries exhibit a series of channels. The main canyon has a vertical relief from rim to axis of about 370 m at the position of this section, with the steepest wall on the southeastern side.

Section 3-4 illustrates another crossing of the canyon close to its head. A well defined channel is evident, situated against the steeper southeast wall. The axis of the canyon can also be seen in the regional bathymetric sections extending down to the 6000 m contour in the New Britain Trench (Fig. 7).

As discussed in an earlier section, the Markham River follows the Markham Lineament, and the Markham Canyon is also clearly structurally controlled by the Huon Lineament, which may be a continuation of the Markham Lineament. Recent research has demonstrated that in water depths below eustatic influences submarine canyons are cut entirely by submarine processes of sediment movement (Shepard & Dill, 1966). A brief reconnaissance of Markham River sediments at its mouth showed its bedload to be composed of sand, gravel, and pebbles. This bedload is being transported seaward by a river current of the order of



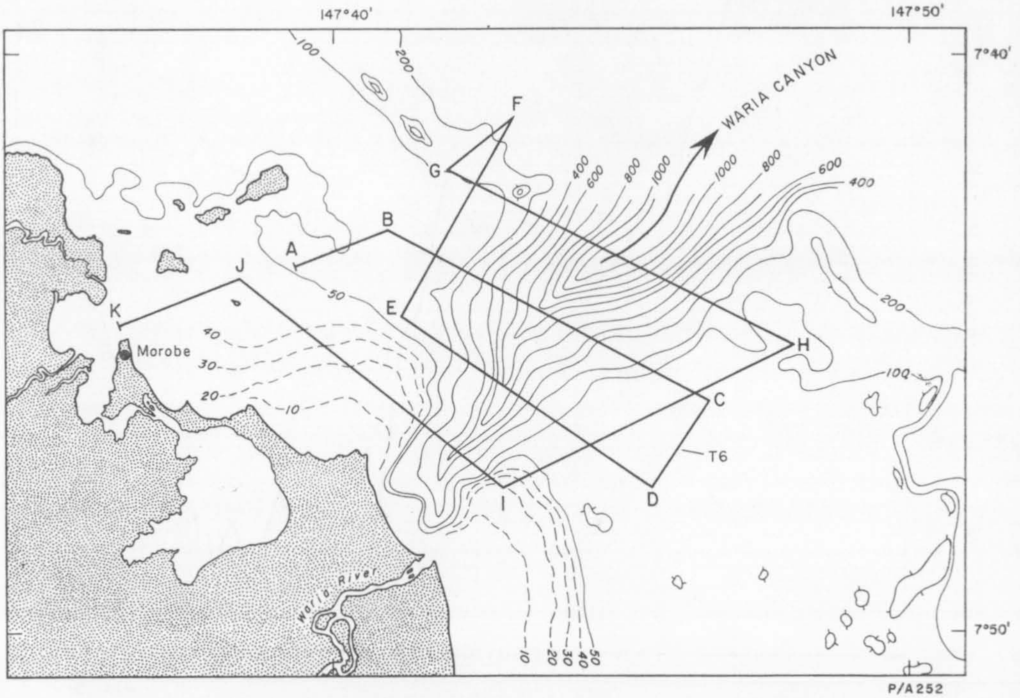
8. Cross-sections of the Markham Canyon. For locations see Plate 1. Vertical scale exaggeration x11.

3 to 4 knots, and is being moved directly into the submarine canyon, where it apparently slumps downslope to the basin. On existing sparse evidence it is only possible to speculate on the geometry and lithology of the resulting deep basin deposit. However, it would most probably be forming an abyssal fan where the canyon emerges at the base of the steep slope, possibly at the western extremity of the New Britain Trench. Conglomeratic and sandy sediments are likely to be mixed with slumped argillaceous sediment derived from the river's suspended load, resulting in large-scale pebbly mudflows. These probably grade laterally into finer-grained turbidites basinwards.

Repeated submarine disturbances caused by slumping of mud deposits from the Markham River have been noted by residents in and near Lae. Resulting slump topography is evident on some of the echo-sounding records, taken over a steep mud bottom near Lae wharf. The records show a highly irregular bottom topography, in complete contrast to the normally smooth contours expected in a depositional area.

Francisco Canyon

Immediately southeast of Parsee Point, a well defined canyon cuts across the shelf towards the estuary of the Francisco River. Lack of sounding data makes this canyon's seaward extent uncertain, although on regional topographic



9. Bathymetric map of the Waria Canyon. Contours in metres. Location of Sparker Traverse No. 6 indicated by letters.

considerations it must join the Markham Canyon and drain into the New Britain Trench. Like other large rivers in the area, the Francisco is currently delivering a heavy load of sediment into the ocean in the vicinity of the canyon, including a coarse sandy bedload.

Waria, Eia, and Gira Canyons

These canyons have been discussed previously by Sprigg (1947). They all extend to within less than a mile of the present shoreline (Fig. 9 and Pl. 2) and each canyon is obviously related to a large river.

The Waria Canyon (Fig. 9) extends to within a kilometre or so of the Waria River estuary, and is apparently intercepting most of the river's bedload and some of its suspended load. The Waria River has produced a well defined deltaic bulge in the present shoreline as well as in the bathymetric contours down to 50 m. This symmetrical deltaic bulge has been breached by the canyon. The present axis of the canyon is at least 500 m below sealevel where it crosses the edge of the deltaic bulge in 50 m of water. At the shelf edge the axis of the canyon is at a depth of over 1500 m. Although the shelf is being downwarped in this area, it is apparent that processes of submarine erosion have been responsible for the major part of this canyon cutting.

The Eia Canyon terminates one and a half kilometres seaward of a pre-existing mouth of the Eia River (Sprigg, 1947) and the Gira Canyon appears about the same distance seaward of the present mouth of the Gira River. Sprigg notes the absence of new canyon formation opposite the new Eia River mouth, which suggests to me that this river has changed its outlet in Holocene times, since the last eustatic low sealevel stand. On this basis it would seem that a drowned channel adjacent to a steep slope may be necessary to trigger off submarine canyon erosion, as this topography would localize the sediment stream. However, at the present day, the Eia River sediment is subject to no such localizing mechanism after reaching the shelf, and is thus at present constructing a delta.

SPARKER TRAVERSES

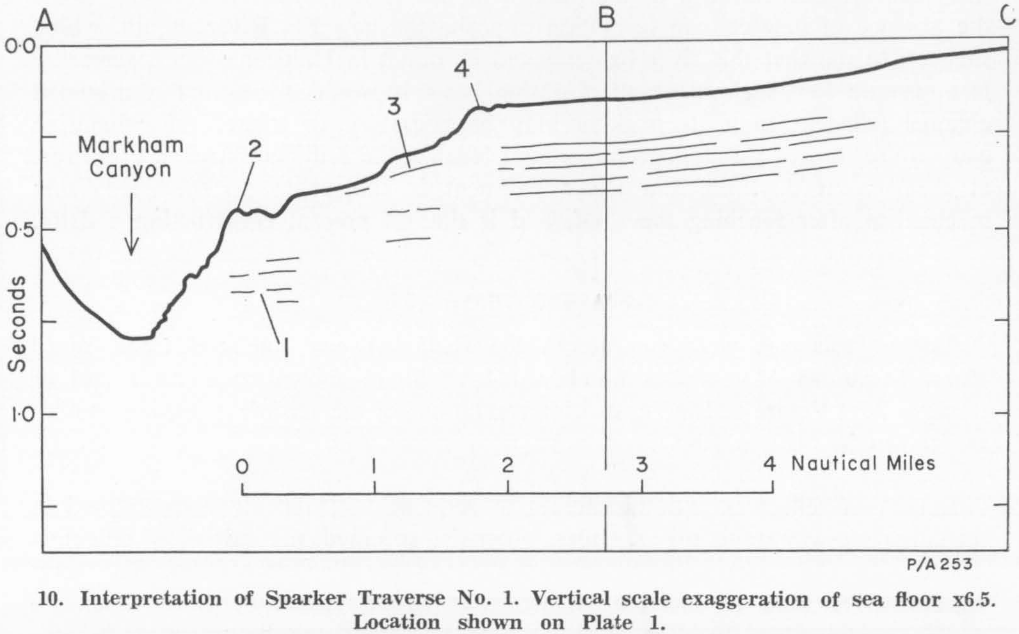
Sparker traverses were run across the shelf between Lae and Cape Ward Hunt. Locations of traverses numbered 1 to 6 are shown on Plate 1 and of traverse 7 on Figure 9. Line-drawn interpretations of the seismic reflection profiles are shown in Figures 10-17.

Depths of reflectors and thicknesses of sequences of reflectors are quoted in seconds (two-way travel time). Unless otherwise specified, the attitude of reflectors will be stated as the apparent altitudes along the line of section. The term 'basement' is used to indicate an irregular strong reflector below which no obvious sedimentary bedding exists. Where basement can be traced to islands or to the mainland within the study area, it is invariably composed of ultrabasics and volcanics of the Papuan Ophiolite Province.

Traverse 1

Traverse 1 (Fig. 10) begins at point A on the steep slope leading into the Markham Canyon. The record is of poor quality, but some interesting features can be detected. The canyon axis, at a depth of 586 m, has a flat floor. The south wall of the canyon truncates some reflectors at 1*, proving the canyon to be in part an erosional feature. Above the canyon rim, at 2, the continental slope shows indications of reflectors parallel to the surface slope, as at 3. At 4, at the present break in slope between the shelf and slope, a knoll appears which, because of its location and seismic reflectivity, is almost certainly a Pleistocene or Recent coral reef. Reef coral is virtually opaque to the seismic energy of the low-power sparker system used. From the shelf-break across the shelf to C, a series of closely spaced reflectors occurs to a depth of at least 0.25 seconds beneath the shelf.

This traverse lies within a zone of extremely high turbidity, caused by suspended Markham River sediment. Much of this argillaceous sediment is settling on the shelf and slope, causing up-building and outbuilding. Such a highly turbid environment as exists today would inhibit the formation of coral reefs. When reef building occurred is therefore somewhat puzzling, as the river would have presumably been even more active than at present during Pleistocene low sealevel stands. One possibility would be that changes in the ocean current regime may have maintained clear water in the vicinity of the outer shelf in this area in the past, and allowed coral growth.



10. Interpretation of Sparker Traverse No. 1. Vertical scale exaggeration of sea floor x6.5. Location shown on Plate 1.

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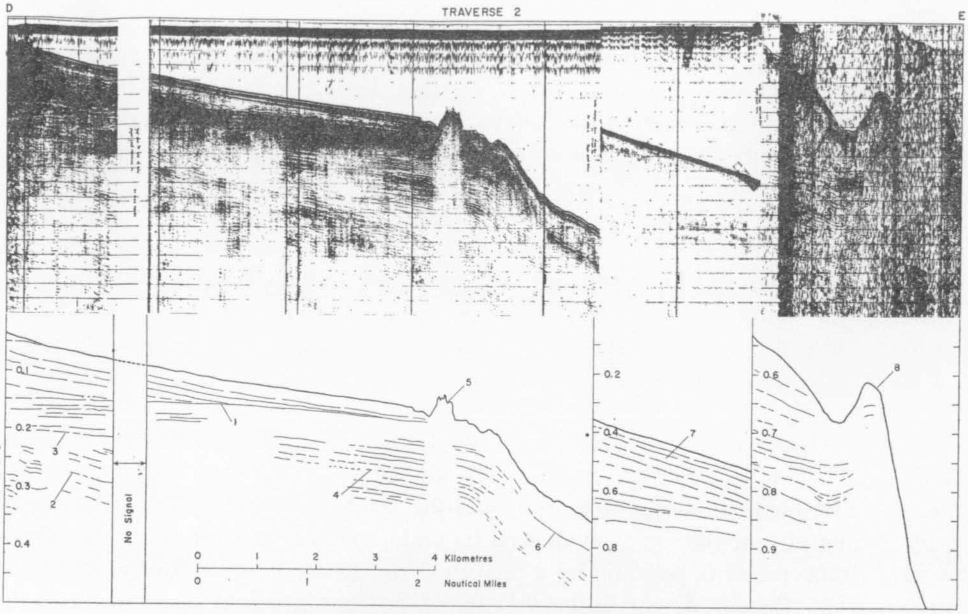
* Numbers quoted in description of the sparker traverses refer to localities indicated on the line-drawn interpretations.

