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Marine Geology of the Huon Gulf Region, New Guinea

by

C.C. von der Borch

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FOREWORD

Dr C.C. von der Borch of the Horace Lamb Oceanographic Centre, Flinders University, was engaged by the Bureau of Mineral Resources to take part in a marine geological cruise in the Solomon Sea in 1968, and he acted as cruise leader for part of this time. He is now working at the Scripps Institution of Oceanography, California.

A few minor alterations to von der Borch's interpretations of the sparker profiles have been made by H.A. Jones of the Bureau as a result of further study of the seismic records.

SUMMARY

The geological history of the seafloor of the western Solomon Sea is discussed from the point of view of the regional bathymetric and structural framework and the detailed bathymetry, structure and history of the continental shelf between Lae and Cape Ward Hunt. In a regional sense, relationships between major onshore and offshore structures are described. It is suggested that a large-scale left-lateral displacement of the western end of the New Britain Trench is related to the major Markham-Ramu Lineament onshore. This lineament also controls the position of the Markham submarine canyon, which is the major conduit in the region feeding sediment to the ocean basin. The structural framework and geological history of the narrow continental shelf between Lae and Cape Ward Hunt is discussed in finer detail, on the basis of sparker seismic reflection profiles. The shelf is a geologically young constructional feature, composed in upper stratigraphic levels of a coalescing series of deltaic deposits, showing deltaic foreset bedding. In some areas these beds can be seen sitting directly on older non-sedimentary basement. Quaternary features, particularly those related to eustatic sealevel fluctuations, are apparent. "Geologically active" submarine canyons traverse the shelf in several localities. These were either initiated during Pleistocene low sealevel stands or, more probably, pre-date the Pleistocene and have evolved during shelf sedimentation by a combination of axial downcutting by abrasive sediment flowage and rim up-growth by settling argillaceous sediments.

INTRODUCTION

Purpose and Scope of Investigation

The field data on which this report is based were collected during a marine geological cruise in New Guinea waters by the Bureau of Mineral Resources early in 1968. A description of the bottom sediments of the continental shelf between Lae and Morobe has been given by Walraven (1968) and in this report a detailed study of the morphology and structure of this region is given, based mainly on the seismic profiling records obtained during a series of sparker traverses across the narrow continental shelf and upper continental slope. The regional geological history of the western Solomon Sea, and the structural framework into which this local pattern fits, are also described.

The location of the area of study is shown in Figure 1.

The Huon Gulf area is of particular interest from a marine geological point of view. The mainland of New Guinea and the adjoining deep ocean basins constitute one of the most tectonically active areas in the world today. This activity has produced extreme variations in relief between the mountainous landmass of New Guinea and the adjacent steep sided ocean basins; youthful topography exists in many areas right down to the water's edge, and the continental shelf is either completely absent, or in early stages of formation. The high precipitation and extreme relief result in rapid denudation with heavy stream discharge and large scale transport of sediment. The oceanic environment, however, is one of relatively low energy. Tides are virtually non-existent in the region of the Huon Gulf and tide-induced currents are at a minimum. The Solomon Sea itself is a water mass of restricted dimensions; ocean swell activity is consequently low, resulting in only minor erosion by wave attack and little longshore transport of sand-sized sediment.

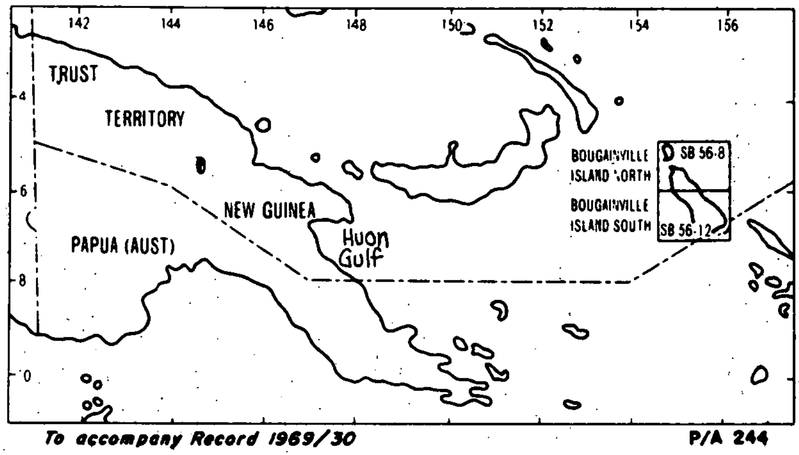

Figure 1. Location map

Continental slopes in the area are close to the present shoreline reproducing conditions which probably existed repeatedly off more stable landmasses during low sealevel stands of the Pleistocene. At the present day, due to the world-wide post-Pleistocene transgression, those stable landmasses are fringed by wide shallow continental shelves, which essentially isolate the steep continental slope zone from the land. As a result of this, the present regime of erosion and sedimentation in the vicinity of the slope off most land areas is not that which has produced the major observed bathymetric and sedimentary features. Detailed studies of modern sedimentary and erosional processes of the Huon Gulf region, therefore, may throw light on some of these features, such as submarine canyons, which cannot be satisfactorily explained in terms of existing conditions.

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. Apart from this, Krause (1965, 1967) has published reports on the marine geology and submarine 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 Haatjens et al. (1964) and Ruxton et al. (1967), and Holocene denudation rates on a young dissected volcanic cone have been determined by Ruxton and McDougall (1967). Previous regional geological studies are documented in the following section.

Hinterland geology

A comprehensive summary of the geology of southeastern New Guinea has been given by Thompson and Fisher (1965), see Figure 2, while Thompson (1967) has described the geological history of the area. A description of the Papuan Ophiolite Belt has been given by Davies (1967). The following short summary has been condensed from the above publications.

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). These are discussed in the following section.

Northern New Guinea Arc

This area is bounded on the southern side by the Markham-Ramu lineament which represents, at least in part, a major strike-slip fault. The Northern New Guinea Arc extends into New Britain, where its southern boundary is taken as the New Britain Trench. The northern boundary of the arc is the chain of volcanic islands extending from the mouth of the Sepik River to the Gazelle Peninsula, northern New Britain. Within the area of this study, on the mainland of New Guinea, the arc is composed of a series of young mountain ranges, including the Adelbert and Finisterre Ranges with a topographic relief of over 4000 metres above sea-level. These 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 of the area. Upper Miocene marine limestones have been elevated to more than 3000 metres above sealevel. Elevated coastal terraces are common, both on mainland New Guinea, particularly near Finschafen, 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

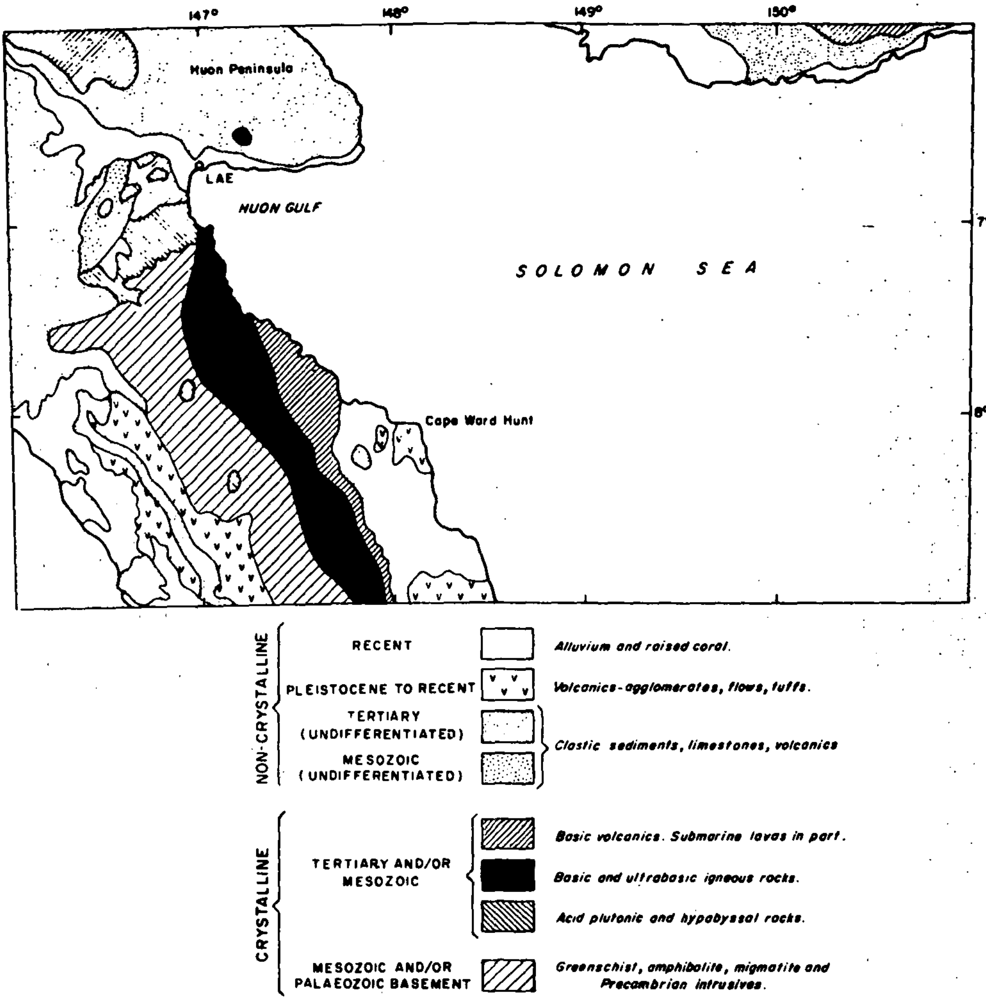

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Figure 2. Geology of southeastern New Guinea, after Thompson and Fisher (1965).

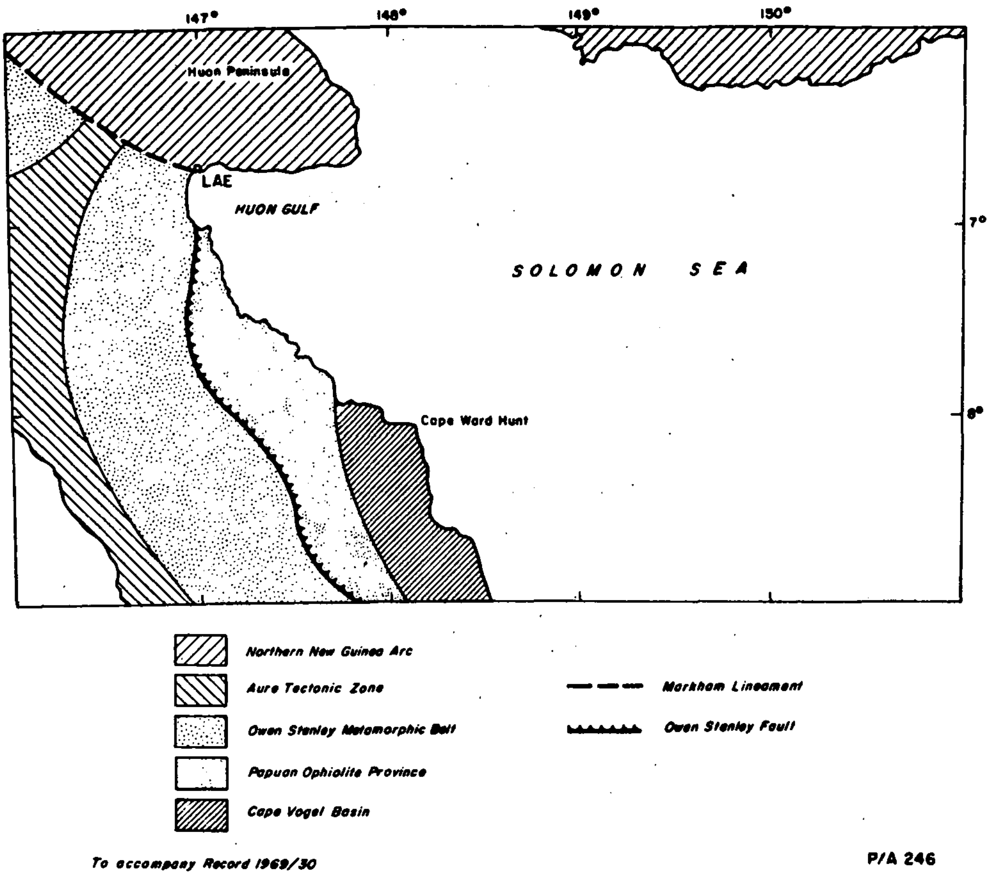

Figure 3. Structure of southeastern New Guinea, after Thompson and Fisher (1965).

in Papua-New Guinea at the present time.

Owen Stanley Metamorphic Belt

This structural unit is mainly composed of regionally metamorphosed greywacke sediments and limestone. It forms the sialic core of eastern Papua-New Guinea (Davies, 1967). Since at least middle Eocene times, this belt has provided an emergent source of clastic sediments. The northern margin of the belt 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 200 miles. This fault appears to be a low angle thrust, dipping eastward at an angle of 20° to 30° (Davies, 1967).

Papuan Ophiolite Province

This 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 (1967) showing 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 (see next section).

An interesting point, relevant to the present study, is the statement in Thompson and 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

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, whilst the Ophiolite Province is currently being submerged.

Cape Vogel Basin

This name refers to a structurally depressed and topographically low-lying 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, Figure 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. Most recent activity occurred at Mount Lamington in 1951 (Taylor, 1958). During this catastrophic eruption the volcano ejected an andesitic magma.

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 C.S.I.R.O. (Australia) 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 the present author's observations, supplemented by extrapolations from the areas studied by C.S.I.R.O. workers.

Emergent Coastal Areas. Within the area of Figure 5, 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 occur on the Huon Peninsula in the vicinity of Finschafen. Coastal topography in these regions is typically steep both above and below sealevel. Low-lying swampy coastal regions are absent and the coastline is not deeply embayed. Elevations in excess of 2000 metres typically occur only 7 miles inland from the coastline. Fringing coral reefs are absent or poorly developed in these strongly emergent areas. Elevated reef coral of possible Pleistocene age forms low shoreline cliffs along New Britain's southern coast. This is also the case along the seaward side of Dreger Harbour on Huon Peninsula.

Submergent Coastal Areas. Both the Papuan Ophiolite Province and the Cape Vogel Basin have drowned coastlines and provide evidence of regional submergence. From the vicinity of the Markham River mouth near Lae, southeast to Morobe, the coast is backed by steep ranges, with elevations of about 2700 metres occurring some 17 miles 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. Beachridges are present, suggesting a locally prograding shoreline. Lagoonal and deltaic developments are relatively common, with deltaic bulges occurring 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 the vicinity of 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. The area is 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. During squalls, northwest to southwest winds may attain velocities of up to 40 knots for short periods. Between storms, generally calm conditions prevail. During the monsoon season, 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 from 20 to 30 knots. Winds of these velocities may persist for several days on end. During the period of the southeast trades seas of the Huon Gulf region tend to be choppy although heavy seas are rare.

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

Table 1

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

Average rairfall figures in inches for Finschafen, quoted in U.S. Hydrographic Office "Sailing Directions for New Guinea ,1936.

Drainage.

The high rainfall and extreme topographic relief of the area are responsible for high stream discharge rates. The main rivers flowing into the Huon Gulf are, from northwest to southeast, the Markham, Francisco, Morobe, Waria, Gira, Mambare, Kumusi and Musa. Collectively, these rivers drain a hinterland with an area of about 15,000 square miles, and a relief in excess of 4000 metres. Stream discharge figures for the region are sparse and information on sediment loads is nonexistent. The only available data refer to the Markham and Waria Rivers (Table 2). The Waria River figures were collected at Garaina, a mountain station situated at least 50 river miles upstream from its mouth. At best, the figures only give a sketchy idea of the orders of magnitude of stream discharged rates.

Table 2.

River	Mean Flow (Cu.ft/sec.)	Max.recorded flow (Cu.ft/sec.)	Drainage area (miles^2)
Markham	15,000	> 150,000	5,000
Waria	3,000	58,200	1,625

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 in the study area, particularly the Markham and Waria, drain into the ocean directly into the heads of submarine canyons. These canyons approach to within less than a mile 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, and is published in various coast pilot volumes. The Pacific Islands Pilot (1956) states that a strong current, setting southeast, is initiated in the Huon Gulf, apparently caused by discharge of water from the Markham River. The U.S. Hydrographic Office (1936) states that rise and fall of tide is very small in the Huon Gulf area, and 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 whilst carrying out 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 prior to the observation. The above data, although inadequate suggest that coastal currents exist which attain velocities capable of transporting suspended sediment.

During the northwest monsoon, as stated above seas are generally calm in the Huon Gulf area. A short period choppy swell develops during the southeast trade season. Due to the limited fetch in the Solomon Sea, long period swells are absent along this stretch of New Guinea coastline. Significant long period swell activity associated with the high wave energy occurs along the southeast facing coast of New Britain. This swell originates from areas to the south and southeast, and may be generated by 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. Sounding density for contours is shown in Figure 4. Cross sections of the New Britain Trench have been plotted from the above soundings.

The detailed bathymetry of the Lae-Cape Ward Hunt shelf (Plate 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 (Plate 2) have been constructed from a local beacon triangulated survey by H.M.A.S. Moresby in 1944. An average of seven sounding lines per mile are published on this plotting sheet. Contours of the Waria Canyon (Fig.9) have been constructed from a triangulated survey by H.M.A.S. Shepparton in 1943. Sounding line density on the Shepparton survey was about three