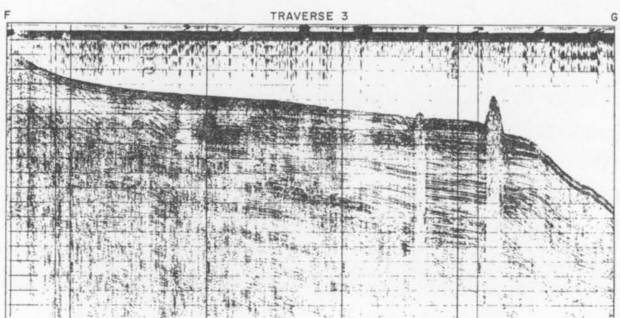
Traverse 2

Traverse 2 (Fig. 11) begins close inshore at point D and extends across the shelf, here 6 km wide, and down the upper slope to a water depth of 732 m. A strong sub-horizontal reflector (1) is evident across the entire width of the shelf, overlain by foreset beds of modern deltaic outbuilding. This reflector may represent an erosional surface developed during the last low sealevel stand, which occurred about 30,000 years ago (Kulp, 1965). The present shelf surface is parallel to the foreset beds and is a depositional zone receiving the suspended sediments of the Ingari and Markham Rivers. Below reflector 1 on the shelf a thickness of at least 0.2 seconds of bedded sediments is present. These sediments show some tilting and gentle folding at 2, beneath a strong reflector 3. However, towards the outer shelf at 4, deeper beds are conformable with the present surface. A well defined Pleistocene or Recent coral reef about 33 m high occurs at 5 and evidence of current scour can be seen on either side of it. The reef is apparently perched on the sediments of the outer shelf, because reflectors may be extrapolated and matched across the seismic shadow zone. Also there is a faint indication of reflectors crossing the shadow zone about half way down the record. The break in slope at the edge of the shelf here is at 117 m. The upper slope is one of outbuilding, as evidenced by underlying parallel reflectors. However, a strong reflector at 6, overlain by a disturbed zone, may be indicative of slumping at this level. Deeper down, in the vicinity of 7, slope gradient decreases and the surface is underlain by conformable beds at least 0.25 seconds in thickness. A marked change in slope occurs at 8, in the vicinity of a channel or small submarine canyon. Here, the relatively flat-lying beds appear to be truncated by the steep slope below 8, although the irregular bottom relief in this area is clearly responsible for a number of spurious reflections and this interpretation must be tentative. The channel is underlain by down-curved reflectors, suggesting that it has been maintained in its present position and has cut and filled its way up through the section as sedimentation has proceeded. However, some curvature in the sub-channel reflectors would be produced by the deeper water column above the channel, assuming a significantly higher velocity in the sediments than in water, and spurious reflections from oblique path waves are also to be expected.

Traverse 3

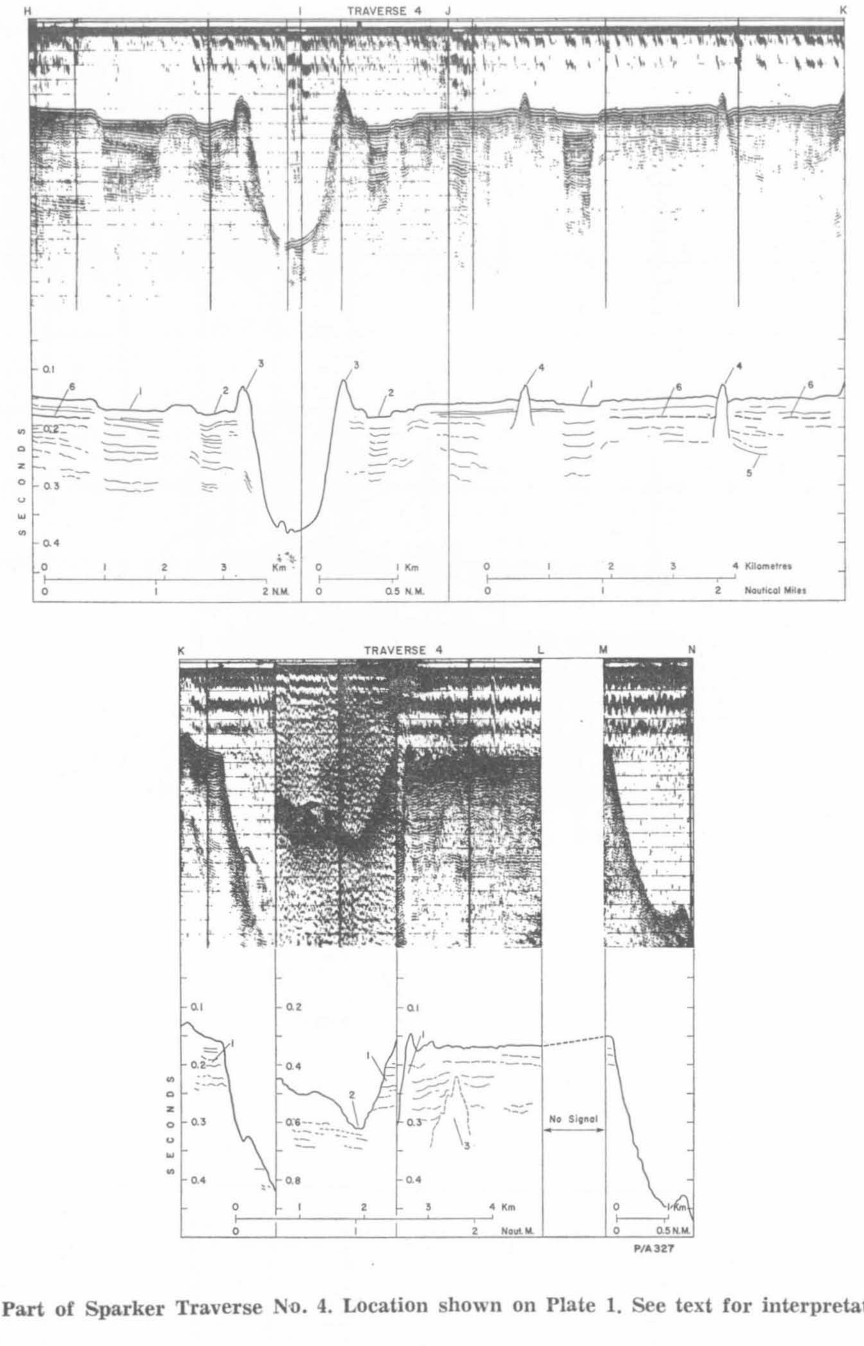
The profile of Traverse 3 (Fig. 11) is similar to that of Traverse 2. It begins at point F, on the deltaic bulge opposite the Buang River. Reflector 1, possibly correlating with its counterpart in Traverse 2, may represent the surface exposed during the last low sealevel stand at about 30,000 years B.P. Above this, as in Traverse 2, well defined deltaic foreset beds occur, wedging out rapidly across the shelf. The relatively steep slope near F represents the major outbuilding slope of the submarine portion of the Buang delta. Farther across the shelf, a small coral reef structure appears at 2, with the major reef build-up at 3, near the break in slope. Scouring is evident around both structures. As before, both of these



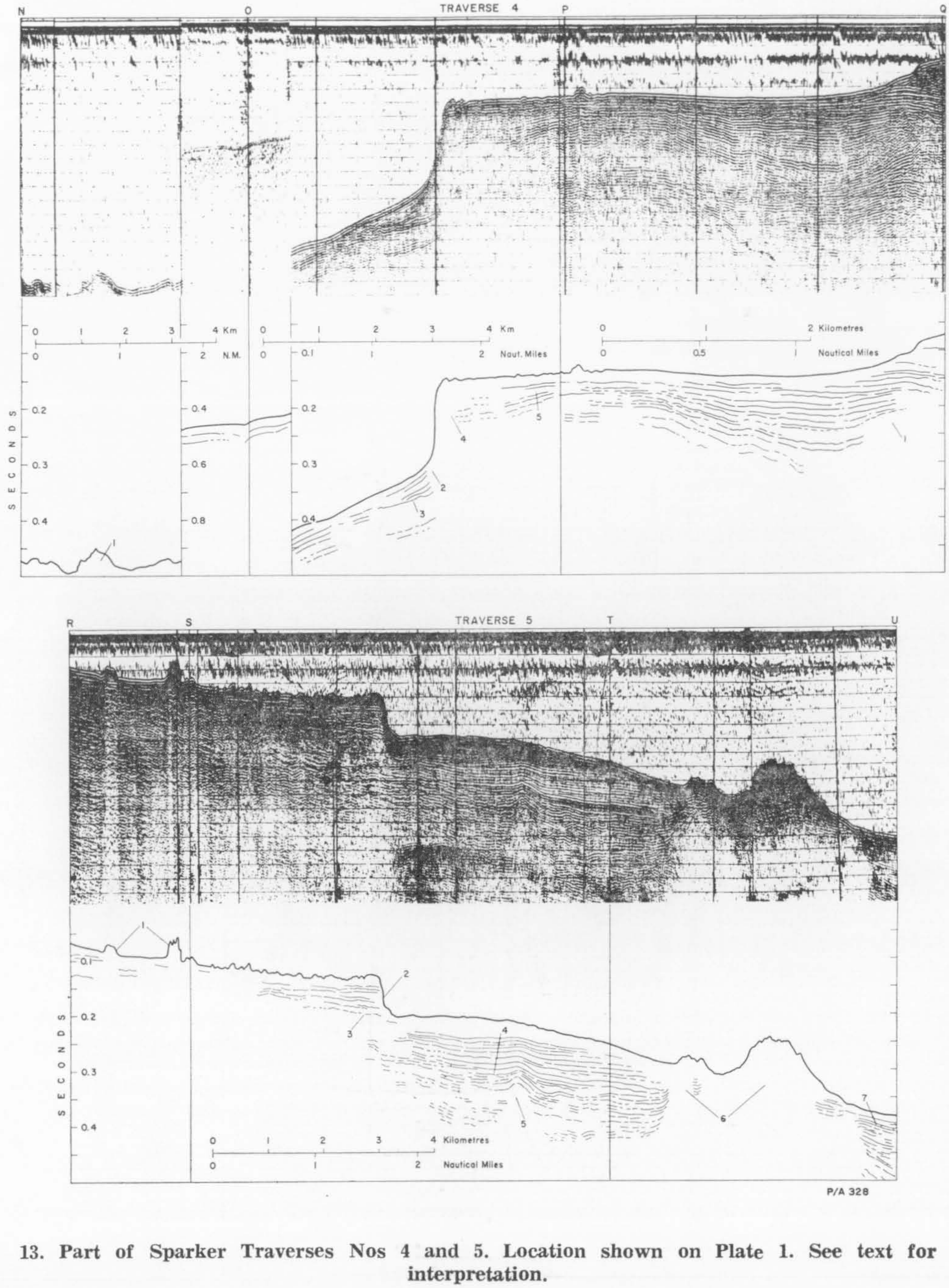


11. Sparker Traverses Nos 2 (above) and 3. Location shown on Plate 1. See text for interpretation.

reefs are perched near the top of the sediment column, as evidenced by matching reflectors on either side of the underlying shadow zone. Reef building possibly began during the Holocene rise in sealevel, and there is no evidence to suggest that the reefs were built up with the sediment column at the shelf edge.



12. **Part of Sparker Traverse No. 4. Location shown on Plate 1. See text for interpretation.**



13. Part of Sparker Traverses Nos 4 and 5. Location shown on Plate 1. See text for interpretation.

The depth of shelf-edge break of slope along this section is 117 m. Seaward of 3, the slope is underlain by conformable deposits, except in the vicinity of 4, where large-scale slumping is evident.