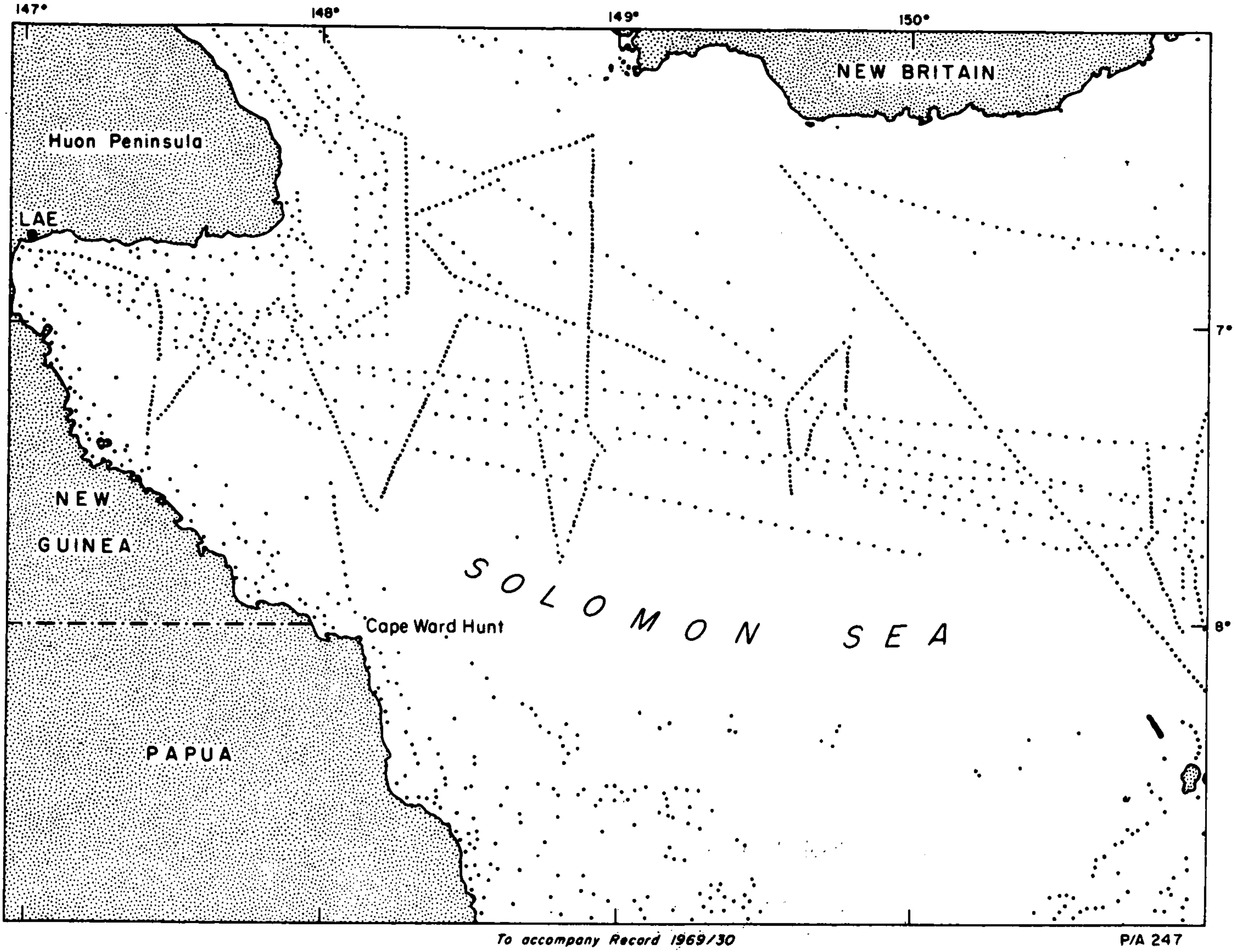

Figure 4. Density of soundings, western Solomon Sea. Taken from R.A.N. Hydrographic Office Oceanic Soundings Sheet, area 290.

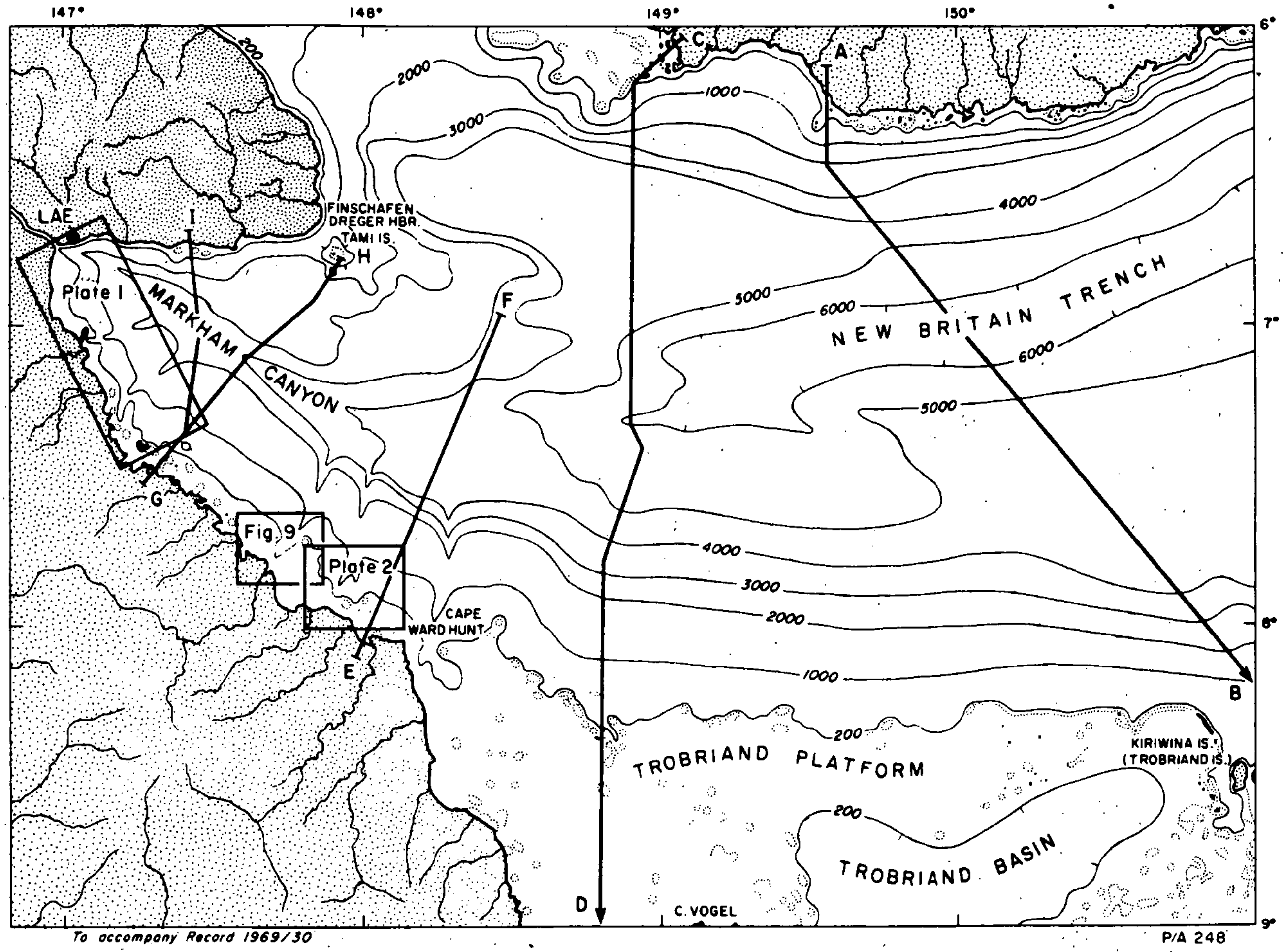

Figure 5. Regional bathymetry, western Solomon Sea. Contours (metres) constructed from Oceanic Soundings Sheet, area 290. Location of cross sections (Fig. 7) indicated by letters.

sounding limes per mile. The last two areas have previously been contoured by Sprigg (1947).

Bathymetric profiles obtained during the Bureau of Mineral Resources cruise were collected using a Furuno 850 echo sounder. In steep topography, due to slow chart speeds, useable bathymetric profiles could only be obtained by reducing ship's speed to about 3 knots. This echo-sounder had a depth limitation of 480 metres.

Seismic profiles were obtained using an Edgerton Germehausen and Grier 3-electrode Sparkarray, powered and activated by an E.G. & G Power Supply and Trigger Capacitor Bank. Data was recorded on an Ocean Sonics GDR-T recorder. The above combination produced a 1000 Watt-second spark. Sediment penetration ranging up to 0.25 to 0.5 seconds (two-way travel time) were obtained 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. Major physiographic features of the seafloor are as follows.

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 and Hess (1963) as one of several linked trenches situated south of New Britain, southeast of the Solomon Islands and west of the New Hebrides. This series appears to be unique amongst oceanic trenches in that it is convex towards the Pacific Ocean. 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 occurring 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 these trenches.

Between longitudes 149° and 150°E sounding density is sufficient to reveal a pronounced inflection 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 Krause (1967) in the D'Entrecasteaux Islands and Louisiade Archipelago.

Bathymetric sections across the region under discussion are shown in Figure 7, with localities illustrated in Figure 5. 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 metres. Very little evidence for a flat floor is present.

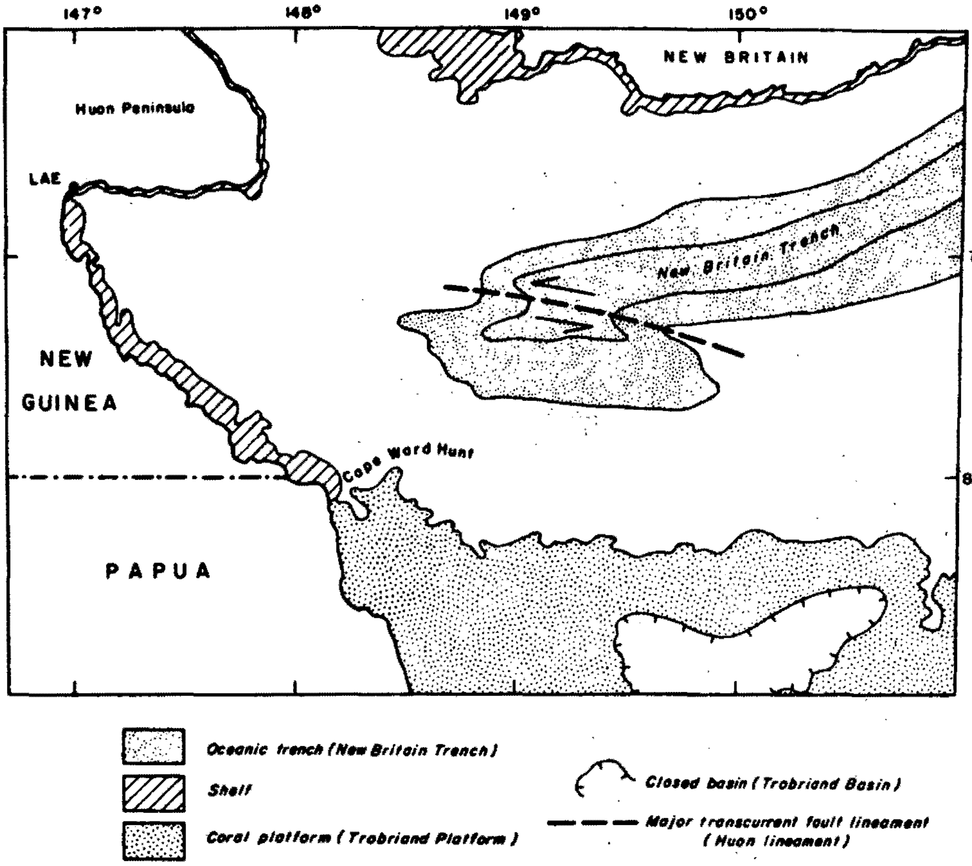

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Figure 6. Structure of sea floor, western Solomon Sea.

The northern wall of the trench is 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 New Guinea's north coast, crosses the western end of the trench in the area of the seafloor shear zone. A broad, flat, obviously sedimentary floor is present in the trench axis, possibly an abyssal fan deposit, bounded on the south by a steep, 1000-metre scarp. A channel with an axial depth below the flat floor of 200-300 metres occurs on the north side of the trench axis, 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 an approximately V-shaped profile, and show no evidence of a flat valley. 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 less than 100 metres. Formerly, this area has been included within the province of the Cape Vogel Basin (Paterson and Kicinsky, 1956). This may be structurally correct, but the term platform is more appropriate, following normal marine geological terminology.

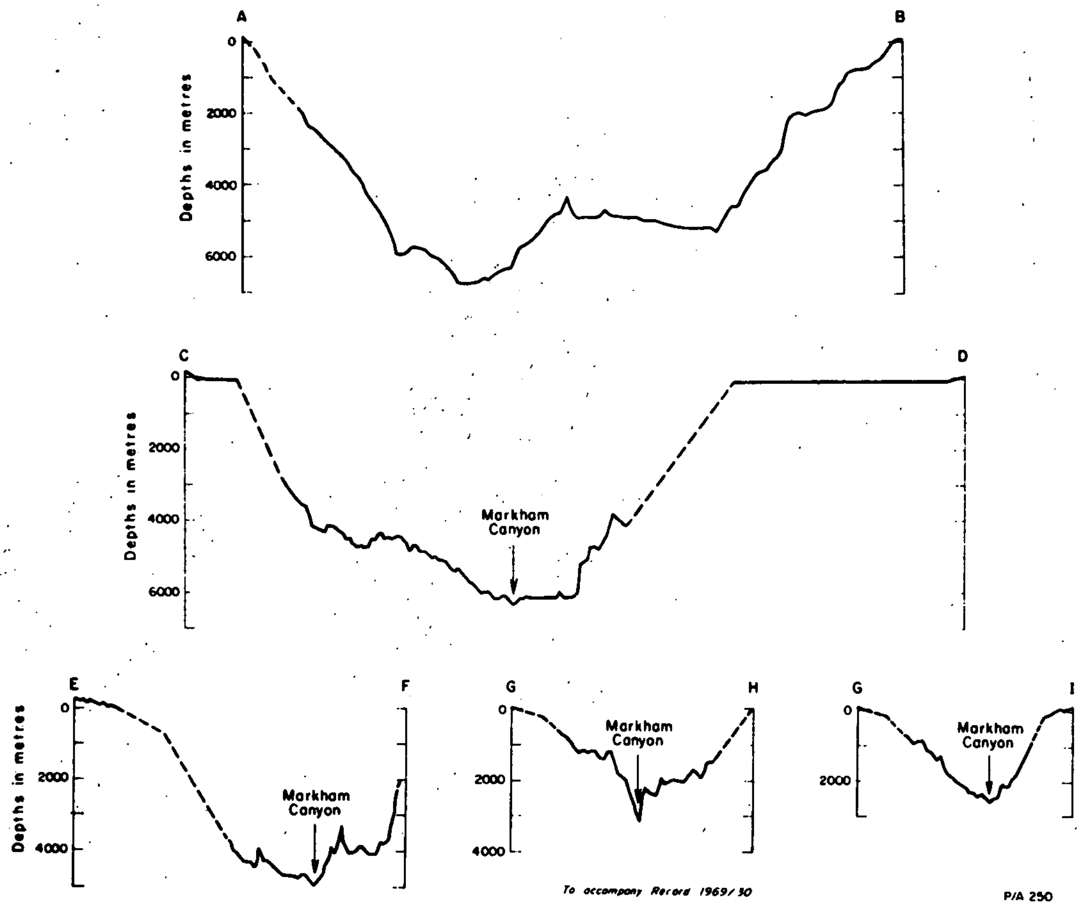
The eastern portion of the Trobriand Platform may be somewhat complicated structurally, as Kiriwina Island is formed by an elevated coral reef. This emergence may be localized, however, as the major portion of the platform shows signs of slow subsidence, as evidenced by the coral reef distribution. It is likely that the whole area is one of calcareous sedimentation, dominated by reef-building coral and algae and derived talus. The platform's northern margin, 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, herein called the Trobriand Basin (Figs 5 and 6). Sparse soundings on Admiralty Charts indicate water depths of at least 970 metres within the basin. On existing data, the basin is silled at a depth of 200 metres at its connection with Goodenough Bay, off the southeastern corner of Figure 5. Elsewhere around the basin sill depth appears to be no deeper than about 100 metres. Access of terrigenous sediment to this basin would be possible in the vicinity of Cape Vogel, where the basin adjoins the mainland of New Guinea.

Lae-Cape Ward Hunt Shelf

A narrow continental shelf fringes the northeast coast of New Guinea, between Lae and Cape Ward Hunt. Shelf width varies from 3 to 5 miles. Several submarine canyons cut across the shelf to head close inshore off mouths of large rivers. Shelf-break depth varies from 102 metres in the southeastern section to 117 metres near Lae. The shelf is terminated in the vicinity of Lae by the Markham Canyon. In the southeast, near Cape Ward Hunt, the shelf merges with the Trobriand Platform.



<u>Figure 7.</u> Cross sections, western Solomon Sea. For locations see Figure 5. Depths in metres. Vertical scale exaggeration X 17.

Figure 8. Cross sections of the Markham Canyon. For locations see Plate 1. Depths in metres. Vertical scale exaggeration X 11.

Detailed bathymetry and structure of the Lae-Cape Ward Hunt Shelf

Plate 1 shows a contoured chart of the area of detailed study. Shelf development is entirely absent on the Huon Peninsula east of Lae. This area is actively 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 shelf progradation. 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, thereby providing a mechanism for the preservation of sedimentary deposits, with resultant terrace development.

Morphology

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

A series of elongated highs occurring immediately landward of the 150-metre contour in the Lae-Parsee Point section are coral reef formations, rising to within about 40 metres of present sea-level. These are typically situated above the drop-off into deep water at the shelf edge.

Shelf-break depths for this section, as determined from the sparker records, vary from 109 to 117 metres, and continental slope angle averages 1.6°. According to Shepard (1963) the world average for shelf break depth is 132 metres 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 metres.

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. Further 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, shelf morphology is dominated by a pronounced convex bulge of the shoreline and bathymetric contours down to a depth of at least 300 metres. This is apparently a large submarine and sub-aereal deltaic body related to the Bitoi River.

Southeast of the Bitoi River a series of basement-rock islands occur across the shelf. Shelf-break depths in this area, on limited traverse data, are somewhat shallower than those further north, being of the order of 102 metres.

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

This canyon extends to within a few tens of metres of the mouth of the rapidly flowing Markham River. Between the canyon head and the estuary are 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 1 mile to the south. This lagoonal zone may have been a previous outlet of the main river.

The configuration of the Markham Canyon head 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, 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 metres 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-metre 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 on sedimentary processes associated with submarine canyons has demonstrated that in water depths below eustatic influences they are cut entirely by submarine processes of sediment movement (Shepard and Dill, 1966). A brief reconnaissance of Markham River sediments at its mouth showed its bedload to be composed of sand, gravel and pebbles. This bed-load is being actively transported seaward by a river current of the order of 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 conjecture as to the geometry and lithology of the resulting deep basin deposit. However, it would most likely 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 sediment 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 the vicinity of 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 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 sediment load 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 Plate 2) and each canyon is obviously related to a large river.