Traverse 4

Traverse 4 is illustrated in Figure 12 and 13. It begins with section H-I-J-K, representing a profile across the shelf and down the upper slope normal to the shoreline trend, a return traverse up the slope, and a line sub-parallel to the shoreline. The most outstanding features on this portion of the traverse are the graben-like structures 1 and 2, tentatively correlated as numbered on Figure 12. Both are associated with depressions in the section, and a relatively thick succession of reflectors occurs beneath the depressed zones. Furthermore, they lie within areas of bedded sediments, as evidenced by subsurface reflectors occurring on either side of the possible grabens. If graben 1 has been correctly correlated from section H-I to section J-K, then a trend sub-parallel to the coast and to the trend of Parsee Point is indicated. Coral reef formation is apparent at 3, at the shelf edge. Possible basement ridges or coral reef developments appear at 4 as the traverse line approaches shore. Evidence of structural deformation appears at 5. A strong reflector 6, visible only in shallower water regions and overlain by horizontal strata, may be an erosional surface formed during the last low sealevel phase.

Section K-L-M-N traverses the axis of the Francisco Canyon. Subhorizontal strata, truncated by the canyon walls, are evident at 1. Subhorizontal layering is also apparent below the canyon axis. The canyon itself (2) has a flat floor. Complex overlapping reflections at 3 may represent an irregular basement high.

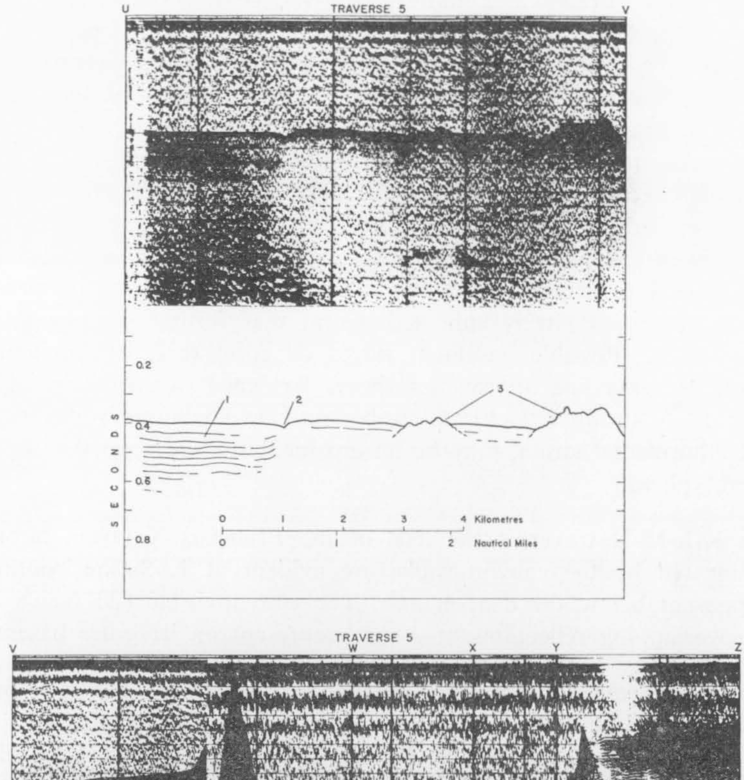
Section N-O-P extends from the offshore extension of Parsee Point to the continental slope and shelf. Rough bottom topography is evident at 1, opposite Parsee Point, in a water depth of 360 m. From a point just seaward of O to position 2, conformable slope deposits appear to have prograded over strong reflector 3. A steep slope occurs above 2, slightly oversteepened in the record by faulty reproduction. Evidence of truncation of subhorizontal reflectors by this slope, either by faulting or by slumping and erosion, appears at 4. Shoreward of 4 the shelf is underlain by conformable deposits over a possible unconformity at 5.

Section P-Q of this traverse extends parallel to shore into Salamaua Harbour. A succession of reflectors at least 0.2 seconds in overall thickness is present. These reflectors have a basin-like form. Structural disturbance increases down-section; and possible basement produces complex parabolical reflectors at 1.

Traverse 5

Section 5 (Figs 13 and 14) extends from Baden Bay, across the shelf between bedrock islands, along the slope parallel to the shelf-break and back across the shelf.

The first part of the profile (R-U) represents a traverse from Baden Bay across the shelf to the upper slope. Two knolls, possibly coral reefs (1), are crossed in Baden Bay. From S to position 2 the present seafloor has an extremely irregular form, underlain by horizontal reflectors down to what may be relatively shallow basement at 3. A distinct scarp occurs at 2, possibly related to faulting.



14. Part of Sparker Traverse No. 5. Location shown on Plate 1. See text for interpretation.

On the seaward side of this break, a sequence of well bedded subhorizontal sediments extends down to 4, draped over a possible bedrock ridge at 5. Farther seaward, at 6, a well defined basement area forms a peak flanked on the seaward margin at 7 by conformable slope deposits.

The portion of the traverse from U to V represents a section sub-parallel to the continental slope. Well bedded conformable deposits occur at 1. A possible channel at 2 may represent the distal portion of a small submarine canyon. Two bedrock inliers crop out on the seafloor at 3, surrounded by horizontal sediments.

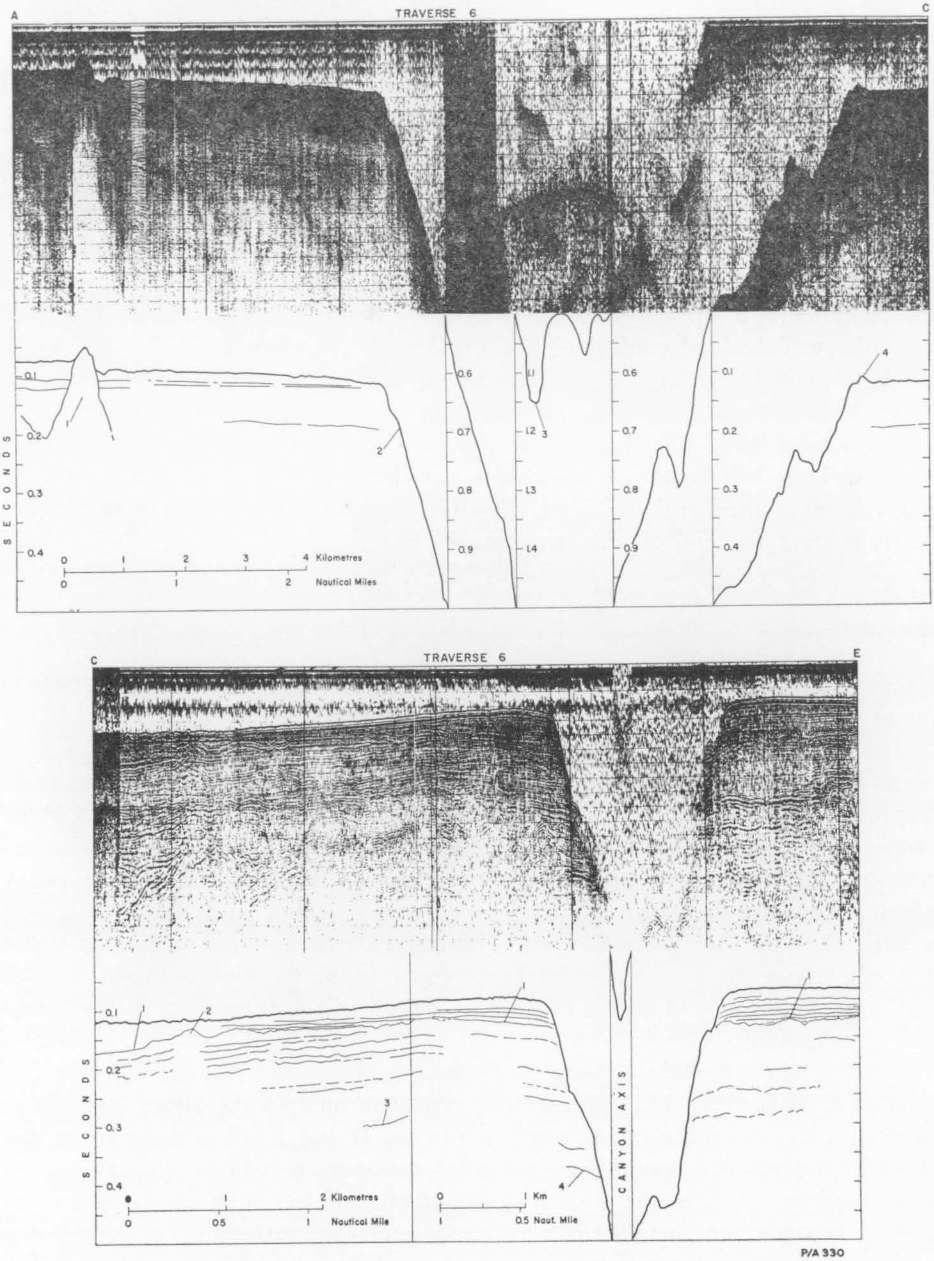
Section V-Z extends from the upper continental slope across a pinnacle-like bedrock inlier and up the slope to the shelf. Bedrock crops out at 1 and is flanked by well bedded conformable slope deposits. A steep bedrock peak at 2, possibly topped by coral reef, is flanked on the landward side by a series of bedded sediments parallel to the present slope of the seafloor. A strong reflector at 3, associated with a complexity of parabolic echoes, may represent irregular basement. The shelf break occurs at a water depth of 102 m, and a coral reef again occurs at the break in slope. Possible basement occurs below the strong reflector 4 near the end of this traverse.

Traverse 6

Traverse 6, from A to K (Figs 15-17), embraces the portion of the Waria Canyon on the continental shelf as well as the Waria River delta.

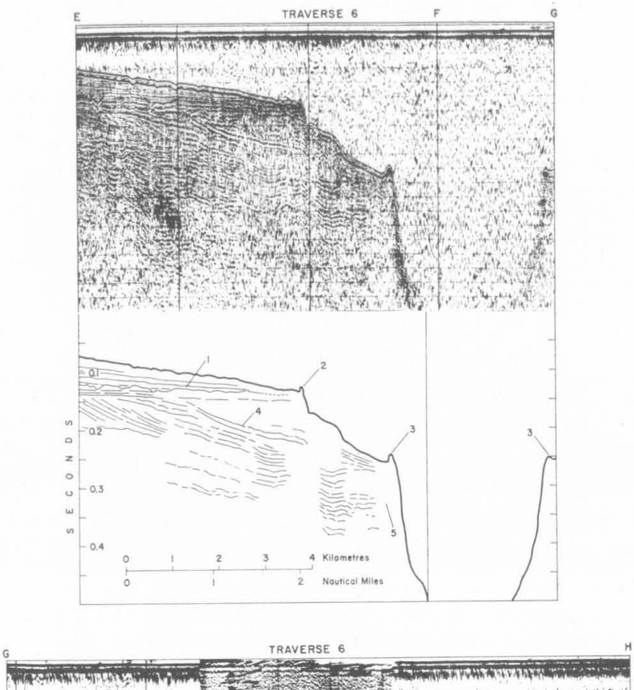
Section A-B-C (Fig. 15) shows a cross-section of the Canyon and associated sedimentary framework half way across the shelf. A distinct basement ridge appears at position 1, associated with islands off Morobe Harbour. Horizontal strata or deltaic foreset strata dipping normal to the line of section occur conformably below the shelf on either side of this ridge, and these strata are truncated at 2 by the Waria Canyon. The canyon axis appears at 3, at a water depth of 790 m. A possible coral reef occurs at 4, on the southeast rim of the canyon. Below 4, and on the other side of the canyon, truncation of horizontal strata is suggested.

Section C-D-E (Fig. 15) represents a profile normal to the shore from C to D, followed by a crossing of the canyon between D and E. Most notable on this section is the strong, continuous, irregular reflector 1, which appears on all seismic sections taken in the area in water depths of less than about 90 m. As before, it is suggested that this is a subaerial erosional surface developed during the last low sealevel stand. If this is true, then about 0.07 seconds (2-way time) of flat-lying Holocene sediments overlie this surface. Assuming a velocity of about 1700 metres per second for these sediments, a thickness of about 60 m has been deposited in the area during the past 20,000-30,000 years. Below unconformity 1, a section of subhorizontal sediments at least 0.13 seconds in thickness



15. **Part of Sparker Traverse No. 6. Location shown on Figure 9. See text for interpretation.**

shows signs of slight structural disturbance. A possible basement high at 2 penetrates surface 1. Irregular basement, represented by complex parabolical reflectors, possibly occurs below strong reflector 3, at a depth of about 0.2 seconds below the seafloor, and may crop out on the canyon well below reflector 4. Above 4, and also on the opposite wall of the canyon, subhorizontal strata are truncated.