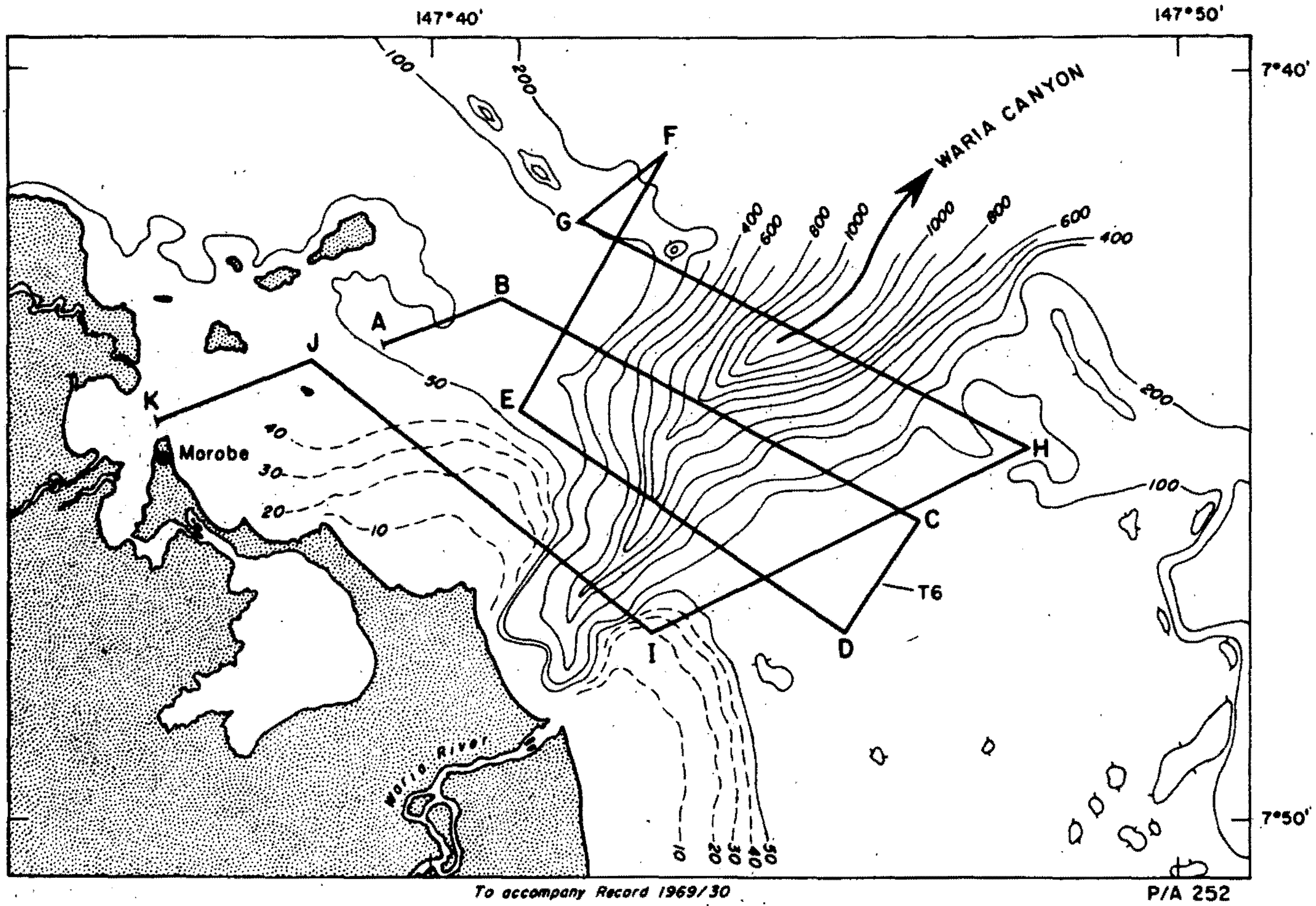
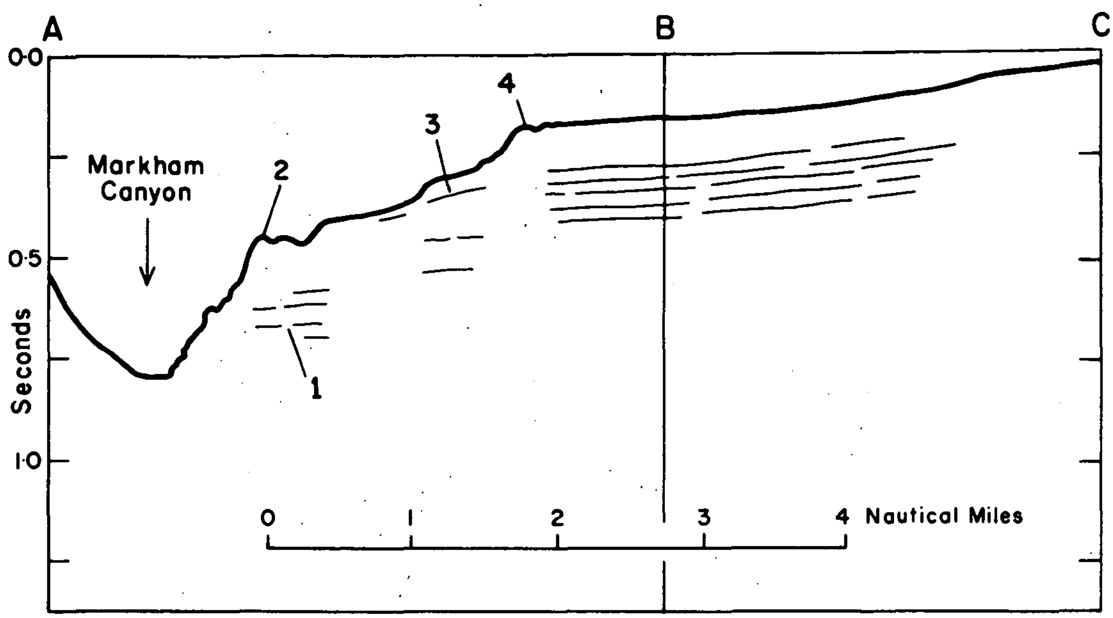


Figure 9. Bathymetric map of the Waria Canyon. Contours in metres. Contours below 1100 metres not shown. Location of sparker traverse No. 6 indicated by letters.



To accompany Record 1969/30 P/A 253

Figure 10. Interpretation of Sparker Traverse No. 1. Vertical scale exaggeration of sea floor X 6.5.

The Waria Canyon (Fig. 9) extends to within less than a mile of the Waria River estuary, and is apparently intercepting most of the river's bed-load 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 metres. This symmetrical deltaic bulge has been breached by the canyon (see the discussion in a later section on the results of the sparker traverses). The present axis of the canyon is at least 500 metres below sealevel where it crosses the edge of the deltaic bulge in 50 metres of water. At the shelf edge the canyon axis is at a depth of over 1500 metres. Although shelf downwarping is taking place in this area, it is apparent that submarine erosion processes have been responsible for the major part of this canyon cutting.

The Eia Canyon terminates about 0.9 miles 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, suggesting to the present author 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 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 traverse 7 on Figure 9. An interpretation of Traverse 1 is shown in Figure 10 and photographic reproductions of the records of Traverses 2 to 6, accompanied by line drawing interpretations, are shown in Plates 3-10.

Depths of reflectors and thicknesses of sequences of reflectors are quoted in seconds (two-way travel time). Unless otherwise specified, the attitudes 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 the mainland within the study area, it invariably is composed of ultrabasics and volcanics of the Papuan Ophiolite Province.

Traverse 1

This traverse (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 metres, has a flat floor. The south wall of the canyon truncates some reflectors at 1,* proving the canyon to be 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 beneath the shelf of at least 0.25 seconds.

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

This traverse lies within a zone of extremely high water 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 coral reef formation. It is therefore somewhat of a puzzle as to when reef building occurred, as the river would have presumably been even more active than at present during Pleistocene low sealevel stands. One possibility would be that a change in the ocean current regime at such meteorologically different times may have maintained clear water in the vicinity of the outer shelf in this area, allowing coral growth.

<u>Traverse 2</u>

This profile (Plate 3) begins close inshore at point D and extends across the shelf, here 4 miles wide, and down the upper slope to a water depth of 732 metres. 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 the 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 metres high occurs at 5 and evidence of current scour can be seen on either side of this structure, The reef is apparently perched on the sediments of the outer shelf, as 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, and the sides of the shadow zone are almost vertical. Shelf edge break in slope here is at 117 metres. 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 taller 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

This profile (Plate 3) is similar to 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, wedgeing out rapidly across the shelf. The relatively steep slope near F represents the major outbuilding slope of the submarine portion of the Buang delta. Further 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 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 have built up with the sediment column at the shelf edge.

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

Traverse 4

This traverse (H-Q, Fig. 8) is illustrated in Plates 4 and 5. 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 Plate 4. Both are associated with topographic lows 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. Sub-horizontal strata, truncated by the canyon walls, are evident at 1. Sub-horizontal 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 (Plate 5) extends from the offshore extension of Parsee Point to the continental slope and shelf. Rough bottom topography is evident at 1, opposite the Point, in a water depth of 360 metres. 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 sub-horizontal 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

This section (R-Z, Fig. 8, and Plates 6 and 7) 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 this profile (R-U, Plate 6), 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. On the seaward side of this break, a sequence of well-bedded sub-horizontal sediments extends down to 4, draped over a possible bedrock ridge at 5. Further seaward, at 6, a well-defined basement area forms a topographic high flanked on the seaward margin at 7 by conformable slope deposits.

The portion of this traverse from U to V (Plate 7) 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 highs outcrop on the seafloor at 3, surrounded by horizontal sediments.

Section V-Z extends from the upper continental slope across a pinnacle-like bedrock high and up the slope to the shelf. Bedrock crops out at 1 and is flanked by well-bedded conformable slope deposits. A steep bedrock high 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 parabolical echoes, may represent irregular basement. The shelf break occurs at a water depth of 102 metres, 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.

<u>Traverse 6</u>

This traverse, from A to K (Fig. 9 and Plates 8, 9 and 10), embraces the portion of the Waria Canyon on the continental shelf and the Waria River delta.

Section A-B-C (Plate 8) 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 metres. 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 (Plate 8) 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 in the area taken in water depths of less than about 90 metres. As before, it is suggested that this is a subaereal 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 1400 metres per second for these sediments, a thickness of about 80 metres has been deposited in the area during the past 20,000 - 30,000 years. Below unconformity 1, a section of sub-horizontal sediments at least 0.13 seconds in thickness occurs. These pre-unconformity sediments show 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 wall below reflector 4. Above 4, and also on the opposite wall of the canyon, sub-horizontal strata are truncated.

Section E-F-G (Plate 9) 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 sub-aereal erosional surface related to the last low sealevel stand. This surface extends out towards the shelf edge, but loses its noteable 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 metres. 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 metres, once again surmounted by a possible reef development. 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 sub-horizontal reflectors at 5.

Section G-H crosses the Waria Canyon almost at the shelf edge. Along this section, the canyon axis (1) is crossed at a water depth of 1190 metres, and horizontal reflectors are present below the canyon floor. 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 having a surface velocity of about 2 knots northwestwards was observed.

Section H-I (Plate 10) 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 parabolical reflectors occurs, and reflector 1 is attenuated below its thickest development. On present knowledge this can only be 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 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 in to Morobe Harbour. As in previous sections, the canyon dissects the apparently horizontal beds of the inner shelf. Canyon axial depth at this crossing is 384 metres. Modern shelf sediments appear to drape over the canyon rim 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. Adjacent to this position, basement emerges above sealevel in the form of 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.

DISCUSSION

Huon Peninsula continental margin

The conspicuous absence of continental shelf development on 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 stabilised 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 up-lap 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 above possibility.

Lae-Cape Ward Hunt Continental Terrace

In contrast, 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 times when, according to Thompson (1967), the present outline of New Guinea may have formed. This relatively long time factor, coupled with the slowly subsiding nature 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 shelf break depth varies from 109 to 117 metres, and may have been controlled by Pleistocene low sealevel stands. Coral reef developments occur apparently perched on the sediments above this break-in-slope, and these have apparently grown up during the Holocene transgression. In some areas reef upgrowth has not kept pace with the rising sealevel, with reef tops being as much as 40 metres below present sealevel. In other areas, particularly in clear waters, reefs have remained essentially at sealevel. Reef accumulations buried in the upper sections of sedimentary deposits of the shelf are inferred from sparker traverses in the Waria Canyon area.

Below the shelf break, 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 taking place in steeper sections, a situation which is not uncommon elsewhere (Curray et al., 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 metres. What may be a coral reef development forms a knoll above this deeper slope change, in much the same manner as in the shallower case. This is interpreted as being an older Pleistocene shelf break or shelf breaks 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 are not necessary for canyon initiation.

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 sub-horizontal strata is evident in sparker traverses across the canyon.

The Francisco, Waria, Eia and Gira Canyons all cut across 7 to 10 miles of continental shelf to head opposite existing or pre-existing river mouths. In every case where 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.

As with the case of the continental slope, it is only possible to conjecture as to the ultimate age and growth mechanism of these canyons. Two alternative hypotheses are put forward below.

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. Basement subsidence, accompanied by an approximately equal rate of shelf sedimentation, has apparently occurred. If pre-existing on-shore structures or morphology had positioned rivers at approximately their present localities, then localized sediment supplies for canyon down-cutting 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 canyon rim, as was observed in the Waria Canyon. However, superficial deposits such as these in the canyon edge 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. In such a case the overall effect observed on sparker records would be the truncated strata observed in canyon walls.

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. Following this, the rise in sea level would once again have returned the shoreline to its approximate 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, the author believes that the canyons in this area pre-date the Pleistocene and eustatic sea level changes are not essential for canyon formation. First of all, there is much evidence indicating that submarine canyon formation has occurred throughout geological times. Canyons have been detected by seismic means buried in the geological record (Conolly, 1968, Hopkins, 1966). Other un-buried canyons show geological evidence of having been in existence since pre-Pleistocene times (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) vary 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 canyon down-cutting and shelf up-growth, 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, including the New Britain Trench. Although the mechanisms responsible for such large scale sediment movement are as yet undocumented, it is apparent that some form of submarine sediment flow is required. Possible mechanisms include sediment creep, sediment 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 as to how far this filling process has proceeded at 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.

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R. Thieme constructed the original contours used in Plate 2 and Figure 9.

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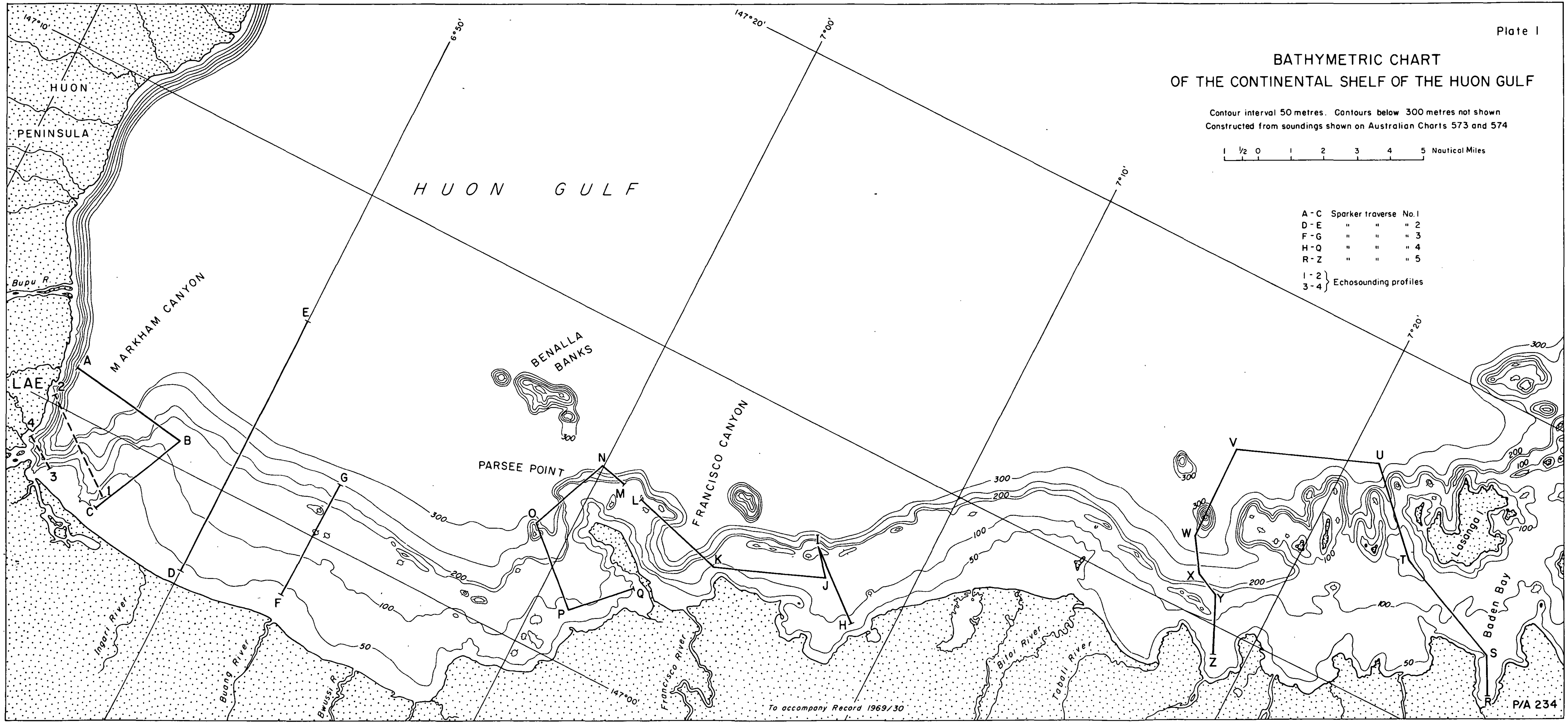
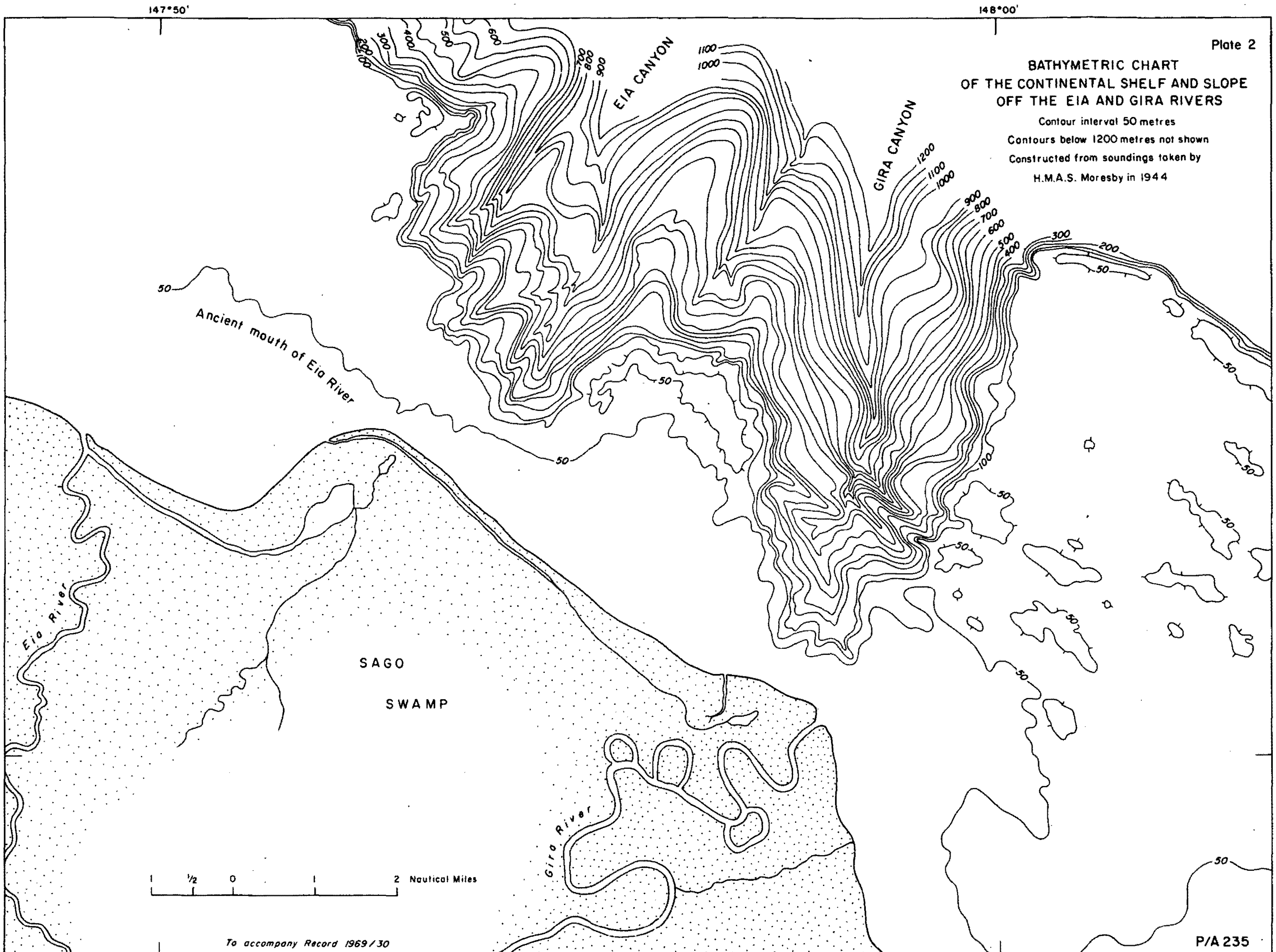


Plate 1
BATHYMETRIC CHART
OF THE CONTINENTAL SHELF OF THE HUON GULF
Contour interval 50 metres. Contours below 300 metres not shown
Constructed from soundings shown on Australian Charts 573 and 574
1 1/2 0 1 2 3 4 5 Nautical Miles
A - C Sparker traverse No. 1
D - E " " " 2
F - G " " " 3
H - Q " " " 4
R - Z " " " 5
1 - 2
3 - 4 Echosounding profiles
HUON
PENINSULA
HUON GULF
MARKHAM CANYON
BENALLA BANKS
PARSEE POINT
FRANCISCO CANYON
LAE
Bupu R.
Ingari River
Buang River
Bwussi R.
Francisco River
Bilai River
Tabali River
Lasanga I.
Baden Bay
147°10'
147°20'
147°00'
6°50'
7°00'
7°10'
7°20'
300
200
100
50
To accompany Record 1969/30
P/A 234