16. Part of Sparker Traverse No. 6. Location shown on Figure 9. See text for interpretation.

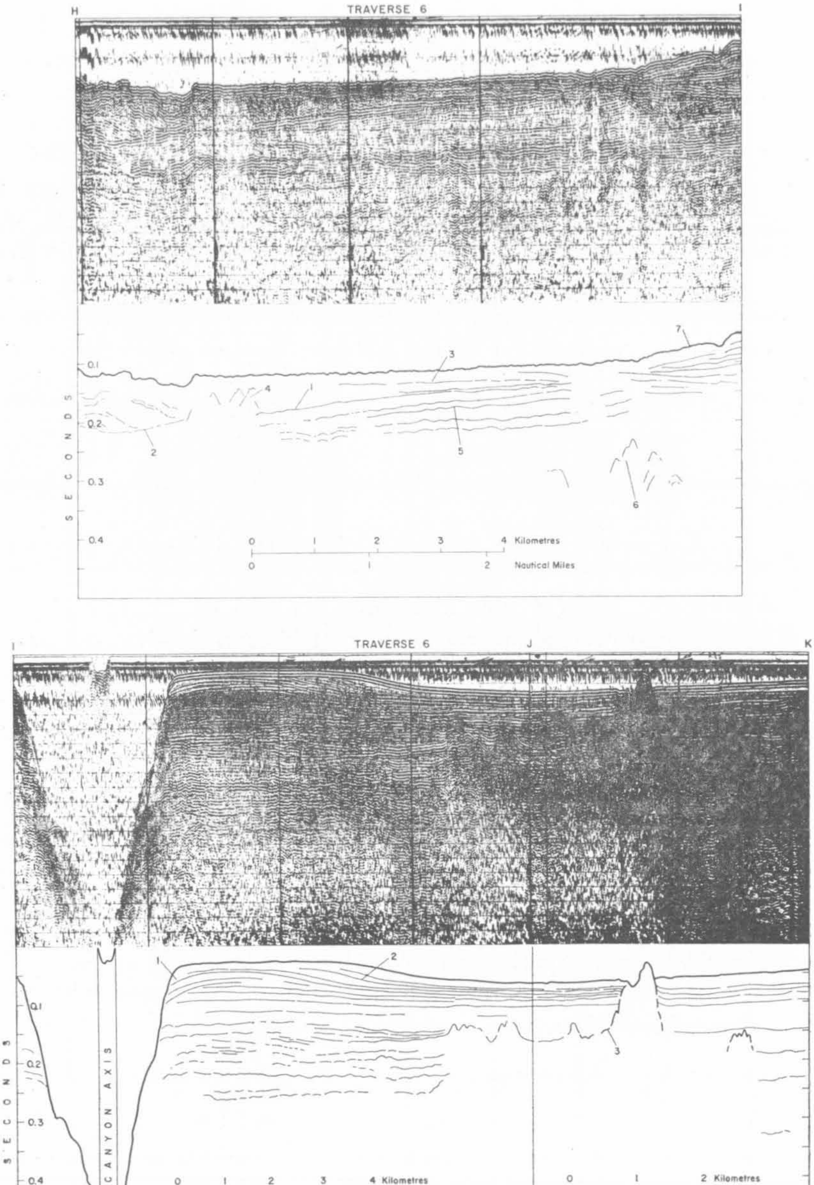
Section E-F-G (Fig. 16) represents a profile across the shelf from the submarine deltaic bulge off the Waria River to part way down the upper continental slope. Seismic reflector 1, a Pleistocene channelled erosional surface, is present in this section. As in previous cases, this may be a subaerial erosional surface related to the last low sealevel stand. This surface extends out towards the shelf edge, but loses its notable channelled appearance in the vicinity of 1. Above 1, a wedge of Recent sediment thinning seawards has prograded to the break-in-slope at 2 at a water depth of 97 m. Above the break-in-slope a possible coral reef occurs. From this point the continental slope has a relatively gentle gradient, and a deeper break-in-slope occurs at 3 at a water depth of 190 m, once again surmounted by a possible reef. Reflector 1 is underlain by a well developed series of deltaic foreset strata presumably of Pleistocene age, including a particularly strong reflector at 4. These foresets extend seawards at least as far as the break in slope at 2. The steep continental slope below 3 appears to truncate a series of rather incoherent subhorizontal reflectors at 5.

Section G-H (Fig. 16) crosses the Waria Canyon almost at the edge of the shelf. Along this section, the axis of the canyon (1) is crossed at a water depth of 1190 m, and horizontal reflectors are present below the floor of the canyon. As in previous cases, the canyon has dissected the apparently horizontal strata of the shelf. A small tributary canyon appears at 2, also cutting strata. At position 3 a strong reflector occurs, underlain by a complexity of reflectors suggestive of basement, in which case 3 would be bedrock surface. Alternatively, the complexities could be due to previous coral reef development. This area of the shelf has a rather rough present-day surface, and appears to be a zone of no deposition. It is interesting to note that in this vicinity a current with a surface velocity of about 2 knots northwestwards was observed.

Section H-I (Fig. 17) represents a profile across the shelf approximately normal to its trend. A strong reflector dipping seawards is evident at 1, and this appears to correlate with 2. Above this at 4 a wedge-shaped body of material represented by complex parabolic reflectors occurs, and reflector 1 is attenuated below its thickest development. On present knowledge this is attributed to coral reef building. Farther inshore from 4, at position 3, well defined horizontal reflectors appear at a stratigraphic level equivalent to 4, representing probable back-reef facies. Below reflector 1, at position 5, minor structural deformation occurs in a series of reflectors conformable with the surface. Complex reflections at 6 may represent basement. At 7 the line of section crosses the seaward slope of the bulge of the Waria River submarine delta, and foreset beds of modern delta building are evident.

Section I-J-K (Fig. 17) crosses the Waria Canyon at a line immediately seaward of the canyon head, then traverses the submarine deltaic bulge of the Waria River and heads into Morobe Harbour. As in previous sections, the Canyon dissects the apparently horizontal beds of the inner shelf. The depth of the axis of the canyon at this crossing is 384 m. Modern shelf sediments appear to drape over the rim of the canyon at 1, and distinct foreset beds of the modern

Waria delta appear at 2 on the deltaic lobe. Definite basement occurs below irregular reflector 3, overlain by bedded sediments. Immediately to the east, basement emerges above sealevel as islets, which are formed of rocks of the Papuan Ophiolite Province type. Morobe harbour is floored in the vicinity of the heads by a thickness of bedded sediment in excess of 0.1 seconds.



17. Part of Sparker Traverse No. 6. Location shown on Figure 9. See text for interpretation.

DISCUSSION

HUON PENINSULA CONTINENTAL MARGIN

The conspicuous absence of continental shelf development on the Huon Peninsula east of Lae, as discussed earlier, may be due to a combination of factors. Steep submarine slopes are immediately juxtaposed to the land in the area, as a result of present-day tectonism. These slopes lead down directly to an oceanic trench, and any sediment delivered by nearby rivers would almost certainly be in an unstable situation and would slump or flow downslope to the basin floor. In addition, the area is very young geologically. If conditions were to be stabilized as they are now, a continental terrace could not form in the area until the adjacent ocean basin was almost filled with sediment. During such filling, abyssal fans would onlap the steep slope and so lessen the angle, allowing subsequent progradation of the terrace. However, the area in question is emerging at a geologically very rapid rate at the present time and the ocean basin floor may be sinking, precluding the possibility of stabilization.

LAE/CAPE WARD HUNT CONTINENTAL TERRACE

In contrast to the Huon Peninsula region, the area of the Lae/Cape Ward Hunt shelf has experienced a somewhat different history. Sparker traverses show the shelf to be largely or entirely a depositional feature, consisting in most areas of a series of coalescing deltas, prograded over older deltaic deposits or over a drowned irregular basement. The whole area coincides with the Papuan Ophiolite Province, which has been relatively stable and slowly subsiding, at least in coastal regions, since at least early Pliocene time, when, according to Thompson (1967), the present outline of New Guinea may have formed. This relatively long time factor, coupled with the slow subsidence of the area and gentle submarine slopes, has allowed the observed sedimentary build-up. The situation has undoubtedly been complicated by Pleistocene sealevel fluctuations, as evidenced by at least one unconformity seen in sparker records. However, the overall picture is one of deltaic sedimentation on a subsiding basement, with the deeper strata showing almost no signs of tectonism.

Present-day depth to break of shelf ranges from 109 to 117 m, and may have been controlled by Pleistocene low sealevel stands. Coral reefs are developed apparently perched on the sediments above this break-in-slope, and have apparently grown up during the Holocene transgression. In some areas reef upgrowth has not kept pace with the rising sealevel, and reef tops are as much as 40 m below present sealevel. In other areas, particularly in clear waters, reefs have remained essentially at sealevel.

Below the break of shelf, a relatively gentle continental slope of about 1:6 exists, underlain by conformable sedimentary deposits showing local slumping. The continental terrace is apparently building upwards and outwards, with slumping in steeper sections, a situation which is not uncommon elsewhere (Curray & Moore, 1964). However, in all sparker sections that extend far enough down the slope, a deeper break-in-slope is found at water depths varying from 192 to 457 m. What may be coral reefs form knolls above this deeper change of slope, in much the same manner as at the shallower break. This is interpreted as being an older Pleistocene break or breaks of shelf with associated reef developments, downwarped to present depths.

SUBMARINE CANYONS

Submarine canyons in the area of study may be of varying ages. Some may have been initiated during Pleistocene low sealevel stands when rivers would have cut gorges or valleys across the exposed shelf and deposited their sedimentary load in the vicinity of the continental slope. However, in many areas of New Guinea shelves are absent and steep submarine slopes are juxtaposed to the shoreline. In such cases, eustatic sealevel changes may not be necessary for initiation of canyons.

The Markham Canyon may be placed in the last category. It is structurally controlled, and follows a structural lineament which also controls the course and outlet of the Markham River. Sediment transported by the river, probably mainly the bedload, is apparently capable of powerful erosion to form the canyon, which is the major sediment conduit of the region to the ocean basin. Erosion of subhorizontal strata is evident in sparker traverses across the canyon.

The Francisco, Waria, Eia, and Gira Canyons all cut across 11 to 16 km of continental shelf to head opposite existing or pre-existing river mouths. Wherever they have been traversed, truncation of sub-horizontal partly deltaic strata is evident on sparker records. The Waria Canyon also has strata of apparent Holocene age draped over its rim.

Like the continental slope, the ultimate age and growth mechanism of these canyons can only be conjectured. Two alternative hypotheses are put forward below.

1. The canyons were initiated during the Tertiary when the present shoreline was morphologically blocked out and they have been maintained in approximately their present positions on the shelf during sedimentary up-growth. Apparently the basement has subsided, and shelf sedimentation has approximately kept pace with the subsidence. If pre-existing on-shore structures or morphology had positioned rivers at approximately their present localities, then localized supplies of sediment for down-cutting the canyons would have been ensured.

Thus the rivers' bed loads would maintain and deepen the canyons whilst the suspended loads would largely flocculate and settle to form offshore deltaic lobes around them. Such fine-grained sediment would undoubtedly drape over the rims of the canyons, as was observed in the Waria Canyon. However, superficial deposits such as these on the edges of the canyons would tend to be unstable and would often be removed by slumping. If such processes persisted, then canyons could be progressively deepened during shelf formation by both down-cutting their floors and up-building their rims. The overall effect observed on sparker records would be the truncated strata in the walls of the canyons.

2. The alternative hypothesis is that the canyons were initiated during Pleistocene low sealevel stands when the rivers were graded to lower base levels and incised pre-existing deltaic deposits to form valleys or gorges across the shelf. Canyon formation due to submarine erosion by sediment would then have been initiated in the continental slope zone. Subsequently the rise in sealevel would once again have returned the shoreline to about its present position, and the drowned valleys so produced would trap and channel much of the river's sediment to the deep sea, causing additional downcutting.

Although Pleistocene processes outlined in the second hypothesis undoubtedly were operative, I believe that the canyons in this area antedate the Pleistocene, and that eustatic sealevel changes are not essential for formation of canyons. First of all, there is much evidence indicating that submarine canyons have been formed throughout geological time. Canyons buried in the geological record have been detected by seismic means (Conolly, 1968; Hopkins, 1966). Other unburied canyons show geological evidence of having been in existence since pre-Pleistocene time (von der Borch, 1968). However, the strongest argument in favour of a pre-Pleistocene origin for northeastern New Guinea canyons is based on their axial gradients across the continental shelf. For the Waria, Eia, and Gira Canyons, axial gradients quoted by Sprigg (1947) range from 1:9.6 to 1:12.7, averaging about 1:11 (5°). Such a slope is much steeper than the present shelf gradient, which is considerably less than 1°. It is simpler to envisage this 5° slope as being a slightly modified relic persisting from pre-shelf times. This slope in the channels would have been preserved by down-cutting of the canyons and up-growth of the shelf; and definite evidence exists from sparker records across the Waria Canyon that such a process has operated at least during Holocene times.

REGIONAL SEDIMENTATION

Sediment derived from the geologically young landmass of New Guinea in this area is either trapped on the growing Lae/Cape Ward Hunt shelf or is channelled into the Solomon Sea Basin and the New Britain Trench. Although the mechanisms responsible for such large scale movement of sediment are as yet undocumented, it is apparent that some form of submarine flow is required. Possible mechanisms include creep, slumping, and turbidity currents. On bathymetric evidence, sediment that escapes the continental terrace becomes channelled into the vast submarine drainage system comprising the Markham Canyon and its major tributaries, the Francisco, Waria, Eia, and Gira Canyons. Most of this sediment must ultimately come to rest at the base of the basin slopes, and must be slowly filling the New Britain Trench. There is no evidence on how far this filling process has gone to the present day; it is possibly only in its initial stages. However, it is certain that the depositional processes observed today also operated in the past in forming some of the sedimentary masses which are now parts of mountainous New Guinea.

ACKNOWLEDGMENTS

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APPENDIX

RECENT MARINE SEDIMENTS OF THE CONTINENTAL SHELF SOUTH OF LAE, NEW GUINEA

by

F. Walraven

SUMMARY

Forty-nine bottom samples were collected along 80 km of the coastline of New Guinea south of Lae. Except for six samples from near the mouth of the Markham River, all were collected from the continental shelf and upper slope in water depths of 15 to 293 m.

The shelf can be broadly divided into two areas: south of Salamaua there are shelf-edge reefs; and to the north there are none. In the northern area there is a relatively consistent decrease in grainsize and increase in carbonate content seawards. Sorting of the sediments also becomes progressively poorer away from the shore. To the south the influence of the offshore reefs is reflected in the local disruption of this pattern, with rapid variations in grainsize and sorting which can be related to shelf morphology.

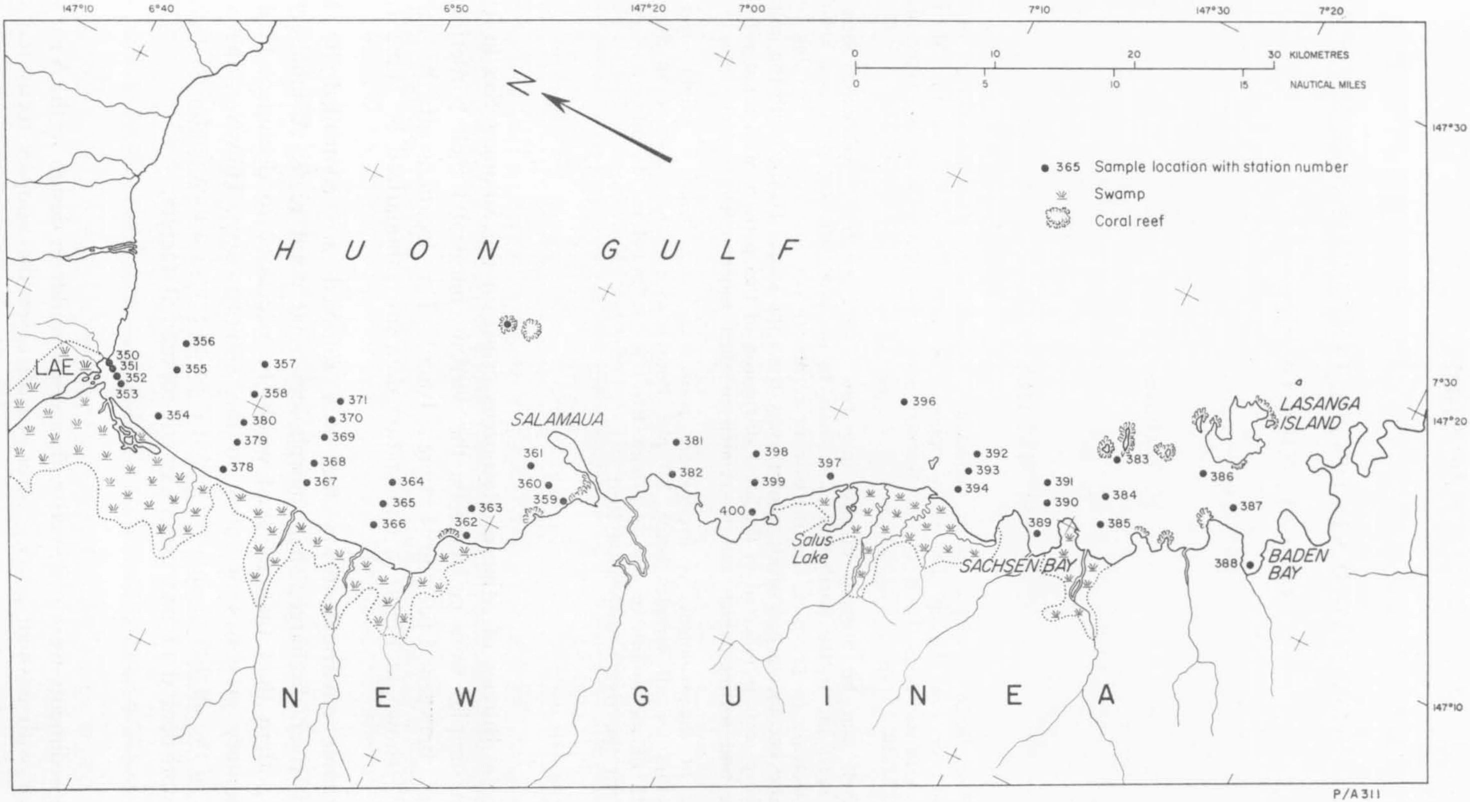
Sorting of the sediments is everywhere poor, the mean inclusive graphic standard deviation value for all samples being 2.0 phi. Poorer sorting than average in the area to the south of the mouth of the Markham River is attributed to the admixture of fine material from the river's suspended load.

During the Bureau of Mineral Resources cruise in the Solomon Sea in 1968, 49 bottom samples were collected on the narrow continental shelf bordering the Huon Gulf between Lae and Lasanga Island. The locations of the sample stations are shown in Figure a and station data are summarized in Table 1.

Depositional environments in the area sampled are controlled by local influences—river discharge, shelf morphology, and coral reefs. A much closer sampling pattern than that achieved would be necessary to document in detail the sedimentary processes operating in this complex area. However, the interpretations of the analytical data presented here do reveal a meaningful relationship between statistical data and observed environmental factors.

Sampling methods

Bottom sediments were collected with a grab similar in design to the Van Veen sampler, or with a small gravity corer. In all cases the samples recovered were thoroughly mixed and represent the top few centimetres of the sediment.



a Location of sample stations

TABLE 1: STATION DATA

Sample Number	Latitude S Degrees	Latitude S Minutes x10	Longitude E Degrees	Longitude E Minutes x10	Date Mth	Date Day	Date Year	Time G.M.T.	Depth Metres
K 68350	06	439	146	589	FE	01	68	2215	18
K 68351	06	442	146	588	FE	01	68	2338	121
K 68352	06	445	146	587	FE	01	68	2358	190
K 68353	06	448	146	585	FE	02	68	0008	110
K 68354	06	470	146	578	FE	02	68	0245	18
K 68355	06	468	146	599	FE	02	68	0405	124
K 68356	06	468	147	009	FE	02	68	0445	238
K 68357	06	497	147	013	FE	02	68	0520	194
K 68358	06	498	147	003	FE	02	68	0535	146
K 68359	07	021	147	020	FE	02	68	2200	64
K 68360	07	012	147	024	FE	02	68	2215	102
K 68361	07	003	147	029	FE	02	68	2302	113
K 68362	06	594	146	595	FE	02	68	2335	91
K 68363	06	591	147	003	FE	02	68	2355	101
K 68364	06	560	146	598	FE	03	68	0300	108
K 68365	06	560	146	588	FE	03	68	0328	95
K 68366	06	561	146	578	FE	03	68	0400	73
K 68367	06	529	146	584	FE	03	68	0438	49
K 68368	06	529	146	591	FE	03	68	0505	77
K 68369	06	528	147	001	FE	03	68	0525	101
K 68370	06	527	147	008	FE	03	68	0540	102
K 68371	06	527	147	014	FE	03	68	0610	112
K 68372	06	436	146	580	FE	05	68	0000	4
K 68373	06	436	146	580	FE	05	68	0012	4
K 68374	06	436	146	580	FE	05	68	0024	4
K 68375	06	436	146	580	FE	05	68	0036	4
K 68376	06	436	146	580	FE	05	68	0048	4
K 68377	06	436	146	580	FE	05	68	0100	4
K 68378	06	499	146	573	FE	05	68	0400	40
K 68379	06	499	146	584	FE	05	68	0420	64
K 68380	06	499	146	593	FE	05	68	0440	91
K 68381	07	052	147	061	FE	08	68	2215	174
K 68382	07	056	147	048	FE	08	68	2230	110
K 68383	07	205	147	132	FE	09	68	2100	24
K 68384	07	209	147	118	FE	11	68	0221	102
K 68385	07	210	147	106	FE	11	68	0310	77
K 68386	07	238	147	143	FE	11	68	0340	168
K 68387	07	254	147	135	FE	11	68	0450	88
K 68388	07	271	147	114	FE	11	68	0530	29
K 68389	07	191	147	092	FE	12	68	0135	81
K 68390	07	188	147	102	FE	12	68	0205	91
K 68391	07	184	147	115	FE	12	68	0225	152
K 68392	07	158	147	112	FE	12	68	0310	93
K 68393	07	157	147	101	FE	12	68	0340	82
K 68394	07	157	147	091	FE	12	68	0410	15
K 68395	07	124	147	107	FE	12	68	0450	293
K 68396	07	122	147	113	FE	12	68	0525	293
K 68397	07	108	147	074	FE	13	68	0020	101
K 68398	07	078	147	069	FE	13	68	0110	161
K 68399	07	083	147	060	FE	13	68	0150	117
K 68400	07	088	147	051	FE	13	68	0220	110

Grainsize analysis

Two slightly different approaches were used in treating the sediment samples for grainsize analysis. Those samples which, when dry, could be easily disaggregated by hand were quartered down to a 50 g sub-sample and sieved, using a set of sievers with apertures ranging from 2000 microns to 63 microns at 1 phi intervals. The –63 micron fractions were then quartered, if necessary, down to 5 to 10 g for pipette analysis.

Standard pipette techniques were used, as described by Krumbein & Pettijohn (1938) and Folk (1965). Demineralized water was used throughout. Soaking for 24 hours and stirring with a mechanical stirrer was found to disaggregate the clay-size particles adequately.

In order to make the data obtained from the pipette analyses comparable with the results of the sieve analyses, 1 phi intervals were used to arrive at the required depth-time intervals for taking the aliquots. The smallest grains determined were 9 phi (2 microns).