147°50'
148°00'
8°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
SAGO
SWAMP
Eia River
Gira River
1 ½ 0 1 2 Nautical Miles
To accompany Record 1969/30
P/A 235

TRAVERSES 2 AND 3

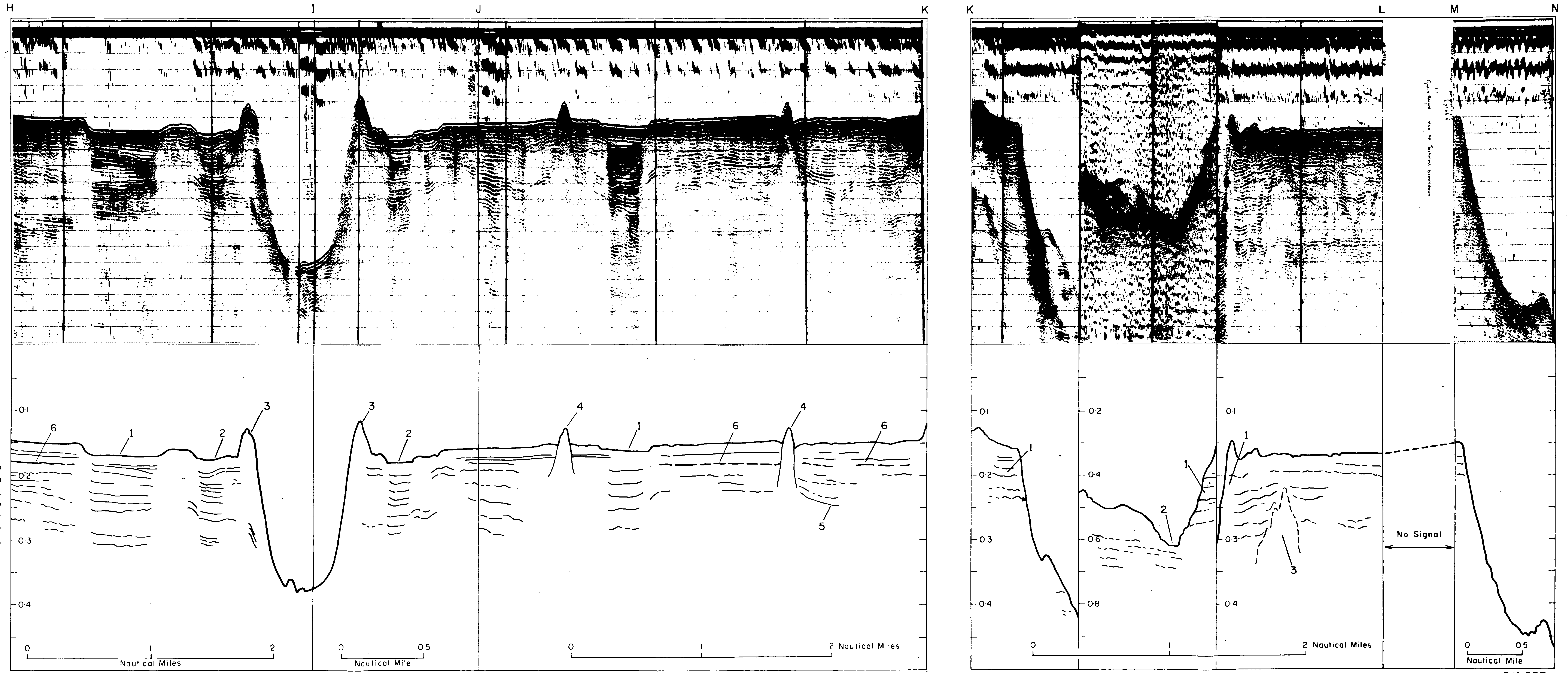
LOCATION OF TRAVERSES SHOWN ON PLATE I

To accompany Record 1969/30

P/A 236

TRAVERSE 4 (H-N)

LOCATION OF TRAVERSE SHOWN ON PLATE I



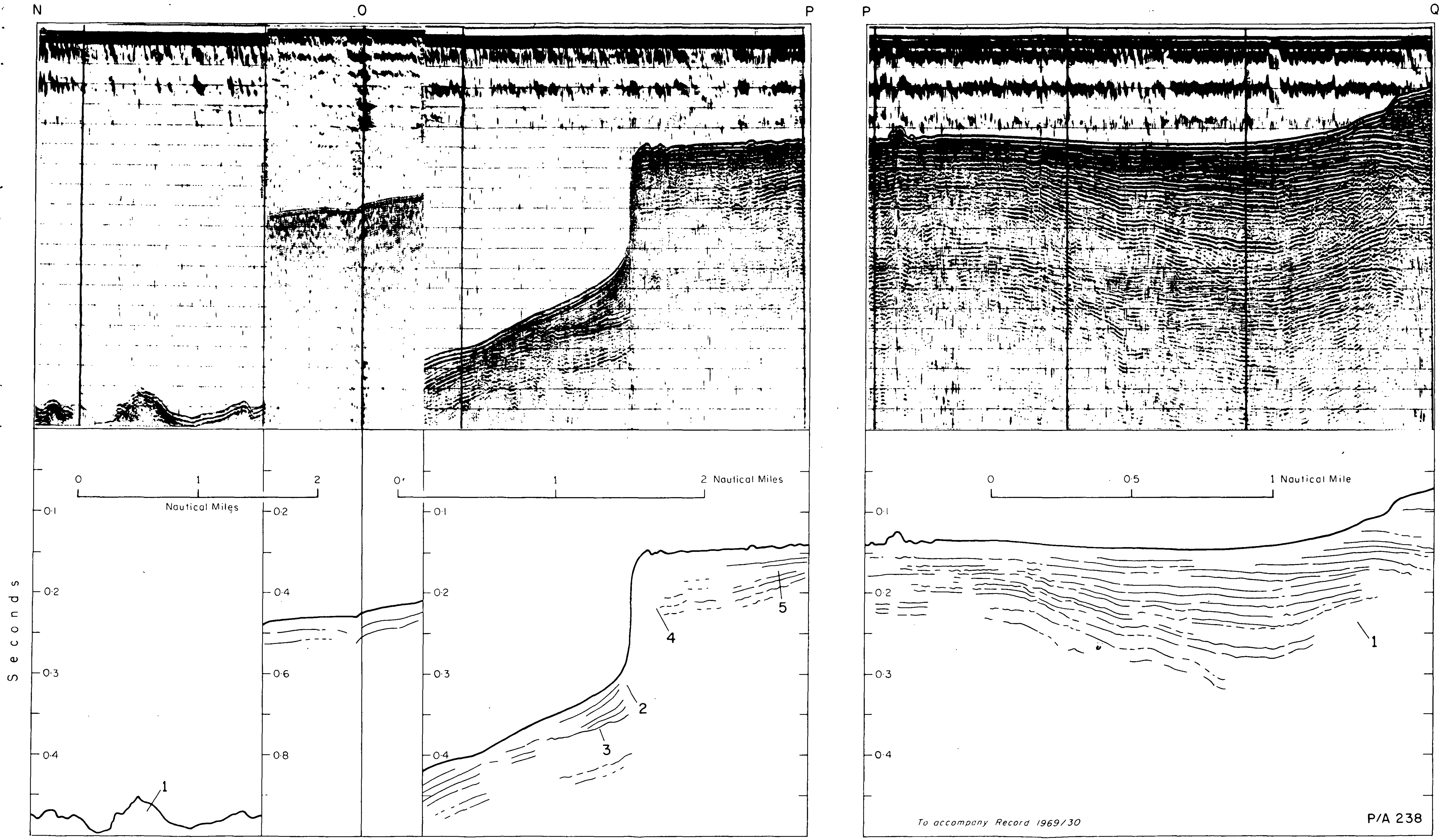
To accompany Record 1969/30

P/A 237

TRAVERSE 4 (N-Q)