The second approach was used on those samples with a high silt content which were not easily disaggregated by hand. These samples were soaked in demineralized water, stirred mechanically, and wet-sieved on a 75-micron mesh sieve. The +75 micron and –75 micron fractions were then dried at 110°C and the +75 micron fraction was sieved as above.

The fraction passing through the 63-micron sieve was then added to the –75 micron fraction obtained by wet-sieving and this subsample quartered down to 5 to 10g for pipette analysis as above. In theory there should be no –63 micron fraction after sieving, but owing to adherence of small particles to larger ones a small amount usually passed through the 63-micron mesh sieve.

The results of the grainsize analyses are given in Table 2 and the moment measures derived from these in Table 3.

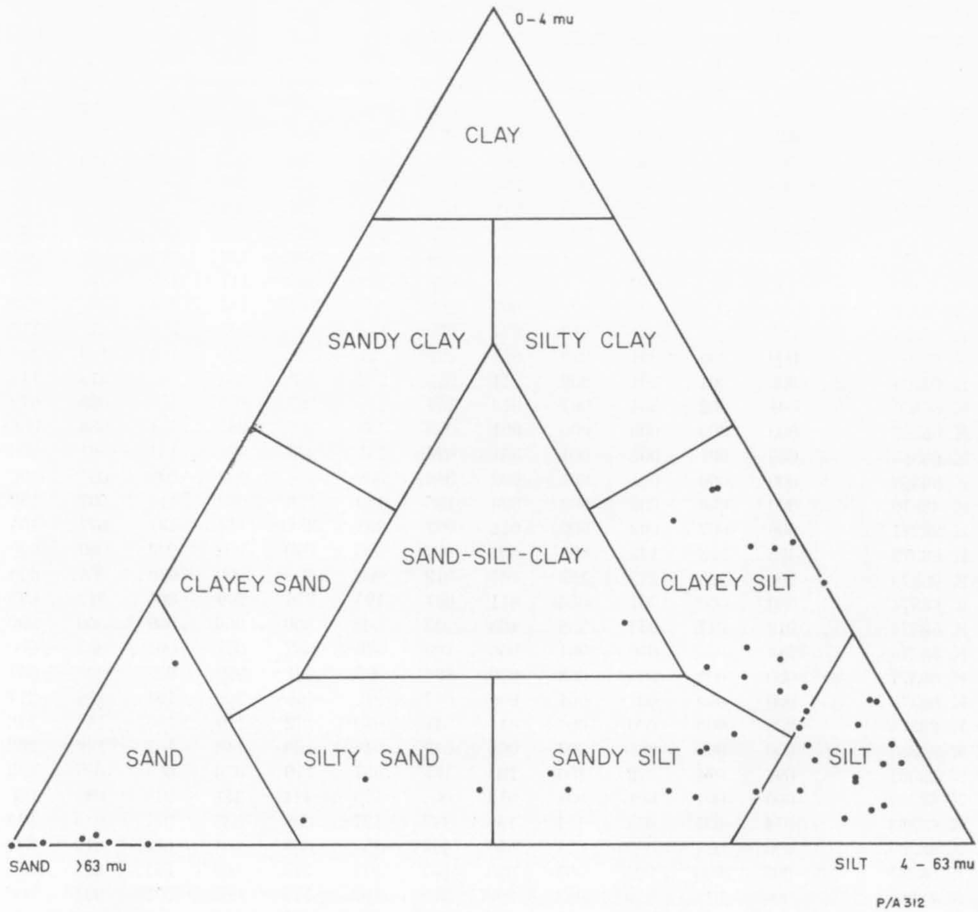
Calcimetry

The calcium percentage calcium carbonate in the samples was determined using apparatus similar to that described by Hűlseman (1967), which measures the volume of CO_2 gas evolved from a known quantity of material. Hűlseman used mercury as the fluid in the burette. This was found to be unsuitable owing to its high specific gravity, which increased the difficulty in equalizing the pressures in the burette and the reservoir. After some experimentation, kerosene was used and it was found that results could be reproduced to within 3 percent. As a check on operational errors, one in each batch of ten samples was duplicated. Results of the calcimetry analyses are shown in Table 4.

TABLE 2: RESULTS OF GRAINSIZE ANALYSES

Percent of total weight x10

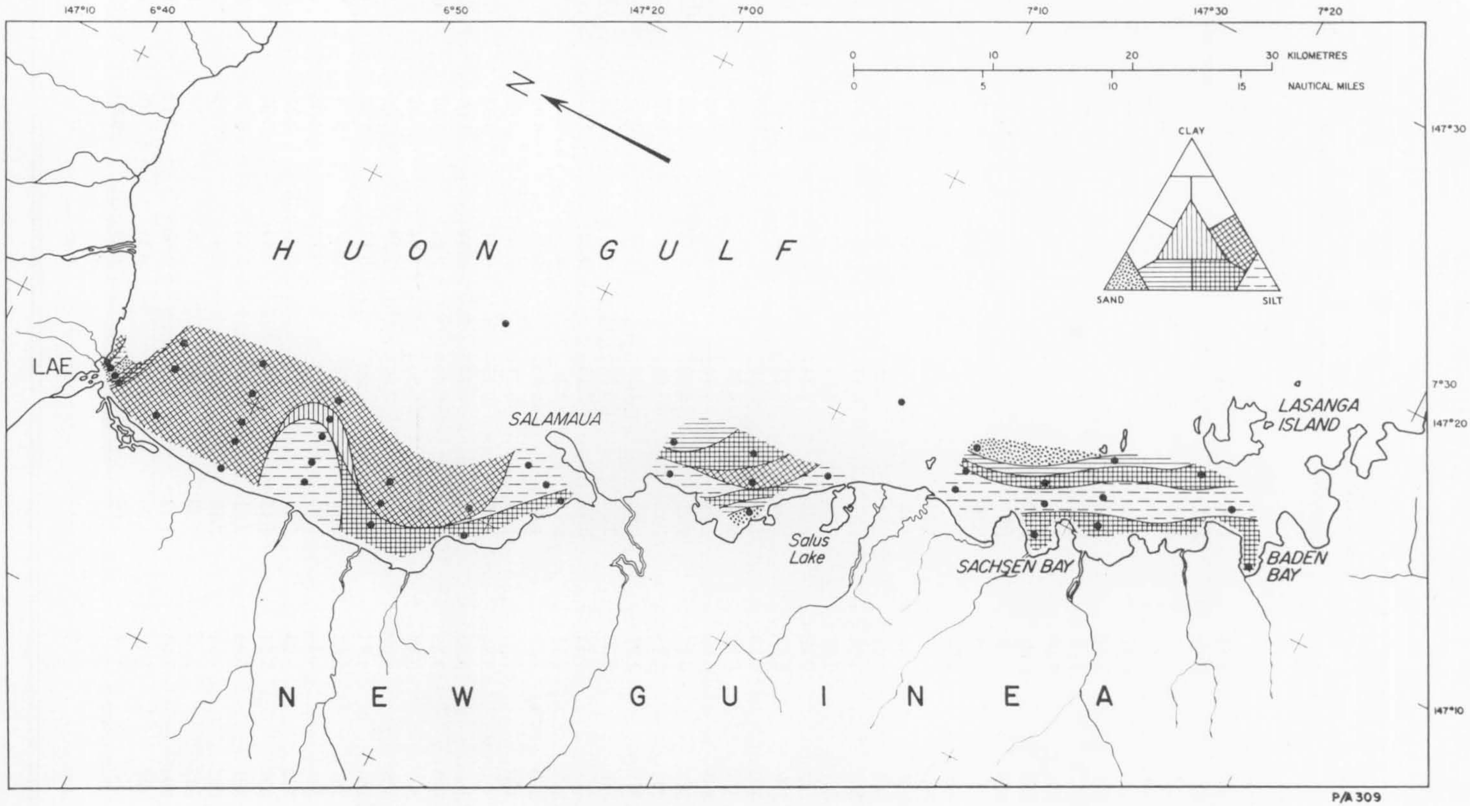
	Size range in phi units											
	<–1	–1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	>9
K 68350	000	001	002	005	008	078	180	241	206	122	080	076
K 68351	000	000	000	000	000	017	113	256	287	159	077	092
K 68352	002	004	009	073	353	464	060	012	005	004	000	012
K 68353	000	000	000	000	000	026	302	289	146	110	063	063
K 68354	000	000	000	000	000	000	047	276	216	150	157	154
K 68355	000	000	000	004	011	075	262	240	139	048	112	107
K 68356	000	000	000	000	000	008	051	182	207	192	156	203
K 68357	000	000	000	001	004	025	126	180	145	163	137	217
K 68358	000	003	005	008	019	083	217	196	124	111	087	146
K 68359	001	004	007	024	077	173	222	229	141	060	024	038
K 68360	001	003	005	012	026	090	241	283	153	074	060	051
K 68361	001	003	008	010	016	079	209	334	117	111	048	063
K 68362	000	001	002	005	007	206	224	214	143	086	054	057
K 68363	000	001	004	013	021	099	124	067	307	165	086	112
K 68364	000	000	004	012	017	087	121	105	121	148	140	245
K 68365	000	001	004	008	011	058	227	258	156	090	075	112
K 68366	001	002	004	007	012	157	186	197	189	114	058	072
K 68367	000	000	000	000	001	025	135	297	281	164	030	066
K 68368	000	001	001	001	001	020	161	270	225	151	061	109
K 68369	000	000	001	001	002	046	305	254	152	098	051	090
K 68370	000	000	002	008	024	196	170	128	092	115	087	176
K 68371	000	002	003	002	011	092	099	334	144	131	077	104
K 68372	425	236	173	098	062	006	000	000	000	000	000	000
K 68373	200	288	272	159	061	019	000	000	000	000	000	000
K 68374	000	000	001	006	011	067	195	376	209	061	042	033
K 68375	012	017	054	235	468	213	000	000	000	000	000	000
K 68376	544	055	056	084	058	100	060	032	007	001	003	000
K 68377	000	000	000	003	270	584	099	031	008	002	002	001
K 68378	000	000	001	004	006	047	042	155	200	192	136	217
K 68379	000	000	000	004	012	041	040	172	119	186	146	278
K 68380	000	000	001	003	009	040	044	160	149	167	138	288
K 68381	096	084	072	104	105	131	087	110	078	053	036	042
K 68382	000	001	001	004	013	063	129	424	211	075	030	048
K 68383	014	035	059	131	195	247	137	090	035	027	015	015
K 68384	000	011	022	014	016	052	123	663	066	023	010	030
K 68385	000	000	002	005	020	167	275	318	100	051	022	033
K 68386	000	011	019	052	106	210	169	179	098	972	934	050
K 68387	000	003	004	017	030	060	165	299	199	122	046	054
K 68388	000	000	005	053	160	170	160	222	110	056	027	038
K 68389	000	000	001	023	059	178	223	298	120	044	022	033
K 68390	000	001	004	009	017	040	072	698	079	036	023	020
K 68391	000	006	013	024	050	136	152	248	160	103	036	071
K 68392	172	194	213	203	115	023	013	024	017	016	004	006
K 68393	000	000	000	001	003	041	214	346	193	106	051	044
K 68394	000	001	000	001	003	114	526	223	080	023	011	018
K 68397	000	000	001	003	008	136	143	321	194	133	022	038
K 68398	109	106	054	071	079	107	067	182	120	086	017	048
K 68399	000	000	002	005	015	149	105	013	355	145	092	118
K 68400	000	000	001	006	270	443	022	062	075	058	022	040



b Triangular diagram of grainsize data based on the classification of Shepard (1954)

TABLE 3: MOMENT MEASURES

		Mean Size	Standard Deviation	Skewness	Kurtosis	3rd Moment	4th Moment
K68	350	6.01	1.71	0.13	–0.18	0.64	24.06
	351	6.56	1.44	0.42	–0.45	1.26	10.90
	352	3.13	1.13	2.14	12.03	3.09	24.42
	353	5.95	1.51	0.82	–0.23	2.83	14.42
	354	7.06	1.50	0.22	–1.26	0.73	8.70
	355	6.04	1.85	0.48	–0.76	3.06	26.05
	356	7.31	1.54	–0.08	–1.10	–0.29	10.70
	357	7.06	1.81	–0.14	–1.14	–0.83	19.88
	358	6.18	2.06	0.03	–0.59	0.30	43.07
	359	5.02	1.80	0.19	0.43	1.14	36.30
	360	5.59	1.74	0.14	0.67	0.74	33.62
	361	5.72	1.75	0.06	0.82	0.34	35.81
	362	5.51	1.76	0.55	–0.18	2.98	26.73
	363	6.38	1.93	–0.37	–0.25	–2.64	38.34
	364	6.90	2.18	–0.46	–0.83	–4.76	49.13
	365	6.08	1.84	0.24	–0.24	1.53	31.68
	366	5.78	1.85	0.13	–0.10	0.80	33.85
	367	6.28	1.35	0.58	0.14	1.42	10.46
	368	6.43	1.58	0.34	–0.13	1.33	18.02
	369	5.95	1.64	0.72	–0.23	3.20	20.25
	370	6.11	2.25	0.15	–1.28	1.69	43.98
	371	6.20	1.79	0.08	–0.13	0.43	29.31
	372	–0.35	1.24	0.94	–0.21	1.80	6.58
	373	0.15	1.21	0.58	–0.37	1.02	5.59
	374	5.70	1.38	0.44	1.06	1.16	14.94
	375	2.27	0.93	-1.17	2.34	–0.95	4.08
	376	0.33	2.36	0.97	–0.37	12.76	82.02
	377	3.43	0.78	2.15	9.35	1.02	4.55
	378	7.18	1.76	–0.46	–0.29	–2.54	26.28
	379	7.37	1.85	–0.60	–0.46	–3.81	29.89
	380	7.38	1.84	–0.57	–0.45	–3.60	29.50
	381	3.34	3.05	0.15	–0.87	4.34	184.80
	382	5.82	1.41	0.36	1.45	1.00	17.59
	383	3.35	2.05	0.44	0.63	3.78	64.46
	384	5.42	1.19	0.30	5.24	0.51	16.68
	385	5.22	1.48	0.86	1.20	2.83	20.45
	386	4.77	2.13	0.26	–0.17	2.48	58.38
	387	5.82	1.72	–0.16	0.66	–0.79	31.63
	388	4.74	1.94	0.42	–0.24	3.05	39.25
	389	5.05	1.61	0.51	0.63	2.13	24.45
	390	5.54	1.15	–0.02	5.54	–0.03	15.16
	391	5.49	2.01	–0.05	0.05	–0.38	49.33
	392	0.94	2.10	1.45	2.63	1.35	110.20
	393	5.92	1.39	0.66	0.26	1.79	12.24
	394	4.96	1.12	1.53	4.68	2.12	11.87
	397	5.72	1.50	0.27	0.11	0.91	15.53
	398	4.04	3.05	–0.32	–0.77	–8.93	192.30
	399	6.42	1.92	–0.26	–0.67	–1.85	31.88
	400	4.17	1.91	1.35	0.81	9.38	50.50



c Distribution of textural types

TABLE 4: CALCIMETRY RESULTS

Sample Number	Percent $CaCO_3$	Sample Number	Percent $CaCO_3$
K68-350	0.94	K68-375	0.64
351	0.63	376	0.30
352	0.46	377	0.63
353	0.72	378	1.78
354	1.95	379	1.38
355	2.91	380	2.62
356	2.14	381	58.0
357	9.37	382	14+
358	6.66	383	67.5
359	5.30	384	15.1
360	12.3	385	2.01
361	15.8	386	45.5
362	7.42	387	33.4
363	4.55	388	0.85
364	2.58	389	5.54
365	3.58	390	15.8
366	0.41	391	26.2
367	0.00	392	66.1
368	0.36	393	0.10
369	0.20	394	0.00
370	4.02		
371	2.90	397	0.13
372	1.11	398	53.0
373	1.48	399	1.95
374	1.30	400	0.50

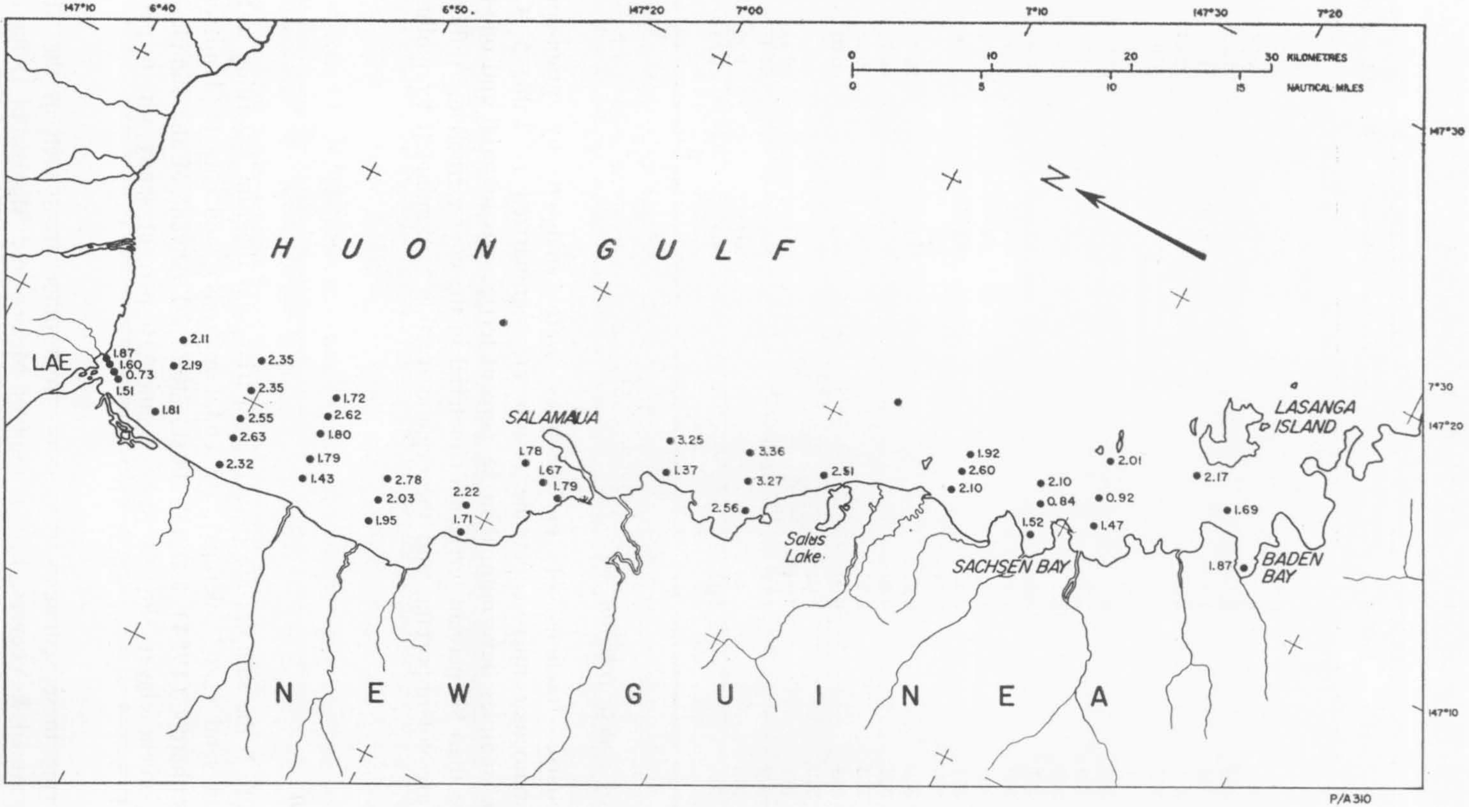
Analysis of coarse fraction

The coarse fractions of the samples were analysed by grain-counts under a binocular microscope; the results are summarized in Table 5. Over half of the samples have more than 55 percent terrigenous material and one-fifth have more than 90 percent terrigenous material in the coarse fraction. Authigenic minerals are not important, and the organic fraction is dominated by molluscan remains.

Discussion

In Figure b the samples are plotted on a triangular diagram according to their contents of sand (>63 microns), silt (63-4 microns), and clay (<4 microns). Using Shephard's (1954) textural classification, 30 percent of the samples are silt, 28 percent clayey silt, 18 percent sand, 16 percent sandy silt, 6 percent silty sand, and 2 percent sandy silty clay.

Comparing these sediments with those from other areas such as the Timor Sea (van Andel & Veevers, 1967), Gulf of Mexico and Mississippi Delta (van Andel, 1960), and Gulf of Paria (van Andel & Postma, 1954), it may be noted



d Variation in sorting values (inclusive graphic standard deviation)

TABLE 5: ANALYSES OF COARSE FRACTIONS

(% volume)

	Coarse fraction (percent by weight of sample)	Terrigenous non-micaceous	Mica	Glauconite	Pyrite	Faecal pellets	Plant fibres	Echinoids	Forams benthonic	Forams planktonic	Molluscs	Ostracods	Polyzoans	Sponge spicules	Coral
K68-350	9.38	44	—	—	—	—	40	—	01	01	14	—	—	—	—
351	1.66	100	—	—	—	—	—	—	—	—	—	—	—	—	—
352	90.53	100	—	—	—	—	—	—	—	—	—	—	—	—	—
353	2.64	90	01	—	—	—	—	—	02	05	01	01	—	—	—
355	9.10	90	—	—	01	—	—	—	—	02	07	—	—	—	—
356	0.82	—	—	—	—	—	—	—	—	—	—	—	—	—	—
357	3.05	32	20	—	—	—	03	—	08	17	14	06	—	—	—
358	11.88	11	01	—	01	—	—	—	12	31	41	03	—	—	—
359	28.59	68	05	—	01	—	—	—	04	02	15	05	—	—	—
360	13.70	02	—	—	—	—	—	02	12	29	54	01	—	—	—
361	11.77	02	04	—	—	—	04	10	12	34	34	—	—	—	—
362	22.08	03	80	—	—	—	—	—	03	12	02	—	—	—	—
363	11.78	02	55	—	—	—	—	—	25	—	18	—	—	—	—
364	11.95	28	55	—	—	—	—	01	01	03	12	—	—	—	—
365	8.21	01	25	01	—	01	04	01	10	15	40	02	01	—	—
366	18.27	25	61	—	—	—	—	—	03	01	09	01	—	—	—
*367	2.70	37	07	01	03	—	05	01	06	27	14	—	—	—	—
368	2.28	36	11	01	01	—	02	—	10	16	21	03	—	—	—
369	4.99	24	60	—	—	—	11	—	03	01	01	—	—	—	—
370	23.08	22	17	—	—	—	04	01	05	09	35	06	01	—	—
‡371	11.01	76	09	—	—	—	—	—	05	02	05	—	02	—	—
372	100.00	98	02	—	—	—	—	—	—	—	—	—	—	—	—
373	100.00	99	01	—	—	—	—	—	—	—	—	—	—	—	—
374	8.46	99	—	—	—	—	01	—	—	—	—	—	—	—	—
375	100.00	100	—	—	—	—	—	—	—	—	—	—	—	—	—
376	89.63	100	—	—	—	—	—	—	—	—	—	—	—	—	—
377	85.66	100	—	—	—	—	—	—	—	—	—	—	—	—	—
378	5.67	38	—	—	03	—	—	—	03	22	23	05	06	—	—
379	5.69	58	—	—	01	—	—	09	07	16	06	—	03	—	—
380	5.36	61	01	—	—	—	01	—	04	09	19	04	01	—	—
381	59.28	56	—	—	—	—	03	02	07	05	19	03	03	02	—
382	8.26	57	—	—	—	—	—	—	13	09	11	06	01	03	—
383	68.09	60	—	—	—	—	—	04	07	08	14	01	05	01	—
384	8.48	33	—	—	—	—	—	—	09	11	36	07	04	—	—
385	19.48	70	—	—	—	—	03	—	08	—	17	01	01	—	—
386	39.79	40	—	—	—	—	—	—	11	09	35	05	—	—	—
387	11.34	45	—	—	—	—	—	—	07	06	35	04	03	—	—
388	38.80	92	—	—	—	—	03	—	01	—	03	01	—	—	—
389	26.14	83	01	—	—	—	05	—	04	—	06	—	—	01	—
390	7.09	20	—	—	—	01	—	—	06	13	55	04	—	01	—
391	22.90	25	—	—	—	—	—	—	08	23	38	06	—	—	—
392	92.11	30	—	—	—	—	07	—	13	08	22	01	04	—	15
393	4.60	04	10	—	—	—	—	—	20	10	48	02	04	—	02
394	11.89	12	35	—	—	17	01	—	04	03	19	03	05	—	—
‡395	12.00	32	07	—	—	01	—	—	09	09	30	08	—	01	01
397	14.82	27	03	—	—	01	—	—	14	17	52	06	—	—	—
398	48.05	35	—	—	—	—	—	—	08	07	41	06	01	—	02
399	17.17	56	02	—	—	—	—	—	03	10	27	01	01	—	—
400	72.03	88	03	01	—	01	—	—	—	—	05	02	—	—	—

* Contains 1 percent volcanic glass. ‡ Contains 1 percent fish remains.

that the content of fine material in the samples from the Huon Gulf is considerably less. This, no doubt, is attributable to the proximity of land to all the samples and to the large amount of sediment being supplied to the shelf.