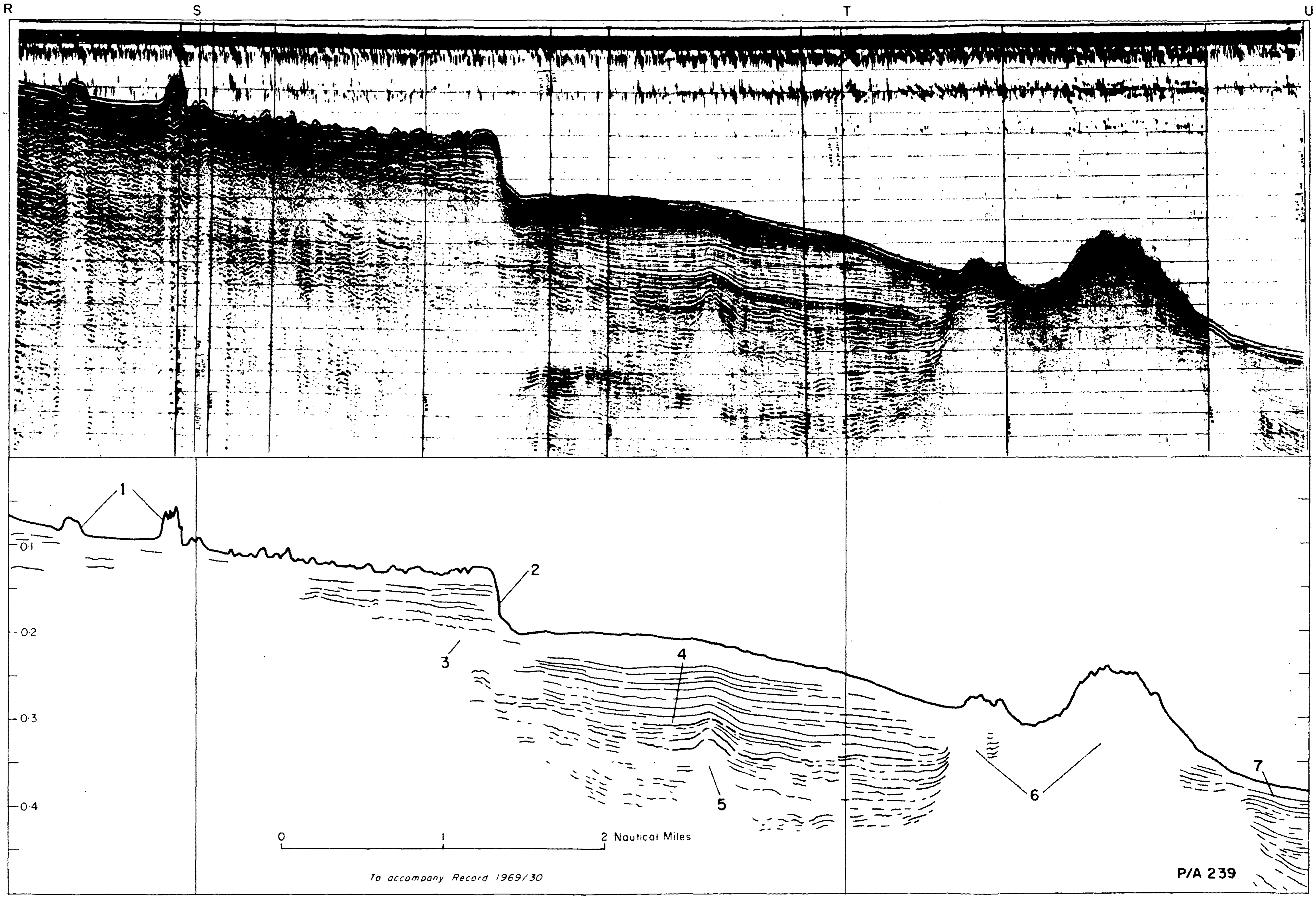
LOCATION OF TRAVERSE SHOWN ON PLATE I

PLATE 5



TRAVERSE 5(R-U)

LOCATION OF TRAVERSE SHOWN ON PLATE I



To accompany Record 1969/30

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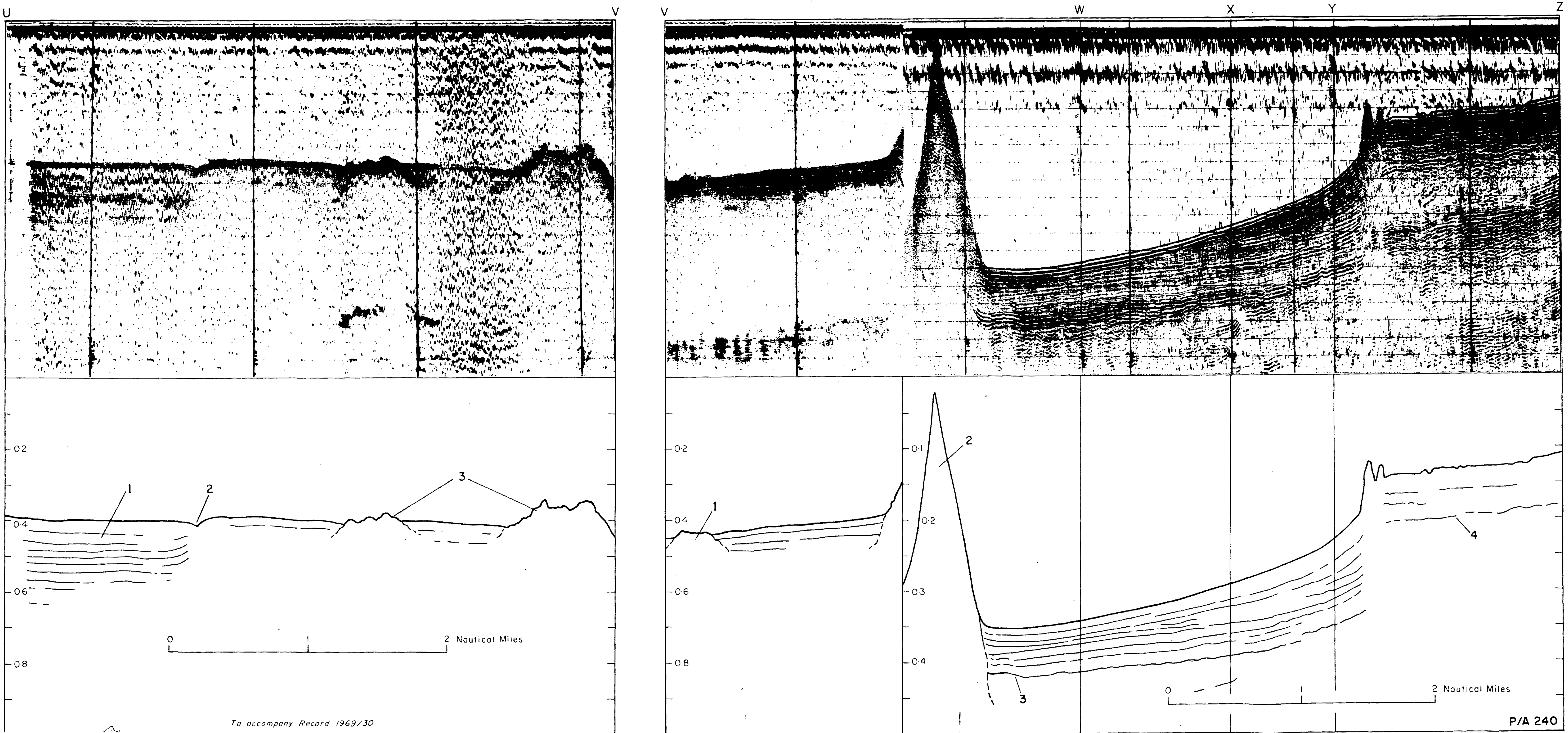
TRAVERSE 5(U-Z)

LOCATION OF TRAVERSE SHOWN ON PLATE I

PLATE 7



To accompany Record 1969/30

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TRAVERSE 6 (A-E)

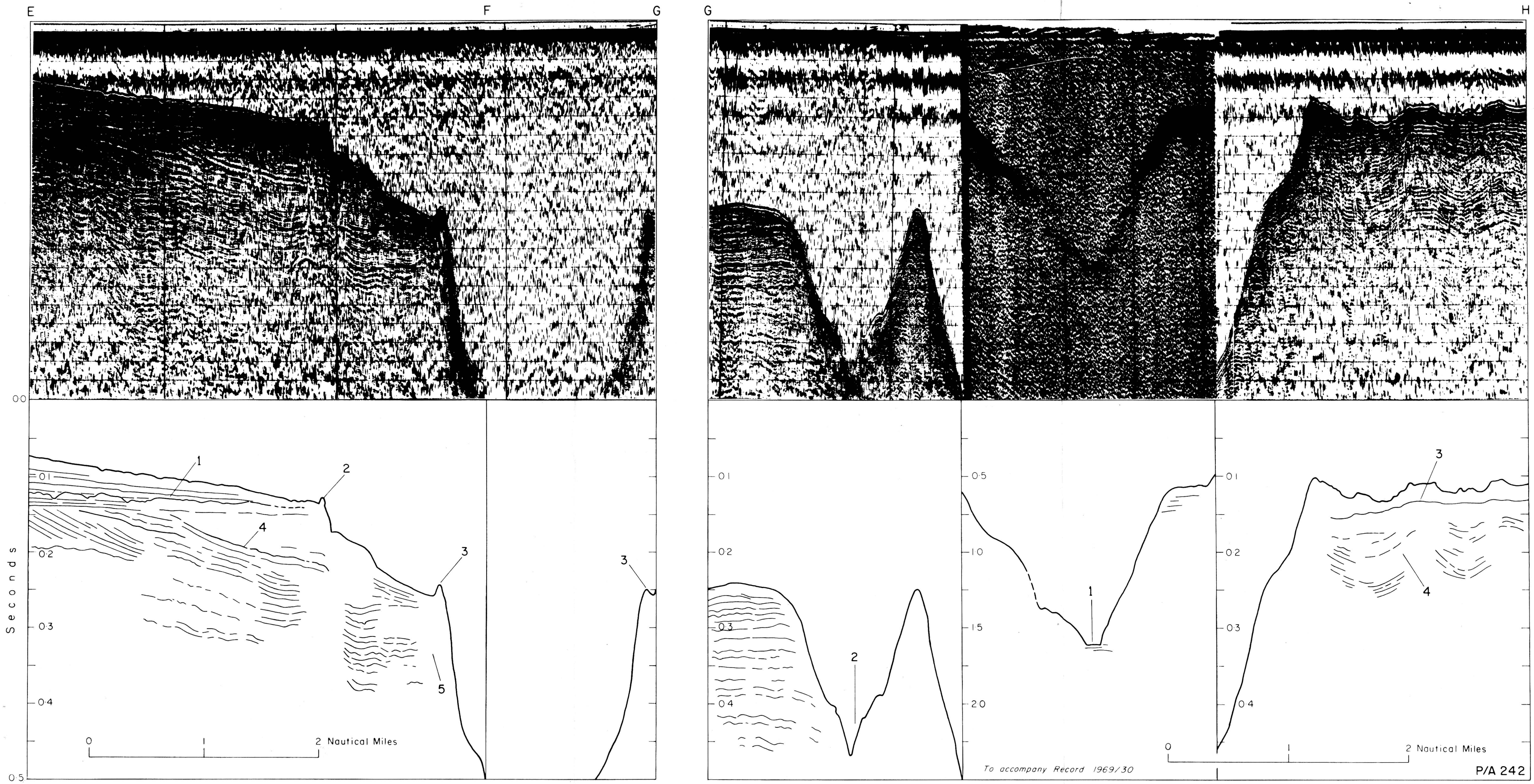
LOCATION OF TRAVERSE SHOWN ON FIGURE 9

PLATE 8

TRAVERSE 6(E-H)

LOCATION OF TRAVERSE SHOWN ON FIGURE 9

PLATE 9



TRAVERSE 6 (H-K)

LOCATION OF TRAVERSE SHOWN ON FIGURE 9

PLATE 10