Figure c shows the distribution of the textural types on the shelf. In the central areas the textures of the sediments follow the expected pattern of decreasing grainsize away from the shore, but to the south this trend is reversed and in the north a large area of fine-grained sediment covers the shelf.

In the southern part of the area this coarsening of the sediments seawards can be attributed to the presence of coral reefs and islands near the outer edge of the continental shelf. The large area of clayey silt covering the shelf to the south of Lae reflects the influence of the Markham River, which is contributing much suspended load sediment to this region.

In general the sediments of the Lae shelf are poorly sorted, with an average inclusive graphic standard deviation value of 2.0 phi. Only five samples fall in the moderately sorted category of Folk (1965). Twenty samples are poorly sorted and the remaining samples are very poorly sorted. The average sorting value noted above coincides with Folk's boundary between the poorly sorted and the very poorly sorted sediments.

Very poorly sorted sediments are commonly associated with rapidly deposited material derived from more than one source, which has had little or no reworking by marine agencies in the area of deposition. Figure d, which is a plot of the inclusive graphic standard deviation, shows the trend of the sorting values. Apart from the anomalous area described above, there is a marked tendency for the sediments to become more poorly sorted seaward. Since the samples close to the shore vary by only small amounts laterally in sorting and mean size, it seems unlikely that the poorer sorting of the sediments farther offshore is caused by the mixing of these sediments only. It seems probable in this case that the deterioration of the sorting seaward is due to the material supplied by the coral reefs, both growing and dead, which are found on the edge of the shelf. This can be noted especially in the region to the south of Salamaua and around Lasanga Island, where very large decreases in the sorting are seen in the sediments closest to the coral reefs.

A plot of the results of the carbonate analyses reveals no clear relationship between carbonate content and depth. As might be expected, carbonate content increases sharply in sediment samples taken close to reefs and also tends to increase with increasing distance from shore. In the area of finer sediments south of the Markham River mouth mentioned above, a tongue of low carbonate content (less than 3 percent) may be noted. This possibly also reflects the control of water turbidity on carbonate content, since this area was postulated to have a relatively high content of suspended material brought in by the Markham River.

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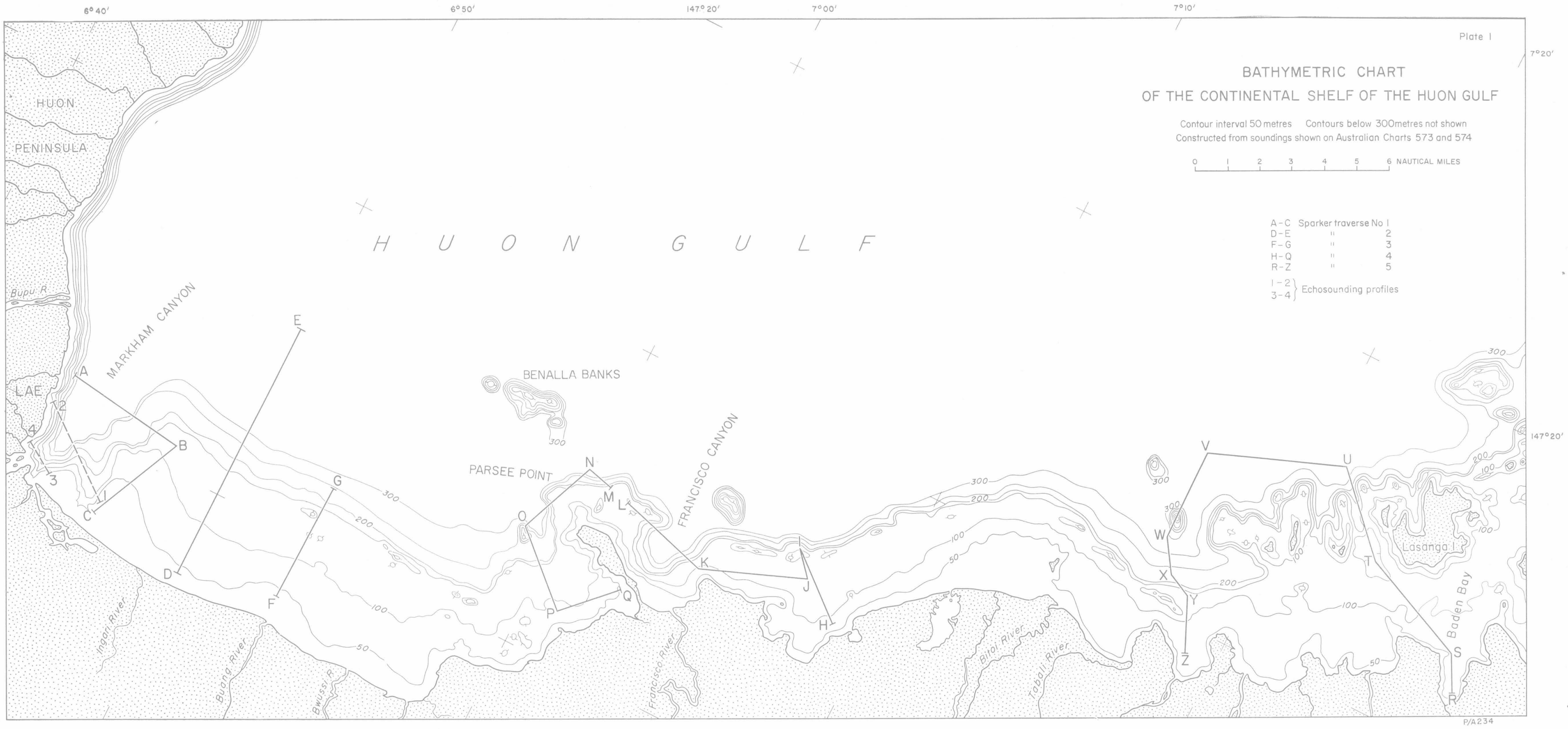
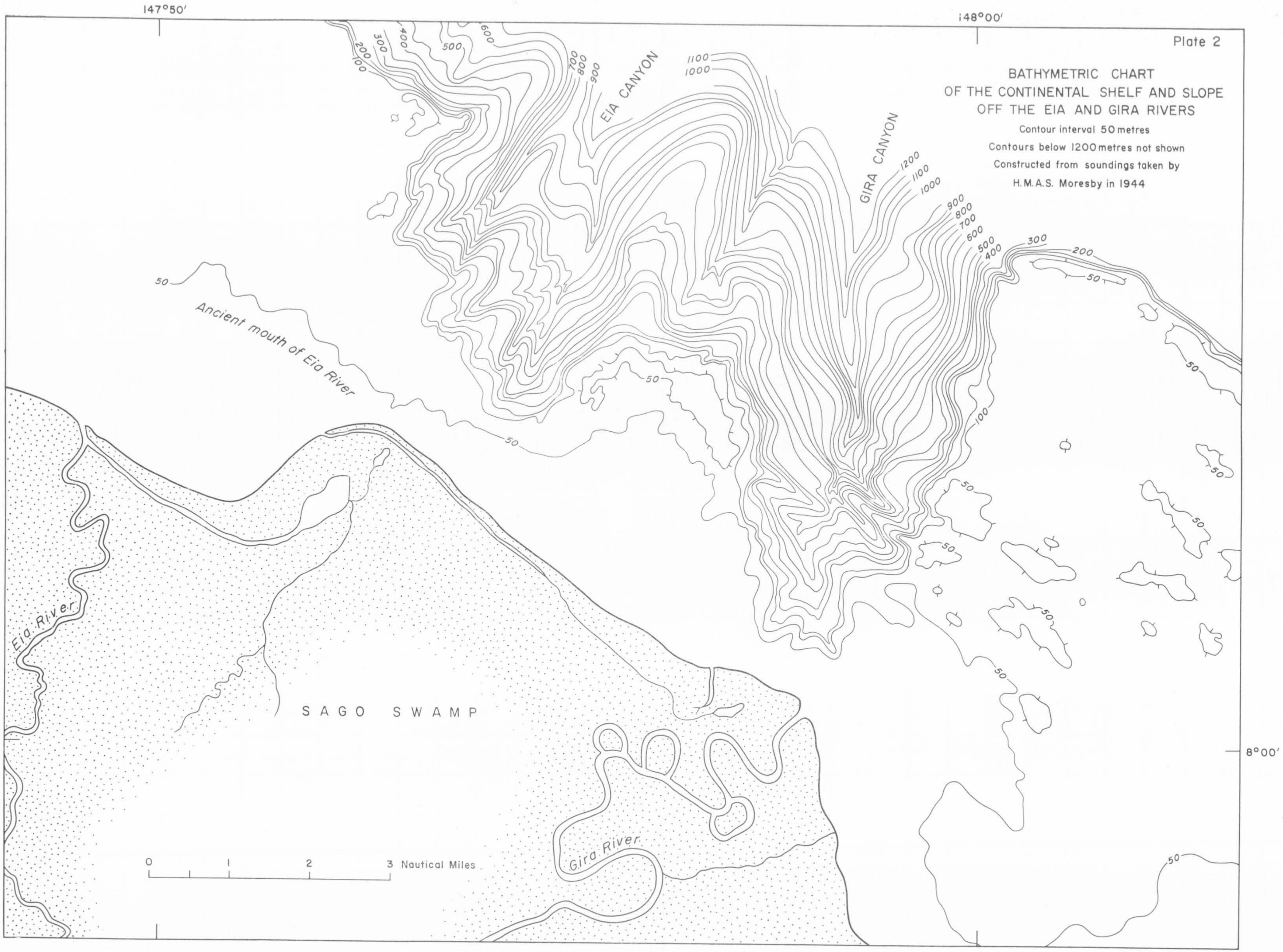


Plate I
BATHYMETRIC CHART
OF THE CONTINENTAL SHELF OF THE HUON GULF
Contour interval 50 metres Contours below 300metres not shown
Constructed from soundings shown on Australian Charts 573 and 574
0 1 2 3 4 5 6 NAUTICAL MILES
A–C Sparker traverse No 1
D–E " 2
F–G " 3
H–Q " 4
R–Z " 5
1–2
3–4 Echosounding profiles
6°40′
6°50′
147°20′
7°00′
7°10′
7°20′
147°20′
HUON
PENINSULA
HUON GULF
Bupu R.
MARKHAM CANYON
LAE
BENALLA BANKS
PARSEE POINT
FRANCISCO CANYON
Lasanga I
Baden Bay
Ingari River
Buang River
Bwussi R.
Francisco River
Bitoi River
Tabali River
P/A234



147°50′
148°00′
Plate 2
BATHYMETRIC CHART
OF THE CONTINENTAL SHELF AND SLOPE
OFF THE EIA AND GIRA RIVERS
Contour interval 50 metres
Contours below 1200 metres not shown
Constructed from soundings taken by
H.M.A.S. Moresby in 1944
EIA CANYON
GIRA CANYON
Ancient mouth of Eia River
Eia River
Gira River
SAGO SWAMP
0 1 2 3 Nautical Miles
8°00′

P/A235